Mouse Eradication on Midway Atoll

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ISLAND CONSERVATION

Preventing Extinctions

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EXECUTIVE SUMMARY

Previously undocumented injuries to nesting adult Laysan Albatross were observed on Sand Island, Midway Atoll National Wildlife Refuge, in December 2015. Remote camera studies confirmed house mice were biting the backs and necks of nesting adult albatross, leading to nest abandonment and mortality. The USFWS initiated spot control of house mice on Midway Atoll to protect nesting albatross until a plan could be developed to eradicate mice from the island; the first step being the assessment of the feasibility of a mouse eradication. In November 2016, Island Conservation and the USFWS initiated an assessment of the feasibility of eradicating house mice from MANWR with a site visit to understand the geographic scope and scale of the Atoll and constraints to an eradication implementation.

The goal of this feasibility report is to assess the technical feasibility and social and political acceptability of eradicating introduced invasive house mice from MANWR, and to explore potential technical and operational options for this project. The eradication of mice has a high likelihood of success if the principles of rodent eradication can be met: delivery of a bait containing a rodenticide into every potential mouse territory, minimize risks of the operation and rodenticide to native species and people on the island, and ensure that biosecurity procedures are in place to prevent, detect and respond to any inadvertent mouse incursion.

We identified no constraints that are insurmountable, but all potential issues must be fully considered and addressed to maximize the probability of a successful mouse eradication. The extensive commensal infrastructure and the community of people that live and work on the island represent the biggest challenges for maximizing efficacy. Changes to some systems and processes in place to support the people on the island will be critical to ensure no alternative food is available to mice during the eradication window. How food is handled, stored, prepared, and waste is managed needs to be evaluated and managed to eliminate mouse access to human source food. These pathways need to be closed at least 6 months ahead of the eradication window to allow residual food items to be flushed from the ecosystem.

We considered various approaches to a mouse eradication on MANWR based on previous successful mouse eradications worldwide. For the highest probability of success, we recommend the use of aerial broadcast of bait containing 25 ppm brodifacoum (supplemented by hand broadcast, bait stations, and use of other mechanical control tools in the commensal infrastructure) with an effective mitigation plan for native species and people.

We considered management of risks to the native species from disturbance during operations and from risk of primary or other pathways of exposure to the rodenticide. Timing of the eradication in the June- August balances the optimum time from a mouse population perspective, and is outside the main seabird breeding season, limiting risks to seabirds, shorebirds (breeding in the Arctic) and bird airstrike hazard (BASH) to the helicopter. Mitigation for other species are considered, and focused on minimizing exposure to disturbance and exposure to the rodenticide.
The sedentary Laysan Duck (listed as Endangered under the US Endangered Species Act) is at significant risk of primary and secondary poisoning and will require protection during the project. We recommend the formation of an independent committee of duck ecology and eradication experts to help inform, develop, and guide the duck protection strategy.
Options to consider minimizing potential for exposure, include translocation of Sand Island ducks to Eastern Island (where mice are believed absent) or capturing and holding ducks on Sand Island until the risk period passes.

The people on Midway Atoll during the eradication will not be at risk from the rodenticide use, however, we recommend evaluation of potential pathways of exposure and implementing simple mitigation strategies out of an abundance of caution. Rainwater collection off the runway should be maximized prior to the bait application, and the collection grates be closed off to prevent bait from entering the system. Further mitigation to consider includes upgrading water filtration systems at the collection points, distribution points and at tap sources. Laboratory monitoring to test for and confirm presence or absence of the rodenticide should be used to evaluate risk of exposure after the bait application. Home gardens and the community garden should be decommissioned temporarily to prevent mice from having access to alternative foods during the eradication window, and is not a potential pathway of exposure of the rodenticide to people.

We identify necessary research and monitoring studies to inform operational planning. Additional studies on implementation to evaluate efficacy of the baiting operation, and confirming eradication, environmental impacts and toxicological monitoring, and for demonstrating ecological change (conservation measures) are not discussed here, but should be considered in any strategic and operational planning.

Visitation and access to the island is tightly controlled by the USFWS. The only access to the island is by ship, barge or by plane that deliver people and supplies, and these pathways represent a risk of reintroducing mice back onto Sand Island. Biosecurity procedures will need to be evaluated and improved to prevent, detect and respond to any mouse or rat incursion on Sand Island, and prevent any inadvertent introduction of mice to Eastern Island.

1. BACKGROUND AND JUSTICATION FOR FEASIBLITY ASSESSMENT

The islands of Sand, Eastern and Spit (Midway Atoll National Wildlife Refuge, Battle of Midway National Memorial, Papahānaumokuākea National Monument (**Figure 1**), support 20 species of breeding seabirds. Most prominent are the ~1.3 million breeding Laysan Albatross (*Phoebastria immutabilis*) (LAAL), and ~56,000 Black Footed Albatross (*Phoebastria nigripes*) (BFAL). A few individual Short-tailed Albatross (*Phoebastria albatrus*) (STAL) have been observed annually on the atoll. In 2004, a population of critically endangered Laysan Duck (*Anas laysanensis*) was established on Sand and Eastern Islands.

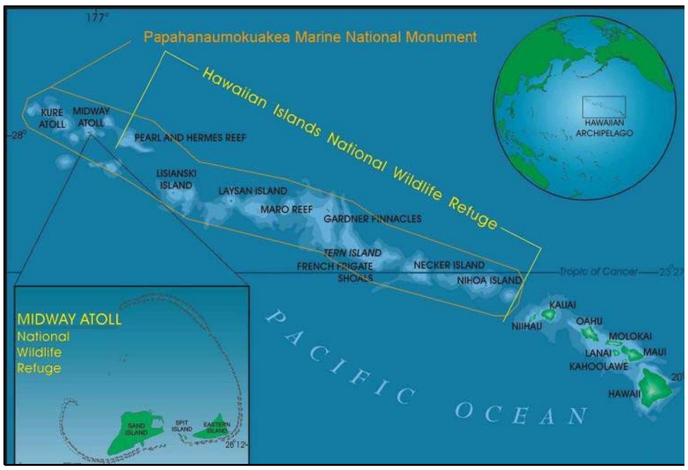

Figure 1. Midway Atoll National Wildlife Refuge, Battle of Midway National Memorial, PapahānaumokuākeaPapahanaumokuakea National

Ship rats (*Rattus rattus*) were confirmed to be introduced onto the islands of Midway Atoll National Wildlife Refuge (MANWR or Midway) with the ramp up of military activities in 1943. It is unclear when house mice (*Mus musculus*) were introduced, but the massive construction and infrastructure maintenance projects (seawall, buildings, housing, and airport runway), suggest the possibility of multiple, inadvertent, introduction events over the last 75 years.

Rats were successfully removed from MANWR in the mid 1990's, facilitating natural recolonization of the Bonin Petrel (*Pterodroma hypoleuca*) which recovered from non-detectable to almost 550,000 individuals by 2008 (Moore, 2009). Since the removal of rats, the mouse population is no longer suppressed and predation upon albatross has recently been recorded.
Although control efforts have been instituted to reduce these impacts, the trend of mouse associated injuries, nest abandonment and mortality over the past two albatross' breeding seasons has seen a significant rise in frequency and area affected.

With conclusive evidence of mouse impacts on breeding albatrosses on MANWR, the United States Fish and Wildlife Service (USFWS) commissioned an assessment of the feasibility of eradicating house mice from the atoll. As a result, USFWS and Island Conservation personnel visited MANWR in the boreal fall of 2016 to assess the atoll in greater detail. This report relies heavily on information acquired during this site visit (Appendix B: Midway Atoll Trip Report) to identify constraints, uncertainty, and potential risks that influence the feasibility of eradicating mice from MANWR while offering recommendations to address them.

2. FEASABILITY GOAL, OBJECTIVES and OUTCOMES

2.1 Goal

The goal of this feasibility assessment is to evaluate the technical and political feasibility, and social acceptability of eradicating introduced invasive house mice (*Mus musculus*) from MANWR and to explore potential technical operational options.

2.2 Objectives and Outcomes

The objective of this feasibility assessment, and the conclusions and outcomes are as follows:

Objectives	Conclusion/Outcome
1. Determine if the principles of eradication can be reasonably applied to a mouse eradication on MANWR.	1.1 Indicate if mouse eradication on MANWR is technically, socially, and politically feasible.
2. Evaluate the constraints to successfully applying the principles of rodent eradication in the MANWR.	2.1 Constraints are identified that must be considered if proceeding with a mouse eradication on MANWR.
	2.2 Options and recommendations are outlined to best apply eradication principles in light of known constraints.
3. Evaluate the uncertainty and the environmental, physical, and human safety risks associated with applying the principles of rodent eradication on MANWR.	3.1 The uncertainties and risks are identified that must be considered in planning of a mouse eradication from MANWR.
	3.2 Options and recommendations are outlined to mitigate risks and address uncertainty associated with a mouse eradication.

3. GEOGRAPHIC SCOPE: MIDWAY ATOLL NATIONAL WILDLIFE REFUGE

Midway Atoll National Wildlife Refuge is a part of the Hawaiian Islands located in the North-western portion of the archipelago. The atoll is an unincorporated insular possession of the United States and remains the only island within the archipelago that is not a part of the state of Hawaii. Midway is low lying not exceeding thirteen meters of elevation and comprised of three islands, Sand, Eastern, and Spit, with an overall area of 594 hectares (**Table 1**); an inconsistent perimeter of exposed limestone reef is present but not included in the area total as it can easily be submersed by large sea swell. A channel, roughly one kilometer wide is present between Sand and Spit Island. The distance between Spit and Eastern Island is roughly 30 meters although this channel fluctuates and can be difficult to distinguish at times (**Figure 2**).

Island	Size (ha)
Sand	452
Eastern	136
Spit	6
Atoll Total	*594*

Table 1. Atoll area.

Much of MANWR has been heavily modified by dredging and filling to expand the landmass of individual islands to accommodate its historic use as a military installation which once could support up to 5,000 people. Infrastructure, including an active airstrip, a decommissioned airstrip, and a repurposed military base, remains present. The islands, except for Spit Island, comprise a range of habitats including non-vegetated, grassland, shrubland, forest, sandy beach, and various combinations of each (Jones & Jones 2008). Spit island can be characterize as being dominated by coral rubble and sparse shrubs.

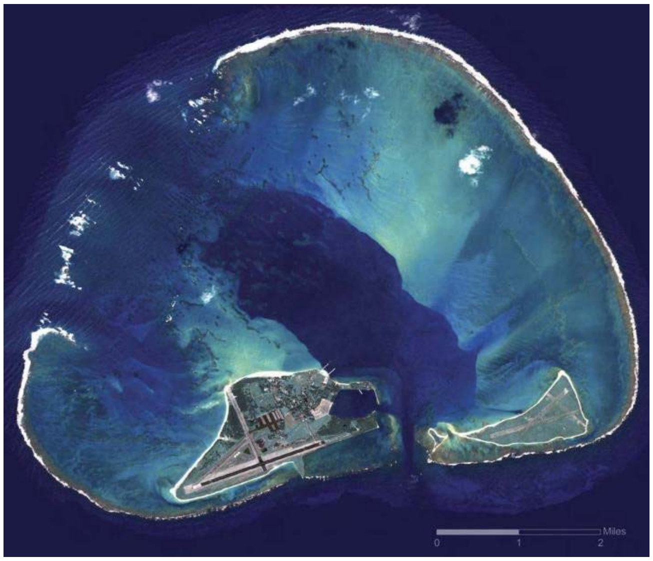

Figure 2. Midway Atoll National Wildlife Refuge (Google Earth, 2016)

Midway is inhabited by a fluctuating population of up to 57 permanent residents (Jones & Jones 2008); all of which are based on Sand Island with well-developed infrastructure including subterranean utilities (electricity, potable water, and an open sewer system), paved roadways, and roughly 115 structures including a commercial kitchen and dining hall. An influx of visitors to support island-based projects can elevate the population numbers to ~78 inhabitants (Jones & Jones 2008) while unplanned emergency landings from aircrafts in distress has, and can, temporarily balloon local numbers to several hundred (Flint pers. comm. 2016). Eastern Island is routinely visited for research and restoration purposes although accommodations on site are only intended to support day trips; Spit Island is visited infrequently. At present, MANWR is primarily used to serve as an emergency landing strip for extended twin engine operations (ETOPS) and as a national wildlife refuge managed by the USFWS. Roughly forty base operation staff from DBSI, are present, contracted by the USFWS, and remain present year-around to ensure facilities, utilities, and dinning related services are running smoothly. Most operations staff, apart from management, are Thai nationals with varying degrees of fluency in English. DBSI is also responsible for arranging the logistics of all supplies and other resources brought to the island. Other temporary residents include contractors working on infrastructure (construction and demolition) and USFWS volunteers to conduct albatross counts in December.

Access to MANWR is limited to boat or aircraft. Sand Island hosts Henderson Field which has an active 7,900 ft. by 150 ft. runway and is staffed and prepared to accept a wide range of aircrafts up to large jet liners such as Boeing’s 747 model. Routine visitation is contracted by USFWS and occurs approximately every two weeks via a private gulfstream jet with seating for up to fifteen passengers and limited cargo. Vessels accessing the island are infrequent but include a resupply barge, the Kahana, twice a year and annual National Oceanic and Atmospheric Administration (NOAA) research vessels that make MANWR a stop while voyaging to more remote north-western Hawaiian Islands. A seaport and wharf are present which can accept large ocean-going vessels as well as small crafts. Vehicle access to the seaport and wharf is possible although large cargo would necessitate a mobile or ship-based crane for offloading.

Weather on MANWR is monitored at the Henderson Field airport and two seasons dominate the annual climate; warm and cool (weatherspark.com). The warm season duration typically spans from late June through early October and has an average high of 85 and low of 78 degrees Fahrenheit. The cool season duration typically spans from late December to mid-April with an average high of 71 and low of 63 degrees Fahrenheit (weatherspark.com). The average annual amount of precipitation is 41.3in, with January being the wettest month with an average of 5in. June is typically the driest month with 2.2in of precipitation (**Table 2**) (weatherbase.com). Dramatic variation in precipitation timing and volume is possible during El Niño and La Niña conditions. Located at 28°12'N, daylight hours range from 10:22 to 13:55 hours per day with the longest day occurring in June during the boreal summer.

Average Precipitation **42 years on record*

	ANNUAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
in.	41.3	5	3.8	3	2.5	2.3	2.2	3.3	4.3	3.5	3.5	3.8	4.1

Average Number of Days with Precipitation **39 years on record*

	ANNUAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Days	160	16	14	12	11	9	9	15	15	15	14	14	16

Table 2. Precipitation trend including average volume (inches) and average number of days per month with precipitation (weatherbase.com).

House mice are confirmed extant on Sand Island. All evidence to date (anecdotal and recent observation) strongly suggest that mice are absent from Eastern and Spit Island. The ~1km wide channel separating Sand from Eastern and Spit islands is very likely sufficient to act as a natural barrier to mice moving between the islands, if unassisted by people.

If mice are absent from Eastern and Spit Islands, the islands can be excluded from the logistical planning for the eradication, thereby simplifying the project. However, additional surveys are necessary to confirm mouse presence/absence.

4. THE TARGET SPECIES, IMPACTS AND BENEFITS OF ERADICATION

4.1 Target Species for Eradication

This feasibility focuses on the eradication of introduced house mice (*Mus musculus*) from MANWR. No other introduced mammals (domestic, feral or wild) are known to be present on the Atoll. However, rats may have been inadvertently reintroduced to the island in early September 2016 as the resupply ship was known to carry rats. Periodic observations of a "large rodent", and a single photo suggests that rats may have been re-introduced to the atoll. Fortunately, the planning for and subsequent eradication of mice would remove any population of rats that may be present on the Atoll.

4.2 Impacts of Introduced Rodents

The impacts from invasive predatory mammals, including mice and rats, are one of the leading causes of species extinction on islands (Blackburn *et al.* 2004; Duncan and Blackburn 2007). Rodents living in close association, or commensally, with humans have been introduced to more than 80% of the world's islands and have a pronounced effect on island ecosystems (Towns et al. 2006). In addition, the extinction of many island species of mammal, bird, reptile, and invertebrate have been attributed to the impacts of invasive rodents (Andrews 1909; Atkinson 1985; Daniel and Williams 1984; Hutton *et al.* 2007; Meads *et al.* 1984; Tomich 1986), with estimates of 40 – 60 percent of all recorded bird and reptile extinctions globally being directly attributable to invasive rodents (Atkinson 1985, Island Conservation analysis of World Conservation Monitoring Centre data).

Rodents can also have negative direct and indirect impacts on native species and ecosystem functions. For example, a comparison of rodent-infested and rodent-free islands, and pre- and post-rodent eradication experiments have shown that rodents depressed the population size and recruitment of birds (Campbell 1991; Jouventin *et al.* 2003; Thibault 1995), reptiles (Bullock 1986; Cree *et al.* 1995; Towns 1991; Whitaker 1973), plants (Pye et al. 1999), and terrestrial invertebrates (Bremner *et al.* 1984; Campbell *et al.* 1984) on invaded islands. In particular, rodents have significant impacts on seabirds, preying upon eggs, chicks, and adults and causing population declines, with the most severe impacts on burrow-nesting seabirds (Atkinson 1985; Jones *et al.* 2008; Towns *et al.* 2006).

In addition to preying on seabirds, introduced rodents feed opportunistically on plants, and alter the floral communities of island ecosystems (Campbell and Atkinson 2002); in some cases degrading the quality of nesting habitat for birds that depend on the vegetation (Wegmann 2009, Young et *al*. 2010). On Tiritiri Matangi Island, New Zealand, ripe fruits, seeds, and understory vegetation underwent significant increases after rodents were eradicated from the island, indicating the rodents previous impacts on vegetation (Graham and Veitch 2002).

Rodents are documented to affect the abundance and age structure of intertidal invertebrates directly (Navarrete and Castilla 1993), indirectly affect species richness and abundance of a range of invertebrates (Towns et al. 2009), and have contributed to the decline of endemic land snails in Hawai`i (Hadfield et al. 1993), Japan (Chiba 2010), and American Samoa (Cowie 2001).

There is also increasing evidence that rodents alter key ecosystem processes. For example, total soil carbon, nitrogen, phosphorous, mineral nitrogen, marine-derived nitrogen, and pH are lower on rodent-invaded islands relative to rodent-free islands (Fukami et al. 2006). In rocky intertidal habitats, invasive rodents affect invertebrate and marine algal abundance, changing intertidal community structure from an algae-dominated system to an invertebrate dominated system (Kurle et al. 2008).

Given the widespread successful colonization of rodents on islands and their effect on native species, rodents have been targeted as key species for eradication by many managers of island wildlife (Howald et al. 2007).

4.3 Impacts of rodents on MANWR

Historically, introduced rats (Rattus rattus) on MANWR decreased seabird populations and contributed to the extinction of the Laysan rail and Laysan finch before they were removed in 1997 (Fisher and Baldwin 1946). With the successful rat eradication, house mice were subsequently released from rat predation and competition pressure, and the mouse population irrupted to densities higher than that seen prior to the rat removal (Klavitter and Eggleston 2011). House mice appear restricted to Sand Island, and have not been observed on Eastern or Spit Island. While the loss of seabird populations due to predation by introduced rats has been well documented globally (see Atkinson 1985), until recently, house mice were not believed to have an impact on breeding seabirds. The significance of the threat has likely been overlooked in the past (eg. Wanless et al. 2007), and impacts from house mice may be more significant when they are the only introduced mammal, possibly "triggering" predatory behavior (Wanless et al. 2007; Jones and Ryan 2009). For example, house mice on Gough Island are believed to be responsible for the high mortality of Tristan Albatross (*Diomedea dabbenena*) chicks (Cuthbert et al. 2004; Wanless et al. 2007; Davies et al. 2015), petrels and shearwaters (Wanless et al. 2007). On Marion Island, wounds consistent with mouse attacks have been found on chicks of Wandering Albatross (*Diomedea exulans)* and Dark-mantled Sooty Albatross (*Phoebetria fusca*) (Jones and Ryan 2010).

Figure 3. Adult Laysan Albatross with wounds caused by bites from house mice, Midway Atoll, 2016. (Photo: USFWS –MANWR.

A 2015 annual survey of nesting Laysan Albatross on MANWR documented bloodied and injured adult birds (**Figure 3**) in three localized areas on Sand Island. Rodents were suspected, and time lapse photography confirmed house mice repeatedly attacking nesting adult Laysan Albatross, crawling onto the head, neck and back of birds (**Figure 4**). The predatory behavior of mice started at a single location and then jumped to two additional sites approximately 100 m distant. From those two locations, it appeared to radiate out with each passing day, suggesting a learned behavior (M. Duhr-Schulz, pers. comm.). On confirmation of mouse predation, the USFWS successfully initiated a mouse control program in the affected areas to curb the ongoing threat, and no additional wounded adults or chicks were subsequently detected as of February 2016. In total, 480 adult Laysan Albatross were confirmed to have injuries and wounds consistent with mouse bites. Nest abandonment was higher in the areas affected by mice (M. Duhr-Schulz, pers. comm.). Of the forty-two carcasses recovered, necropsy and histopathology results indicate that the proximate cause of

Figure 4. House mouse climbing on to the back of a Laysan Albatross, Midway Atoll, 2016. (Photo: USFWS-MANWR).

mortality was sepsis (bacterial infection) originating in open wounds consistent with mouse bites (T. Work, pers. comm.). Therefore, mice are confirmed as the ultimate cause of death for bitten Laysan Albatross during the 2015/2016 breeding season on Midway Atoll. This same phenomenon was again present in the 2016/2017 breeding season with a substantial increase in the number of affected albatross to 242 dead adults, 1218 bitten birds, and 994 abandoned nests and site locations from 3 to 50 distinct areas, as well as an expansion of total affected area from 4 acres to 27 acres (USFWS unpublished data).

4.4 Benefits of rodent eradication on MANWR

The conservation benefits of rodent eradications include increases in abundance and breeding success of seabirds as well as a variety of other taxa including, landbirds, reptiles, mammals, land snails, and plants. Owing to the well-documented impact of rodents on seabirds (Jones et al. 2008), significant benefits are predicted for existing seabird colonies on MANWR and may promote an increase in recolonization by species including the short-tailed albatross (*Phoebastria albatrus*). In Western Mexico, the eradication of black rats from 5 islands resulted in the protection of 46 seabird populations (Aguirre-Muñoz et al. 2008). Direct benefits to breeding seabirds have also been reported, including an increase in nest site occupancy, nesting attempts, hatching success, and reduced nest depredation (Amaral *et al.* 2010; Jouventin *et al.* 2003; Smith *et al.* 2006; Whitworth *et al.* 2005); a result already witnessed on MANWR where Bonin petrel (*Pterodroma hypoleuca*) populations increased from fewer than 5,000 nesting pairs in the 1980s to over 135,000 breeding pairs in 2008 after the eradication of rats (FWS 2010; Pyle and Pyle 2009).

Change in productivity was the most commonly reported demographic response in bird populations after rodent eradication in a review by Lavers et al. (2010). They found that productivity increased by 25.3 percent in 112 studies of 87 species. Increases in abundance of native land birds after rodent eradication have also been reported. The abundance of 4 species of native land birds increased between 10 and 178 percent during the 3 years after rat eradication within New Zealand (Graham and Veitch 2002), and endemic species have even recolonized islands after local extirpation by rats (Barker *et al.* 2005; Ortiz-Catedral *et al.* 2009).

At the ecosystem-level, successful native plant restoration has been documented after Norway rat eradication (Allen et al. 1994). Furthermore, the removal of rodents has been carried out to create rodent-free refuges for native and endemic fauna and flora that are at risk from rodent impacts elsewhere in their range. By 2003, rodents had been eradicated from more than 90 offshore islands in New Zealand, allowing for the translocation of native birds, reptiles, amphibians, and invertebrates to these predator-free refuges (Towns and Broome 2003). Once MANWR habitat is free from mice, results from the ongoing restoration of habitat and native species is projected to continue and likely improve. Laysan Ducks may benefit from reduced foraging competition for the species that mice also take for food.

Benefits to the human community on MANWR is expected. Vegetable garden yields are likely to increase once mice, an omnivorous species, are eliminated and rodent foraging pressure is no longer present on crops, gardens and food stuffs. Where infrastructure exists, mice are known to chew holes, urinate, defecate and nest in areas where refuge and food is found; often in dwellings inhabited by humans and in areas utilized for storage. Although the presence of mice on MANWR present an unknown, if any, health risk to people, the presence of rodents elsewhere in commensal areas can lead to an increased risk of disease including: toxoplasmosis, lymphocytic clorio-meningitis, plague, leptospirosis, hantavirus and salmonellosis. Once mice are removed from commensal areas, the hygiene of a building and its contents will be improved. Ultimately, the removal of mice eliminates a primary vector of such diseases and lessens the risk to humans.

5. KEY ERADICATION PRINCIPLES APPLIED TO RAT and MOUSE ERADICATIONS

5.1 The History of Rat and Mouse Eradications from Islands

Rodent eradication has become a mainstream tool for island managers, and its use to protect threatened species and ecosystems has increased significantly over the last decade. By 2015, Samaniego (2016) documented 944 attempts of rodent eradications (10 different target rodents) on 692 islands globally. In total, 87 (9.2%) house mouse eradication attempts were reported from 76 islands in 17 countries (Samaniego 2016). Most of these mouse eradication attempts were in the temperate region, with 32/87 (~36%) mouse eradication attempts in the tropics.

Island size does not appear to be a limiting factor for successful rodent eradication. Eradication attempts and successful eradication operations have been reported from small offshore islets to very large islands, including the largest known mouse eradication on Macquarie Island at 12,873 ha (**Figure 5**). Mice eradication is being planned or considered for very large islands such as Floreana Island in the Galapagos (~18000 ha) (K. Campbell, pers. comm.) and Marion Island in South Africa (~33500 ha) (Parkes 2014).

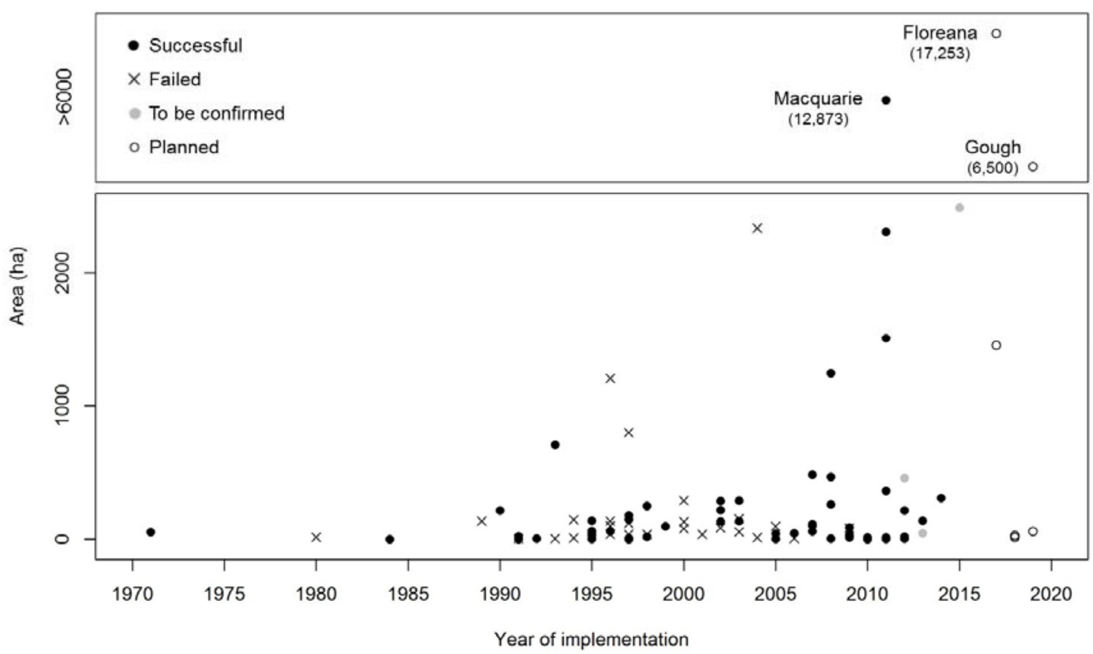

Figure 5: Global mouse eradication attempts on islands over time and by island size (DIISE 2016; Samaniego 2016).

5.2 Mouse Eradication Successes and Failures

House mouse eradication from islands is highly probable when the principles of rodent eradication are effectively applied; however, it cannot be guaranteed. Mouse eradications, from all islands attempted from 1970 to 2015, had an overall reported success rate of 71%. In comparison, overall success of rat eradications is ~ 87% (Russell and Holmes 2015), which reinforces the perception that mice are particularly difficult to eradicate (Samaniego 2016). The reasons for this lower rate of success for house mouse eradication is unclear and has been the subject of some investigation (Samaniego 2016; Mackay 2011). Factors contributing to failure could include some or a combination of natural history differences between rats and mice that could make it harder to target 100% of the population (e.g., behavioral - foraging; travel distances; home range sizes), or that mice have been a secondary target of eradication (i.e., eradication programs targeting multiple species are known to be more challenging), or ineffective eradication strategies or management approaches that failed to reach all mice (i.e., individual mice are not removed and recolonize the island) (see Parkes 2014). More recent successful mouse eradication projects include six (of ten total) on islands >400 ha, all of which faced the greater complexity of targeting two or more species for eradication, and were conducted in temperate regions. Within the tropics, the largest mouse eradication attempt (Mer Island at 459 ha) is awaiting to be declared successful. Of the three largest mouse eradication attempts with a known outcome (success/failure), two were successful (219-289 ha) (Samaniego 2016).

Between 2005-2015, the success of house mouse eradication increased to 93.3% (n= 31 islands) (Samaniego 2016). The increase in success has been attributed to greater international cooperation, knowledge sharing and lessons learned between eradication practitioners (Veitch *et al*. 2002, 2011), and the establishment of best practice guidelines for the eradication of rodents in temperate (Broome et al. 2014) and tropical ecosystems (Keitt et al. 2015). Today, successful rodent eradications on all but the smallest of islands (< 5 ha), rely on the use of rodenticides. More specifically they rely almost exclusively on anticoagulant rodenticides (DIISE 2016).

The Eradication Principles Applied in Rat and Mouse Eradications

All eradications, regardless of the target species, are grounded in three fundamental principles (Cromarty et al. 2002):

1. Every individual must be put at risk with the proposed removal technique(s).
2. The technique(s) must remove individuals at a rate faster than they can replace themselves (i.e., breed) and,
3. Immigration must be zero, or effectively be managed to zero (i.e., identify and respond effectively to eliminate any reintroduction).

For rat and mouse eradications, these principles have been defined as (see Howald et al. 2007):

1. Deliver a highly palatable bait containing a toxic rodenticide into every *potential* rodent territory,
2. Ensure bait is available for long enough that every mouse has access to a lethal dose;
3. Time the baiting operation to when the rodent population is most likely to consume the bait.
4. The short-term risks and impacts to non-target wildlife, people, and the environment from disturbance and the rodenticide is minimized wherever possible; i.e., the benefits of the eradication must outweigh the costs.
5. Biosecurity procedures must be able to sustain the eradication, with effective prevention, detection, and/or an effective response to any incursion.

These principles have been further developed into recommended Best Practice Guidelines to maximize the probability of successfully removing rodents from temperate islands in New Zealand (Broome et al. 2014) and from tropical islands (Keitt e al. 2015).

6. CAN MICE BE ERADICATED FROM MANWR?

The feasibility of an eradication is a multi-dimensional analysis that considers technical, environmental, social, political, and legal factors. These factors must be evaluated independently, but will collectively determine the feasibility of a mouse eradication from Midway Atoll.

6.1 The Constraints that Must be Overcome for a Successful Mouse Eradication

While all rodent eradications from large islands apply the same fundamental principles of eradication, the technical approach implemented in each island is unique and tailored to its specific wildlife communities, ecosystem function, and landscape features. A first step in selecting the best technical approach to a rodent eradication is to identify local constraints to the operation and how they impact the overall probability of success, as well as the potential risks from the operation to the local environment. The constraints will limit the likelihood of success of the eradication and this feasibility assessment will describe the best approaches to overcome them on Midway, while striving to eliminate, minimize, or mitigate the risks that these approaches impose on the environment. The overall goal is to provide decision makers with enough information to determine whether a house mice eradication from Midway Atoll outweighs the potential risks of the operation.

The major constraints identified on MANWR that will influence the design of a mouse eradication are:

6.1.1 Commensal Infrastructure

Successful rodent eradications have been predominantly carried out on remote, uninhabited islands, without permanent human settlements. Humans provide food and shelter to rodents, and commensal species such as the house mouse can become wholly reliant on humans. This commensal behavior can represent a significant risk to an eradication attempt, decreasing the probability of success. There is precedent to rodent eradications from human inhabited islands (a total of 94 documented – DIISE 2016), but these operations require supplemental treatment strategies such as mechanical devices and modification of bait application methods. The commensal environment of Sand Island would be no exception.

The commensal environment on Sand Island is extensive and a result of a long history of human habitation and infrastructure, representing over a century of occupation. The structures on Sand Island vary in age, construction type, condition, and on how they are used (if at all). The commensal environment can be described in whole, or as a combination of the following three categories:

a. Inhabited Spaces

    i. Living spaces
        1. *housing and dining facilities, food storage and food preparation sites*
    ii. Work spaces

1. *offices, utility buildings, covered storage, recreation facilities, covered garden / nurseries*

b. Abandoned Structures

   i. *condemned structures where access is not permitted* due to physical or other safety reasons.

c. Subterranean Access Points

   i. *high voltage service boxes*
   ii. *electrical conduit junction sites*
   iii. *sewer system access points*
   iv. *waterline junction sites and valves*
   v. *abandoned junction points – water, oil and electrical services*

All man-made infrastructure on Sand Island represent complex and challenging areas for the eradication and will require specific strategies to ensure bait is applied to every potential mouse territory, including within the infrastructure.

The airfield and its active runway present an additional challenge given the fact that it must remain fully operational during the eradication window. Sand Island has an active Federal Aviation Administration Part 139 certified airfield with a 2407 m long by 46 m wide runway. The runway and taxiway is maintained as emergency landing site for extended twin-engine operations (ETOPS) flights across the Pacific Ocean. A number of subterranean utility access points exist adjacent to the runway (not on the runway). There are tight controls on access onto and use of the runway but due to the lack of refugia for mice, baiting of this area will not be necessary. Mice have infested the building used to support the airport crew, and are actively controlled through trapping and poisoning.

6.1.2 Native Species

The presence of wildlife on and around islands targeted for eradications present an inherent challenge. In essence, the operation must be able to deliver bait to every mouse on the island while minimizing availability of the rodenticide to other species. Additional to the toxicological risks, the operation may also impose disturbances and habitat alterations that could have negative impacts on the ecosystem.

Although impacts to native species are only ecologically significant if they pose a population level effect, as a principle, any risks to wildlife should be eliminated, minimized or mitigated whenever reasonably possible. The benefits of the eradication must outweigh the environmental costs and mitigation strategies must be considered in the trade-off framework (Broome et al. 2014).

Although there are no species endemic to MANWR, the Atoll is of high significance for several terrestrial and marine species, including:

- The **critically endangered** (non-migratory, resident) Laysan duck, extant on Sand and Eastern Island;
- The Endangered short-tailed albatross that has bred in the recent past on Eastern Island and recently is represented by a pair of birds attending a site on Sand Island;

- High density breeding populations of Laysan albatross (LAAL) and Black-footed albatross (BFAL) present for about 8-9 months of the year;
- Globally important populations of bonin petrels and red-tailed tropicbirds.
- An introduced population of canaries (*Serinus canaria*) that may have cultural significance and may warrant protection;
- A resident population of spinner dolphins (*Stenella longirostris*) in the lagoon;
- Overwintering shorebirds such as the Bristle-thighed Curlew (*Numenius tahitiensis*), a species of special concern.
- **Endangered** green (*Chelonia mydas*) and hawksbill (*Eretmochelys imbricate*) sea turtles that use the beaches for resting without known nesting areas.
- **Endangered** monk seals (*Neomonachus schauinslandi*) that use the beaches and foreshore vegetation for resting and pupping, and can be found on the island year-round.

6.1.3 The Community of People Living and Working on MANWR

Local communities are often key stakeholders in island eradication projects. Their close connection to the island often mean that their culture and livelihoods depend on its natural resources, and they will ultimately bear the burden of any negative consequences from the eradication on those resources. On the other hand, they are also directly or indirectly impacted by the effects of invasive species and stand to benefit from the outcomes of a restoration project. Moreover, local communities have an important role to play in maintaining islands free from the invasive species, which often requires changes in behaviour. Therefore, their involvement is vital to the success of most eradication projects. In the feasibility assessment context, it is important to account for the local communities' interest in pursuing an eradication project, and willingness to participate in the long-term restoration effort.

The year-round community of people on MANWR includes USFWS staff and volunteers, base operation staff (Chugach management and foreign national Thai citizens), and temporary contractors or researchers. Sand Island has extensive infrastructure, processes and systems (utilities) in place to support the ~57 people that live and work on the island - from housing to a common eating space (the Clipper House), small scale agriculture to recreation facilities, transportation to recycling, garbage and waste disposal - in effect, a functioning, albeit small, municipality.

The house mice on MANWR, as a commensal species, are taking advantage of human foodstuffs. They feed on dry goods, trash and crumbs, and fresh grown foods alike. They are using foodstuffs from garbage and recycling waste receptacles, from the landfill, community and home gardens and in common use areas. They are known to chew through containers to gain access to dry goods and feed directly on fresh foods from community gardens. Additionally, they likely use wastewater (black and dish water) in the sewer system. The daily cycle of cooking, cleaning, creating trash, and inadvertently leaving food residues that are accessible to mice represent a significant risk to the success of the eradication since it will create additional difficulties to ensure all mice are attracted to eradication tools (bait, traps, etc). If the commensal environment on Midway is not adequately addressed, mice will avoid or will not gain access to the tools designed to remove them.

Making the appropriate changes to the systems and process in place will require a commitment from everyone on the island. The community on Midway must value the benefits of the eradication over the short-term costs associated with it. Changes to systems and processes create necessary changes to day to day behaviors, such as food handling and garbage management, and can be disruptive to established lifestyles. Therefore, such changes will likely take time to be adopted and implemented fully. The human community on Midway will play an integral role in the success or failure of the operation and their commitment to immediate changes in behavior and adoption of broader biosecurity measures will be paramount.

7. TECHNICAL APPROACH TO ERADICATE MICE FROM MANWR

The only viable approach to removing house mice from MANWR is the use of rodenticides. Other tools and strategies used to control mice were considered, but there is no evidence that they would have a reasonable probability of success.

7.1 House Mouse Control Tools Considered but Dismissed as Main Methods of Eradication

7.1.1 Mechanical Removal Only

A primary limiting factor in using only mechanical methods is labor, especially with mice. Traps must be maintained at a high density in all areas of the island until confirmation of eradication could be considered. Trapping efficiency would decrease with population size, and the last individuals would take significantly more labor to remove. There is a high likelihood that the diminishing returns on labor would mean that financial resources ran out before eradication could be achieved. There are no known house mouse eradications using traps or other mechanical means alone (DIISE 2016).

Even with sufficient labor resources, it would be a major challenge to know when to stop removal effort; possibly necessitating years of effort. Animals become increasingly difficult to detect at lower densities and in the case of mice, an extremely small population can be effectively undetectable, making it impossible to know if the population has been eradicated or merely suppressed at very low levels.

Although mechanical means have been dismissed as a primary approach, these tools have value in addressing some of the unique conditions present on MANWR and will be considered as part of a multi tool approach to the mice eradication on Midway.

7.1.2 Biological Control

The introduction of another species (e.g. predators such as mongoose or cats) to eradicate mice is not considered practical nor biologically feasible, and would not be legal. There are many failed introduction events (e.g. mongoose into Hawaii to control rodents) that have resulted in catastrophic outcomes for native species. As the rodent population decreases the predators shift their focus from rodents onto easier to catch prey, such as seabirds. The result is almost always a failed eradication and a new invasive species.

7.1.3 Emerging Technologies

Ongoing research continues into the development of technologies for the control of introduced rodents. If these tools in development become available, they may have incremental or transformative impacts on the ways in which eradication projects are approached. These are technologies like reproductive inhibitors, species or genus specific toxicants, or genetic biocontrol. Unfortunately, while these methods are in development, to our knowledge none are likely to become available and proven in the foreseeable future.

7.1.4 Excluding Mice from Buildings

Mouse-proofing buildings would not in itself meet the proposed conservation goals, but could serve as one of the tools used to eliminate the need to target mice within buildings. It is unlikely that a process for mouse-proofing buildings could be implemented in a cost-effective way, and the efforts would provide little value once mice were eradicated from the entire island. Instead, it would be more efficient and cost effective to specifically target mice in and around buildings as part of the overall eradication campaign.

7.2 Primary Options Considered for Eradicating Mice from MANWR

Delivery of bait containing a rodenticide into every potential mouse territory is the only viable option to remove house mice from MANWR. For eradication of mice from MANWR, we evaluated four distinct approaches to deliver rodenticide bait that have been used successfully on island rodent eradications worldwide. They are:

- bait stations,
- hand broadcast,
- aerial broadcast using a helicopter and bait sewing bucket, or
- a combination of the above.

7.2.1 Bait Stations

Bait stations have been used from very small to relatively large islands to eradicate introduced rats and mice (DIISE 2016). Bait stations typically used in island rodent eradications have been either commercially manufactured plastic bait boxes, or plastic pipes, or other material. Either design allows rodents to enter the stations freely to access bait placed in the center. The major advantage of bait stations is that bait can be delivered to all mice while preventing most non-target birds and other species from gaining access to the bait (primary exposure). Additional advantages include controlled bait delivery, lower mobilization of the rodenticide into the ecosystem (only the bait consumed by rodents and potentially invertebrates), and easier removal of residual bait. Further, bait delivery into stations is highly controlled, and doubles as monitoring of the progress of the eradication since bait take declines as rodents are removed from the ecosystem. A disadvantage of bait stations is that rodents can be neophobic and will take time to get used to and enter bait stations to consume the bait (Kaiser et al. 1997). Consequently, dominant rodents may exclude conspecifics from gaining access to stations until they succumb to the rodenticide. Thus, the time delay between initiation of baiting and eradication may be significant, potentially resulting in a longer operation. Usually, rodent eradications with the use of bait stations take many months to up to two years until the islands can be declared rodent free with a high level of confidence.

For eradication purposes, bait stations are placed systematically on a grid pattern in all habitats across the entire island. Once placed, bait crews will arm and check stations regularly and re-arm each station over a period of months until bait take by rodents decline to zero. MANWR, bait stations were used successfully to eradicate introduced *R. rattus* in the 1990s. Stations were spaced at ~50 m intervals with live traps in between,, ensuring that at least 2 stations were found in every potential rat home range.

- Considerations on the use of bait station on MANWR for mice eradication

Infrastructure: A bait station approach would also have limitation on MARWR, especially in condemned commensal infrastructures that are unsafe for access by ground crews. Without access to all the structures, some mouse territories are likely to be missed, and may survive the baiting operation. Even one pregnant female could recolonize the island, negating the eradication effort.

Non-target species: One of the benefits of bait stations is the reduced primary exposure risk to non-target species. On MANWR, bait stations would offer some, but not complete protection to terrestrial birds, including the Laysan Duck and shorebirds from primary exposure to the bait. Moreover, bait stations would not eliminate the secondary exposure risk through mobilization of rodenticide into the environment by contaminated insects (e.g., cockroaches, ants) and other invertebrates (e.g., crabs). As such, a bait station approach would minimize the non-target poisoning risk but would not eliminate the need for additional mitigation measures to protect the Laysan Duck and shorebirds.

Operational challenges: The logistics of implementing mouse eradication on MANWR using bait stations alone would be significantly more complex than a rat eradication, primarily due to their smaller home range, which would require a much higher density of stations. Bait stations would need to be deployed at a maximum of 20m spacing, with 10m providing greater confidence that at least one station would be accessible in every potential mouse territory. Assuming a 10m x 10 m grid across the island, we estimate a minimum of 45,200 bait stations across the 452 ha Sand Island would be necessary. This figure does not account for key commensal habitat which would require additional treatments. We estimate that >450 km of trails would need to be opened, flagged and maintained to support crews walking regularly to install, service, monitor, and eventually remove the stations from the island. These trails would have to be opened in key habitat such as the coastal fringe of high density *Scaevola* sp., and through habitat with Bonin Petrel burrows which are found wherever the substrate allows for excavation by the birds (widespread on Sand Island). Frequent use of these trails would result in collapsed burrows across the island, and would pose a significant safety hazard to crew members (leg injuries). As a reference, we estimate that a single check of every bait station would require ~200 person days. Assuming a manageable crew of 40, an individual station would be visited at a minimum of 5 day intervals.

A bait station approach to a mouse eradication on MANWR would be by far the largest bait station operation ever undertaken with regards to the number of stations being managed. A bait station approach to mouse eradication on Midway Atoll would be extremely labor intensive, and could take up to two years of station maintenance, to have a high probability of success. Furthermore, it would not fully address the infrastructure which cannot be fully accessed by people for safety reasons, would not completely remove the need to mitigate against impacts to Laysan Ducks and shorebirds, and could cause significant mortality of burrow nesting seabirds, and disturbance to nesting albatross during the breeding season.

7.2.2 Broadcast of Pelleted Bait

In the 1990's, island managers began to explore more efficient techniques to finish eradications more quickly on larger islands, and adopted broadcast approaches, either by hand or by aerial techniques utilized in the agricultural industry (Howald et al. 2007). Bait, in the form of cylindrical or round(ish) pellets, is broadcast evenly across the entire landscape at a pre-calibrated application rate (measured in kilogram or pound per land area (hectare or acres)- kg/ha or lbs/acre), such that all rodents have access to it for long enough to find, overcome any neophobia, and consume the bait.

There are major advantages of a broadcast approach that effectively overcome most the bait station approach's shortcomings: 1) all rodents have access to the bait at the same time with no competitive exclusion and minimizes any neophobic behavior; 2) an eradication can be completed with as few as one application (2 or more applications being the norm -DIISE 2016). Thus, a strategy which broadcasts bait across the island, either by hand or with a helicopter, can achieve success in a significantly shorter time frame than with bait stations.

The drawback of a broadcast approach is that the risks to non-target specie from primary exposure to the rodenticide is higher as pellets are scattered evenly across the island all at one time. Non-target birds and other species could be attracted to and compete with rodents to access the bait, leading to primary exposure, and a high risk of mortality if they are sensitive to the toxicant (Howald et al. 2007). Thus, strategies to eliminate, minimize, or mitigate rodenticide exposure risks to non-target species are often implemented. Such strategies may include actions as simple as timing the operation during periods of low non-target species' abundance, to measures as complex as live capture, hold, and release of individuals until imminent contamination risks have passed (see Howald et al. 2005, 2007; Pitt *et al*. 2015).

7.2.3 Hand Broadcast

Broadcast of bait by hand is the second most documented approach to island rodent eradications (DIISE 2016). Bait is typically distributed by a team of baiters who systematically walk on parallel transects stopping at predetermined intervals to distribute pellets as evenly as possible in a quadrant or circle (see http://rce.pacificinvasivesinitiative.org/). As the end of one transect is approached, the teams move over to the next transects and start anew, treating the island in a "rolling front".

For a successful hand broadcast approach, significant advance preparation is required to ensure efficient application, and to minimize delays and errors in bait application. Complexity increases with the size of the land area and the topography of the island being treated. Transects through heavy vegetation would be opened to all baiting points in advance, and each broadcast point would be marked (often with flagging or a pin-flag) and recorded by GPS. Bait would have to be staged at various locations across the island to minimize effort and time needed for baiters to refresh their supplies.

7.2.4 Aerial Broadcast

Rodent eradications using an aerial broadcast approach refers to the use of a commercial-grade bait bucket slung under a helicopter, guided by a GPS to evenly spread bait across the island. The set rate at which bait exits the bucket, swath width, and flight speed are calibrated to achieve a desired application rate. The pilot is guided by a computer connected to a GPS and guidance system to keep the helicopter on pre-programmed bait application flight lines. The bait flow from the bucket is controlled by the pilot at all times, opening and closing the bait bucket on demand to apply bait in desired areas, and minimize bait application into other areas such as the marine environment. Bait application along the shoreline can be accomplished with minimal bait drift into the marine environment. The hopper can be fitted with a deflector to broadcast bait out to one side, allowing the helicopter to fly parallel and close to the shoreline with minimal unintentional bait application.

The major advantages of an aerial broadcast approach are: 1) bait can be delivered into every mouse territory (except in structures), without the need for cutting transects; 2) lower disturbance impacts to terrestrial native wildlife; 3) bait application can be closely monitored for application rate and where bait was applied (and any gaps in flight lines); and 4) increased efficiency in bait delivery.

In addition to the disadvantages of primary exposure to non-target species (as outlined above), aerial broadcast operations can be logistically complex and equipment intensive, requiring detailed planning to build in enough redundancies to ensure a robust implementation to minimize delays and costs in case of equipment failures. In addition, the broadcast operation requires operating in relatively stable climatic conditions (lower winds, no rain and high visibility). Supplemental baiting and treatment in commensal environment are often required with an aerial broadcast approach. High densities of seabirds in the air around the colony may pose a bird – airstrike hazard (BASH).

Considerations for Broadcast on MANWR:

Infrastructure: The active airfield on Midway, its aprons and airport parking areas provide an ideal base to logistically implement an aerial broadcast operation for the eradication of mice from the island. The airfield services from staging, to aircraft storage, fuel and safety support (fire and medical) is ideal for an aerial broadcast approach to a Midway mouse eradication. Aerial broadcast is a suitable primary method for applying bait to MANWR, but will need to be supplemented with alternative methods to ensure bait delivery into every potential territory such as within buildings and subterranean access points.

Non-target species: Broadcast by hand or aerial increases the primary exposure risk to non-target species significantly. Mitigation would be necessary for key species such as the Laysan Duck and shorebirds that could be otherwise poisoned through primary exposure.

Operational challenges:

Hand Broadcast: Baiting points would need to be spaced at a maximum of 20m interval to have enough bait available in every potential mouse territory. To achieve that, we estimate that > 200 person days would be necessary to complete one full hand broadcast operation across Sand Island, not including baiting abandoned structures. This would be a very labor intensive operation that would need to be coordinated and managed very closely and effectively over a period of up to two months (assuming 2-3 bait applications). It is unlikely MANWR's facilities can comfortably accommodate the large work force needed to complete each application in a single day. Reducing the number of people would increase the number of days needed per application, and the complexity of the project.

Aerial: It is uncertain at the time of writing this feasibility if aerial bait application could occur over the uninhabited buildings on Midway Atoll. It is possible that an exception for aerial broadcast could be made as no children and no domestic animals are present on the island, and cleaning of rooftops could be made to minimize risks of the bait persisting in this area of the island. Exclusion of the buildings from aerial broadcast is not likely feasible, and would stratify the island into small, disjointed fragments that would be difficult to avoid by air, and would require diligent hand broadcast application up to and inside the buildings.

A summary of the relative advantages and disadvantages of each technique are outlined in **Table 3**.

Table 3. A summary of relative advantages and disadvantages of primary bait application methods for MANWR.

Method	Relative advantages	Relative disadvantages
Bait stations	• Less total bait • Lower non-target risk	• Labor intensive, including challenges and risks of managing a large team doing repetitive physical labor • Slow, eradication may take many months - years to achieve • Non-target species exposed to risk for a longer period • Prolonged impacts to seabird burrows and disturbance of ground-nesting birds
Hand broadcast	• More fine-scale control over bait application • Limited specialized skill required • Eradication possible within 3-6 weeks of beginning operations	• Labor intensive, including challenges and risks of managing a large team doing repetitive physical labor • Logistically challenging; unlikely to bait entire islands in a single day • Bait readily available to non-target species • Impacts to seabird burrows and disturbance of ground-nesting birds
Aerial broadcast	• Fastest option to apply bait over large areas • Relies on a smaller team • Can apply bait to all areas without the need for cutting trails • Eradication possible within 3-6 weeks of beginning operations	• Bait readily available to non-target species • Reduced fine-scale control of bait application • Requires the most specialized skills • Currently restricted over inhabited areas • Distribution limited to exposed area (e.g. does not distribute bait into buildings) • May inadvertently result in some bait entering the water

Combination of options	• Maximizes chance for success • Taps the advantages of each method • Allows bait to be applied in all habitat including buildings	• More complicated planning • Must train personnel and do quality assurance for a larger number of methods

7.3 Recommended Strategy for Eradicating Mice from MANWR

To successfully eradicate mice from Midway atoll we recommend an eradication strategy that includes the following:

- Aerial broadcast of a pelleted bait containing a rodenticide across the entire emergent land area as the primary approach;
- Supplemental hand broadcast along key shoreline habitats (e.g. across causeways too narrow for aerial broadcast; along sea walls) and in the commensal environment including on the ground and underground infrastructures.
- Supplemental use of bait stations, and mechanical devices (e.g. traps, glueboards) in the extensive commensal environment including on the ground and underground infrastructures.

Rodenticide and Bait Considerations

Several factors must be considered when selecting a bait product for a rodent eradication. Under ideal conditions, the bait product would have demonstrated 100% efficacy under both laboratory and field trials. Additionally, it would have been successfully used to eradicate the target species (i.e. house mice) from other islands.

From an eradication perspective, the selected bait for Midway Atoll must:

- Contain an active ingredient that is known to be highly toxic to mice,
- Be palatable and demonstrated to have very low or no bait shyness by mice,
- Can be delivered into every potential mouse territory on the island.
- Be legally registered for use in compliance with FIFRA (Federal Insecticide Fungicide and Rodenticide Act) in the United States.

Although a total of ten rodenticides are available on the market in the United States, only three anticoagulant rodenticide products are currently registered for conservation use and therefore available for the eradication of rats and mice from island ecosystems at this time:

- Diphacinone D50: a 2-5 g pelleted bait product containing 50 ppm diphacinone, adopted for use primarily in the Hawaiian Islands for main island conservation, landscape control and eradication from offshore islands (Hacco, Inc).
- Brodifacoum 25D: a 1-2 g pelleted bait product containing 25 ppm brodifacoum, designed for use on islands with Mediterranean climates (Bell Laboratories, Inc.).
- Brodifacoum 25W: a 2g pelleted bait containing 25 ppm brodifacoum, designed for use on islands with wet to very wet climates (Bell Laboratories, Inc.).

The major advantage of anticoagulant rodenticides is the delayed onset of symptoms (~2-3 days); they are not known to induce bait shyness (as per acute toxicants - Parkes 2011) and rodents can and do continue to feed on the bait even after symptoms develop. Some rodents are even known to continue to feed on the bait during the latent period, the time between ingestion of a lethal dose and mortality (Howald et al. 2005).

First generation anticoagulant rodenticides, such as diphacinone, are multi-feed rodenticides and rodents need to consume bait, sustained over a period of several days to achieve mortality (varying from 3-12 days). Diphacinone has been successfully used to eradicate rats from islands, mainly using bait stations with relatively few broadcast approaches (DIISE 2016). It has been used to attempt house mice eradication on islands twice, with one reported success and one failure (Samaniego 2016).

Second generation anticoagulant rodenticides, such as brodifacoum, can be toxic after a single exposure or feeding event to sensitive rodents (Kaukeinen 1993). In some laboratory trials, albeit not all, 100% of mortality of rats and mice have been reported after a 3-day choice test (see Pitt et al. 2011). Globally, a total of 87 house mouse eradication attempts have been carried out, and all but two, utilized brodifacoum.

In the interest of completing a house mice eradication on MANWR in the foreseeable future, with a reasonable probability of success, we recommend the use of a bait containing brodifacoum. The use of less robust alternatives would significantly increase the uncertainty of the likelihood of success.

7.3.1 Calibrating a Bait Application Rate and Number of Applications

Bait must be delivered at an application rate that ensures bait is available for all mice for long enough that all mice will be exposed to and consume the bait. The application rate needs to account for other species that compete with mice to gain access to the bait. Species such as invertebrates (eg. landcrabs, insects) can consume a significant amount of bait, but are not affected by the rodenticide. Bait application rates are set to ensure that adequate amounts of bait are available for long enough, regardless of species or individuals that consume the bait. Current practice suggests that a minimum of 4 nights' bait availability may be necessary (Keitt et al. 2015). Initial studies during the November 2016 site visit, suggest that the application rate could be in the 30-40 kg/ha range to ensure that bait is available for a minimum of 4 nights. We recommend additional *a priori* research to calibrate an appropriate bait application rate, at least one year ahead of the planned eradication, during the optimum biological window (seePitt? *et al.* 2015).

We recommend that a minimum of two, possibly three bait applications at equal application rates (Keitt et al. 2015) be used on MANWR. Each application should be spaced approximately three weeks apart, to intercept any new generation of mice that may be missed, and/or emerge after the initial bait application (Keitt et al. 2015).

7.3.2 Mouse Eradication in the Commensal Environment

The successful removal of mice in the diverse commensal environment of Sand Island would require the use of a diversity of rodent control tools. Consideration of the presence of people, potential alternative foods for mice, and the stratified 3-D habitat will influence the optimal and safest strategies for the removal of mice from each structure.

We recommend a combination of treatment options that may include:

- Hand placement of loose bait trays (open top with exposed bait)
- Bait bolas (bait held within rodent-accessible material that can be hung in place to keep out of water)
- Bait stations (within a container or tray)
- Mechanical traps (snap-traps and glue boards)

The estimate of each treatment option's efficacy to target and remove mice is based on the degree that an individual mouse must alter their regular behavior to be put at risk by the tool. Options being considered as appropriate for use must also take into consideration the risk to personnel safety while deploying and maintaining the treatment option. This was noted as an area of consideration regarding the selection of treatment options within historic buildings in dilapidated condition; while not designated as abandoned they are considered as such for the purposes of the assessment.

We recommend that a system be put in place that allows each structure to be individually identified and assigned a unique mouse removal strategy - a structure management plan. The following details should be considered when developing an individual structure management plan:

- Structure category and use
- Numerical identification
- GPS coordinates and map (GIS layer)
- Photo of structure
- Floor plan showing treatment options prescribed
- Details regarding how it is to be treated throughout implementation

7.3.3 Airfield

No evidence suggests that areas of sealed hardtop and cement of the airfield support house mice. However, treatment of habitat directly above of the immediate perimeter of each of these hard surfaces and utility access points will be necessary; particularly where vegetation has grown and airfield utility access points create breaks in the uniformly sealed perimeter surfaces. A runway safety zone skirting, taxiway safety zone skirting, and two blast pads make up the area immediately adjacent to surfaces requiring foreign object debris (FOD) management and are delineated by large conspicuous aircraft control paint-lines. Baiting within these sites up to aircraft control paint-lines and access into airfield utility points was assessed by airfield management and were not considered restricted, or to present a FOD hazard if bait was present. Should bait pellets inadvertently drift onto the active airfield, commercial leaf blowers or airfield sweepers can be used to remove pellets while conducting FOD assessments after treatment.

7.3.4 Special Treatment Areas

Various locations on Sand Island have natural or manmade features that create a sheltered interior space that may harbor mice, but would not be effectively treated by aerial broadcast. These areas would need additional or unique treatments to ensure all mice have access to bait and can be put at risk. These areas include:

- Boneyard, and seaplane base
- Coastal fringe where metal retaining structures combine with eroding sand to make undercut areas
- Rock piles
- Piers

7.3.5 Rainwater Collection Area and Seeps

Freshwater is a critical resource for people and wildlife (in particular Laysan Duck, shorebirds, and migratory waterfowl) on Midway Atoll.

For human consumption, rainwater is collected from runoff adjacent to the runway and pumped into three large storage tanks (the three full tanks can support the island under normal use for ~7 months). Water is distributed to the island community after filtration and filtered again at the tap before consumption.

Although brodifacoum is relatively insoluble in water, and will not readily go into solution unless bound to organic matter, the local community has expressed concern about the potential for rodenticide contamination of the freshwater supply. Out of an abundance of caution, we recommend that a mitigation plan consider maximizing collection of water in the storage tanks ahead of the eradication; disconnecting the water collection and covering the grates prior to bait application; additional filtration; and no additional freshwater collection until informed by a monitored degradation of residual bait pellets, and rodenticide residue.

The pond adjacent to the water tanks, and the artificial and natural seeps are key habitat for shorebirds and waterfowl, particularly the Laysan duck. Exclusion of these areas can be done with careful planning of aerial operations, and we recommend a buffer zone around these areas wherever possible, with consideration of alternative mouse removal methods (mechanical and hand broadcast within these zones). During the November 2016 site visit, biologists on island suggested that temporarily decommissioning the natural seeps (burying them) may be an alternative, and may simplify the aerial application (no areas to avoid., The artificial guzzlers can be emptied, covered with plastic tarps or wood to prevent bait pellets from falling in, and inspected and cleaned before re-activating.

7.4 Improving the Odds of Success: Managing the Constraints and Risks

7.4.1 Optimal Timing for a Mouse Eradication

House mice are partially reliant on humans but are known to feed on the fruits, seeds and the non-native and native plants and grasses, as well as other prey on Midway Atoll. Therefore, the availability and abundance of those food sources likely influence the annual population cycle of mice on MANWR, even if only partially. This annual population cycle in temperate island systems is readily predictable and tied to the seasons, however, in tropical systems this population cycle can be less apparent. In the tropics, mouse abundance is typically in the decline phase or at lowest densities in the driest parts of the year (Ringler et al. 2014). Eradication practitioners exploit these known population cycles and it is thought that eradications are more likely to be successful when the mouse population is in the decline phase of their food dependent population cycle, and the mice are the hungriest (Broome et al. 2014), and more likely to eat the bait. Unfortunately, this annual wet/dry cycle (and associated relatively high/low food abundance) is less predictable in the tropics and may vary interannually, or not at all (Russell et al. 2011) presenting an inherent uncertainty about the weather conditions and making it more challenging to predicting the best time for the eradication.

On Midway Atoll, the average lowest rainfall is from April –July, with increasing rainfall through the late summer and fall/winter. Reports from the island biologists, suggest that the low vegetation, such as grasses, are either dormant or dying back during the summer season due to low rainfall and high heat, as well as trampling by albatross chicks. Thus, the lowest availability of vegetation as a food source to mice, and likely low point in their annual population cycle is probably between May-July, which would be the best time for the eradication based on weather data alone. However further assessment of the mouse population is needed. The role that the nesting albatross play on providing alternative food to mice, and the influence on the mouse population cycle is unclear, and may be significant. There is no data available on the population cycle of mice on MANWR. For this feasibility assessment, it is assumed that mice breed year-round, even though they probably go through annual and likely interannual population cycles depending on the climate (Brown and Singleton 1999; Drost and Fellers 1991)***. In the absence of Midway specific mouse data, w*e strongly recommend that the *annual mouse population cycle on MANWR be evaluated through monthly monitoring using mark/recapture techniques and/or lethal trapping to evaluate reproductive condition, sex and age ratios, and numbers captured over time to inform best timing of the eradication.***

7.4.2 Non-target Species

Implementation of a mouse eradication on Sand Island does present inherent risks to non-target species, including:

- Primary poisoning from directly consuming bait pellets;
- Secondary/Tertiary poisoning from consuming contaminated prey items (eg. poisoned mice, invertebrates).
- Disturbance risks from personnel and equipment delivering bait into every potential mouse territory (e.g., helicopter overflight noise disturbance to resting monk seals)
- Bird strike hazard (BASH) to birds that may be in the air during helicopter operations

From a toxicological perspective, the risk to non -target species during an eradication campaign is a function of species present on the island and their behavior; toxicological properties, composition, and delivery method of bait; the susceptibility of those species to the toxin; and the probability of exposure to the rodenticide either directly by bait consumption or indirectly by feeding on animals that have consumed baits (Howald et al. 2007). Spatial and temporal risks should be minimized, eliminated, or mitigated whenever possible, but ultimately, the species, their status, and the population significance of the risk they face will need to be evaluated. In particular we recommend a thorough Ecological Risk Assessment be prepared for the various species on the island, and results incorporated into the NEPA process and inform any mitigation actions.

On MANWR, there is no one time of year when all species of potential concern are absent, thus, annual use of the island by each species can be used to identify the greatest risk periods so that they can be avoided (**Figure 6**). A more comprehensive assessment of risks and specific mitigation actions will be required and should take into consideration potential short-term impacts through mortality of individuals due to eradication activities and weigh against the benefits of long-term species recovery and protection afforded by a mouse eradication. Mitigation activities can minimize overall impacts, but in some cases, may not eliminate risks completely.

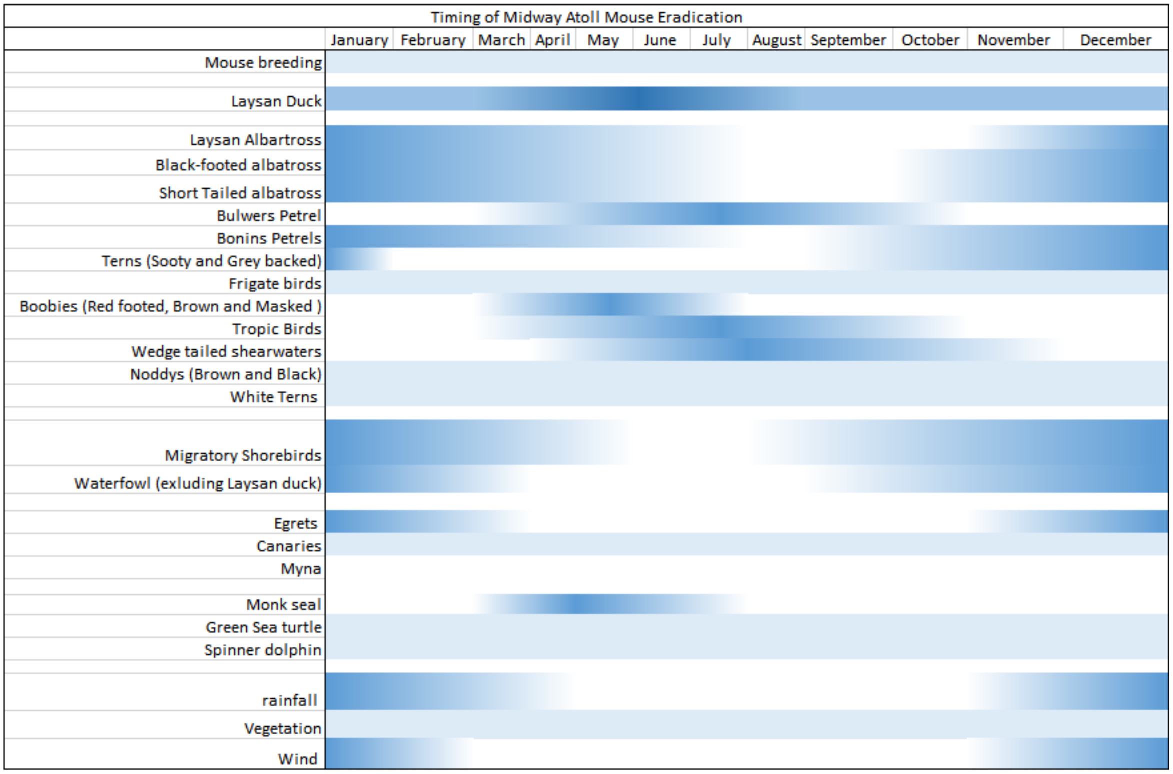

Figure 6: Monthly species abundance, presence, or breeding activity on MANWR. Dark blue indicates high density, light blue low density, and white indicates absence or very low density.

Rodenticide exposure, disturbance impacts and BASH hazards can be minimized through timing the operation to avoid the seabird breeding season, and to target periods when migratory shorebirds are on their breeding grounds in Alaska (e.g. Wegmann et al. 2014; Howald et al. 2005). Timing can also minimize risks to avoid specific behaviour or key windows such as avoiding monk seal pupping, and peak "pica" behaviour period exhibited by albatross chicks. Other strategies to consider include captive holding and release until the risk period passes (e.g., Howald et al. 2005; Wegmann et al. 2014), hazing (scaring away from an area) until the risk period passes, as well as maintaining the antidote, Vitamin K, on hand if an individual is demonstrating signs of toxicosis and can be captured and held for treatment (e.g. Wegmann et al. 2014).

The endangered Laysan Duck is at a high primary and secondary poisoning risk due to its omnivorous diet, and will require mitigation. The Laysan Duck presents a complex mitigation challenge for a mouse eradication from MANWR; they are a non- migratory, year-round resident, that is relatively abundant across MANWR, and routinely fly between Sand and Eastern islands. Thus, the only effective mitigation strategy is to prevent the exposure of the ducks to the bait and rodenticide either through live capture, hold, and release after the risk period passes, or live capture hold and temporary translocation to another island (potentially Eastern Island if mice are confirmed to be absent). ***The MANWR Laysan Duck population is globally significant for the species, and we caution that a robust mitigation strategy will need be developed to protect the population. We are recommending the creation of an interdisciplinary Laysan Duck protection team that designs, consults, tests and oversees the implementation of a robust mitigation plan, with the goal to maintain a healthy population of ducks on to MANWR after the mouse eradication.***

Mitigation actions are often expensive and increase the complexity of a project but are an important aspect for biological, socio-political, moral, ethical and cultural reasons. Short-term impacts are a possibility even with mitigation measures in place (e.g., Rueda et al. 2016). However, some species have shown rapid population growth or increased breeding success after invasive species have been removed (e.g. Howald et al. 2005).

Table 4. Preliminary risk assessment by species, consequence, and potential mitigation strategies.

Species	Disturbance Risk from Helicopter Activity?	Rodenticide Exposure Risk?	BASH Hazard?	Population Significance of Risk?	Mitigation Strategy
Laysan duck	Low	High	Low	High	Captive holding or translocation
Vagrant waterfowl	Moderate	High	Low	Low	Exclude bait from water bodies, do eradication in boreal summer when they are breeding up north
Albatross (all species)	Moderate	Moderate (Pica behavior of chicks)	High	Low	Target bait application timing outside of chick-rearing season ("pica" behavior of chicks remains an unquantified risk)
Migratory shorebirds (Bristle Thighed Curlew, Pacific Golden Plover, Ruddy Turnstone, and vagrants	Low	High (primary and secondary)	Low	High (BTCU), Low (all others)	Timing when birds are on breeding grounds in Arctic.
Burrowing	Low	Low	High	None	Timing eradication

seabirds (Bonin petrel,			(evening flights)		outside breeding season.

Wedge-tailed shearwater, Bulwer's petrel, Tristram's storm-petrel)					
Boobies (Reg-footed, Brown, and Masked boobies)	Low	Low	Moderate	None	Timing eradication outside breeding season.
Great Frigatebird	Low	Moderate	Low	None	Timing eradication outside breeding season
Terns (Sooty and Grey-backed)	Low	Low	Low	None	None
White tern	Low	Low	Low	None	None
Noddies (Black and Brown)	Low	Low	Low	None	None
Cattle Egret	Moderate	High	Low	None	Invasive species but must still be considered as non-target species that will be affected.
Myna	High	Low	Low	None	Invasive species; must still be considered as non-target species that will be affected
Canary	Low	High	Low	High	Captive holding to preserve local population with cultural significance; otherwise global population not impacted
Monk seal	High	Low	None	Low	Avoid pupping season/ minimize overflights

Spinner dolphin	Low	None	Low	Low	Prevent bait application into marine environment; monitor
Green sea turtle	Low	Low	Low	None	Avoidance, minimize disturbance
Hawksbill Sea turtle	Low	Low	Low	Low	Avoidance, minimize disturbance

7.4.3 Managing Human Associated Risks to Eradication Success

MANWR must remain an active community before, during and after an eradication of mice. Certain activities such as keeping the airfield operational, potentially construction/seawall projects, biological monitoring, maintenance of facilities and utilities, will continue, and the eradication must operate around these activities. However, modification to the day to day systems, processes, and infrastructures can and in some cases, must be made to minimize the risk of eradication failure. This section focuses on eliminating or minimizing risks to the operation from the presence of alternate human origin food sources or refugia.

7.4.4 Eliminating Human Food Sources

The island will continue to receive and process deliveries of food and other items, prepare and feed the residents, and generate edible waste before, during and after the mouse eradication.

These human-based food sources are persistent and reliable, meaning at least some number of mice survive by feeding exclusively or nearly exclusively on fresh, stored food and human-generated waste. While is impossible to eliminate these potential food sources (people have to eat), but it is possible to eliminate access to these food sources. However, this will require a change of habits and protocols, and the establishment of secure storage. We cannot overstate the importance of the need to modify procedures and protocols, and how human food is transported, stored, and handled through to consumption and waste on MANWR.

The identification and establishment of new procedures to eliminate mice access to human-based food sources will be a significant project unto itself. Even more challenging, will be changing human behavior to enact the needed protocol. Education, testing and monitoring, and modifications will need to be established to ensure the systems are functioning and achieving the goal of excluding mice. The community member buy-in of the process will require early and frequent engagement. All protocols should be put in place and functioning at least 6 months prior to the eradication to ensure systems become a matter of habit well before the eradication attempt occurs. The implementation of protocols, and ensuring compliance of the process will require a dedicated team member whose role is to prevent mice from gaining access to human origin foodstuffs.

7.4.5 Food Delivery, Handling and Storage

Food arrives primarily by ship, but also comes in via plane. Large shipments of preserved and dry food are limited to roughly twice each year. These large food shipments arrive palletized and shrink-wrapped in shipping containers. These punctuated supply events are offset by near constant arrival of food on planes that transport people to the island.

Large food deliveries are immediately located to one of three locations: freezers, refrigerators and dry storage. It is unclear how rodent proof these storage facilities are, and the older dry storage facilities (previously used as refrigerated storage) are old, rusted in the corners, and not mouse proof. The ship store also stores food items that are available for sale, have reported mouse destruction (chewing through packaging), and does have active mouse traps permanently installed to minimize damage.

The current practices of how food is stored is unacceptable for a mouse eradication to proceed, and recommend that all food is moved into either rodent-proof containers or modify storage locations such that food is inaccessible, or use mouse proof shipping containers or modify buildings or storage rooms so that they are mouse proof. It is imperative that mice do not have access to where food is stored or the food itself, and the mouse eradication should not proceed until this pathway for access to mice is closed.

7.4.6 Food preparation and consumption

Food is prepared in the Clipper House, personal residences, and around BBQ grills. Food is consumed basically anywhere that people go on the island from homes to workplaces, including in the field.

The Clipper House is the main point of food preparation, consumption, and garbage generation. It has the capacity to feed all residents on the island for three meals per day. The restaurant style kitchen, cafeteria style service, and both indoor and outdoor seating for food consumption. The Clipper House facility is maintained very well, and despite extensive food production, waste and garbage management, we found no evidence of mice utilitizing the kitchen facility or eating areas. This is an artifact of both how well the facility is maintained for health standards (clean), and likely the active mouse control around the building. The Clipper House is not mouse proof, and contains an attic space, and a small sump for collecting waste water from the kitchen (food scraps, etc.). There is a small dry goods storage off the kitchen area that has had reports of mice entering, and contaminating foods on the shelf. However, active mice trapping keeps the storage unit mostly free of mice.

The many homes, duplex units, common space (eg. bowling alley, Capt. Brooks) and main work buildings have small kitchenettes to large full size kitchens with full cupboard spaces, and appliances for storing, preparing and cooking food. In addition, BBQs are used by some residents.

The diversity and extensive places that food is prepared and consumed warrants a high degree of caution and consideration during the planning phases of the eradication. The buildings are not mouse proof, and the many individuals involved with food preparation suggests a high degree of variability of how mice get access to food (or not). Ideally, food preparation and consumption would be limited to the Clipper House before and during the eradication. However, this would mean ensuring the Clipper House has the capacity to feed all island residents, and feedback in place to ensure that protocols are in place and being followed to ensure no food is removed, prepared or stored in other places on Sand Island.

Not allowing food outside the Clipper House is preferred, however, compliance may be difficult to enforce. If food is allowed in additional locations, people will need to be provided with rodent-proof food and waste containers, and be fully compliant with handling procedures. Non-compliance with protocols would create a significant and real risk of project failure.

We recommend that a process be developed to identify, design, and establish protocols to minimize the human food pathway to mice on Midway Atoll, with a clear outcome of securing buy in and voluntary adoption (vs. starting with enforcement). Some protocol requirements (eg. rodent proof garbage containers, no bbqs, no loose food) are a minimum and should be enforced.

Finally, in addition to foodstuffs there are multiple small private gardens, a large community garden, small orchard and a large covered hydroponic garden that supplements the availability of food; all gardens are located on Sand Island. Within 3 months of an eradication, any fruits, vegetables, flowers, squash, tubers, etc. must be harvested in advance of the operation, and gardens closed. ***Ideally, all gardens and greenhouses would be completely removed prior to the operation and could re-establish after completion of the operation.***

7.4.7 Waste Disposal and Landfill

Waste disposal creates a significant challenge in eliminating alternate food sources for mice. Current practices create many opportunities for mice to consume garbage, from outdoor garbage and recycling cans, to dumpsters, to the recycling center and open land-fill. The pathways for mice to access garbage on Sand Island is extensive, and waste management systems, infrastructure and processes will need to be significantly modified to close the pathway. We recommend that a mouse eradication not proceed until the waste management system adopts the following recommendations:

- Garbage and recycling containers modified or replaced with rodent proof options (sealed).
- Line containers with thick, top quality trash bags to prevent leaks and spills.
- Bags removed before they are ¾ full to ensure they can tied securely.
- Waste removal frequency is increased to prevent over full containers.
- Containers are sealed if left full overnight.
- Recyclables are rinsed and washed of any food residues before storage
- Clipper House grey water, used oil, and residue from grease traps and fan filters should be disposed of as garbage, and not stored or dumped in sewer.
- Transition open landfill to gas fired incinerator, with frequency of incineration increased to prevent storage of garbage overnight; i.e., garbage incinerated the day of collection.
- Garbage collection truck and trailer is cleaned after each use, and stored in open locations.
- Supplemental rodent control methods will need to be implemented around garbage points to increase the probability of removing mice.

7.4.8 Grey and Black Water

MANWR has a functioning gravity sewer, and septic field. Grey water and black water entering the sewer are potential food sources for mice, and may be living almost exclusively within the system. It will be challenging to address changes to the sewer system, however, there are ways to minimize the risk this situation presents to a successful operation that includes: baiting of the sewer system at all access points, use of supplemental rodent control methods such as traps, glue boards, and other monitoring techniques to ensure that any mice present are effectively removed. ***The significance of the sewer system is unknown, and we recommend a thorough mapping, and evaluation of the system to inform management intervention for mice be done prior to an eradication attempt.***

8. IS THE ERADICATION SUSTAINABLE?

The removal of mice from MANWR is intended to be a permanent solution to abating the predation of breeding albatross, and facilitate restoration of the island. However, failure to eradicate the mice, or a future reintroduction of rats or mice, can negate any conservation gains made with the removal.

The risk of reincursion is very real. In September 2016, the supply vessel, M/V Kahana, transported construction equipment, and re-introduced rats to Kure Atoll, after having spent 5 days tied up at the Sand Island pier at Midway. Detection tools have failed to detect rats on Midway, however, there have been reliable reports and one remote camera photo of a suspected rat on Sand Island. Fortunately, a planned mouse eradication would remove rats from the island as well. It is imperative that biosecurity procedures to prevent, detect, and respond to any incursion should be put in place prior to the eradication to test, refine, and adapt systems and methods and protocols (Broome et al. 2014).

The pathways of introduction via ships, barges and planes transporting goods and people to and from the island are known and controllable, and many examples of biosecurity plans can be drawn from, including examples from other Refuges (e.g. AMNWR, Desecheo) and US Channel Islands National Park, California, focused on preventing, detecting and responding to an incursion of non-native rodents. This biosecurity plan would need to include measures to prevent invasions to the Atoll, but will also require measures to prevent the spread to other islands of the Atoll. For example, evidence suggests that mice are absent from Eastern Island, however, the USFWS regularly transports people and equipment from Sand Island to Eastern and Spit islands. Currently, house mice are at risk of being transported over to Eastern or Spit Islands with the inter island movement, potentially negating the value of Eastern as a translocation site for the Laysan Duck. ***We strongly recommend that biosecurity measures be put in place to prevent, detect, and respond to an inadvertent introduction of house mice to Eastern Island.***

8.1 The Tenets of Biosecurity: Prevention, Detection and Response

8.1.1 Prevention

Prevention, detection and response procedures are all necessary for a robust biosecurity plan, but is in many ways prevention is the most important element. Many invasive species are small and difficult to detect, so once a species arrives to an island the chances of detecting and removing it before a population establishes, or before impacts can be seen, is low. Similarly, money spent on prevention is likely to provide better biosecurity benefit than money spent on detection and response.

Prevention protocol should apply to all pathways, and be specific to match the risk presented by each. Where pathways are linked to contracted service providers, those contracts should mandate compliance with necessary procedures. Examples of procedures are:

<u>Ships</u>

- All ships maintain rodent and detection control measures on board, managed by a trained biosecurity lead;
- All materials inspected before loading;
- All high-risk materials (food) stored in rodent-proof containers;
- Active surveillance during the voyage;
- Vessel returns to port upon detecting a stowed-away invader, if feasible, or is quarantined away from Midway until the threat can be addressed;
- All tie lines have rodent proofing (disks or cones) to stop rodents from running along them;
- Final inspection upon arrival and during unloading;
- Possible fumigation procedures for invertebrate threats.

<u>Planes</u>

- All cargo thoroughly inspected before loading. Suspicious materials/containers not allowed;
- Cargo staged in advance is inside rodent proof containers, and not left open on the tarmac or in a facility with rodents or other pests;
- Inspection upon arrival and during unloading;
- Possible fumigation procedures for invertebrate threats.

Trained detection dogs could be used as part of inspections. These dogs could be employed at the departure points, at MANWR, or both.

8.1.2 Detection and Response

Detection and response measures can overlap, because some tools serve both purposes. However, any detection should trigger additional, more intense, detection and response actions. Detection protocol can include:

- Bait stations, mechanical traps, sticky traps permanently maintained around high risk areas such as:
    - Airport
    - Docks
    - Storage facilities where arriving food goods are taken
- Camera traps
- Tracking tunnels
- Training and educational materials for island staff, including how to identify invasive species, their sign, and reporting procedures.

The response to any detection will be scaled to the circumstances of detection (e.g. the animal was detected and removed, or only definite sign was detected) and species. Clear procedures, including clear lines of authority and responsibility must be in place before the detection occurs. Response kits, including multiple methods to detect and remove the most likely invaders, should be developed and purchased as part of the biosecurity planning process. Relationships with species experts should be established, so they can be contacted immediately to provide guidance.

9. STAKEHOLDER SUPPORT AND ENGAGEMENT

The long-term sustainability of the project is primarily dependent on the actions of the community on island and support staff off-island; their support of the project is critical to the success of the eradication (Griffiths et *al*., 2012). Individuals in communities can perceive the eradication in different ways depending upon the project's relevance to their own interests and livelihood. The community on MANWR has been both directly and indirectly affected by the presence of mice and after a cursory assessment, there appears to be strong support for the eradication of mice from the island; primarily driven by the interest to stop mice from predating upon albatross and to remove the presence of commensal pests. Clear interest to eradicate mice was present amongst USFWS personnel and volunteers as well as from Chugach management and contractors; this interest was evident after receiving regular requests, and suggestions of how, to remove all mice from MANWR. Importantly, changes to prepare for and support a mouse eradication were openly discussed, such as the need to adjust specific daily behaviors, remain vigilant to mouse sightings, and become a cognizant participant in the eradication as a community; concepts which were largely supported by community members with whom the team was able to engage with.

During the site visit we were unable to meet with several management staff and many of the Thai community due to individuals being unavailable or due to a language barrier that challenged effective discussion. An aspect identified that may impact project acceptability are individual's sentiment associated with the death of mice and collateral impacts to non-target species during and shortly after bait is broadcast. Of relevance is the local Thai community; many of whom practice Buddhism and may not feel comfortable with a conservation action that destroys a life to preserve another. The feasibility of this project, an eradication on an inhabited island, will rely on community engagement that successfully reaches all community members, regardless of language or religion. ***We strongly recommend that lines of communication are developed which offer outlets to present and address concerns related to the project as well as present clear expectations regarding how each member of the community plays a role in the success of the project. In addition to direct communication, the use of questionnaires may also provide insight on the local opinion of proposed conservation programs (Ogden and Gilbert, 2011) or to better understand their level of understanding.***

A demographic not directly assessed by the feasibility team includes other groups within Hawaii and internationally whom may be concerned with wildlife protection, maintaining the biological integrity of the wildlife refuge and monument, preserving the historical integrity of the memorial, or animal welfare. Individuals outside of the immediate influence of the project are provided the opportunity to voice their opinion towards the proposed alternatives during a public scoping process. Throughout the development of the project, outreach will be an important consideration when addressing the wider public to improve awareness of the biodiversity and historical importance of MANWR and the problem of invasive species globally. This should be a component within an external communications plan and could be achieved through media releases (e.g. newspaper and magazine articles, radio, TV, signage) to the public (Odgen and Gilbert, 2011; Griffiths et *al*., 2012).

To ensure that this project is socially acceptable it must address, or at the very least be aware of, the concerns of the various stakeholders (Varnham et *al*., 2011; Odgen and Gilbert, 2011; Griffiths et *al*. 2012). Any concerns, and broad social acceptability, can be formally assessed upon initiation of scoping and public comment periods during the National Environmental Policy Act (NEPA) process.

10. POLITICAL & LEGAL CONSIDERATIONS

There are no insurmountable political or legal barriers to a mouse eradication from MANWR; the USFWS-Refuges as the lead agency, landowner, and proponent of the project, have experience with legally implementing the removal of invasive rodents from islands within the US Pacific and elsewhere in the United States. Within the US Pacific, the most recent on Palmya Atoll NWR in 2011 (USFWS 2011). Historical projects elsewhere, and the MANWR rat eradication in the mid-1990s do serve as a precedent for the eradication actions proposed on MANWR; each of which have been held to similar political and legal requirements, and addressed through compliance with NEPA. We did not identify anything unique about MANWR that would limit the likelihood of securing necessary permits or legal compliance. The only exception may be the need for overflight of the building, and recommending a minimum tool analysis in conjunction with the EPA to evaluate the need, and process moving forward. All required permits and consultations are primarily related to the application of rodenticide, working in protected areas, conducting specialized aerial operations, water and air quality, as well as managing and mitigating risks to people and non-target species including migratory birds and federally listed endangered species.

At a <u>minimum</u>, compliance with the following Acts need to be considered, and any permits/consultations secured:

- National Environmental Policy Act (NEPA)
- Federal Insecticide Fungicide and Rodenticide Act (FIFRA)
- National Pollutant Discharge Elimination System (NPDES)
- Migratory Bird Treaty Act (MBTA)
- Section 7 consultation from NOAA and USFWS in compliance with Endangered Species Act(ESA)
- Marine Mammal Protection Act (MMPA)
- National Historic Preservation Act (NHPA)
- Federal Aviation Authority (FAA) - CPA category 2 and HDOA pilot certification category 4
- Papahānaumokuākea Marine National Monument regulations

11. CAPACITY TO PLAN, IMPLEMENT, AND SAFEGUARD A MOUSE ERADICATION

The USFWS and Chugach Corporation have a long and successful history of ensuring efficient operations on MANWR. During the site visit in November 2016, we talked with all parties and conveyed the principles of rodent eradication, and what it might take to successfully remove mice from the island. It became clear during discussions that the vast knowledge and experience working on the remote Sand island should be integrated into the planning and implementation phase of the project, for their involvement may be the determinant of success or failure.

Infrastructure on Sand Island and activities routinely taking place due to base operations are more than sufficient to support an aerial based eradication and all ground operations (bait station/hand broadcast). The infrastructure in place including an airfield and seaport will allow for bait, supplies, and even a helicopter to be shipped directly to MANWR via airlift (e.g. military or USCG airlift support) or by ship, with facilities to offload, stage the equipment and supplies, and base operations for the eradication. Furthermore, the on-island facilities are adequate to comfortably host necessary personnel needed for a mouse eradication (**Table 5**).

Table 5: Key Skills necessary for a high probability of eradication success on MANWR.

KEY SKILL	PURPOSE
Project management	Guide the project through lifecycle
Compliance and permit identification and management	Ensure compliance is evaluated and permits are secured prior to implementation.
Field trial development and implementation	Develop and implement appropriate trials to inform operational planning.
Commensal management	Address community engagement, commensal rodents and infrastructure unique to rodent eradications on inhabited islands.
Thai language translation	Translate inreach and community briefing materials from English to Thai to ensure full understanding of the commensal management plan
Baiting management (aerial, hand, station, loading)	Effectively plan for, and implement the baiting component to achieve eradication.
Field monitoring management	Data collected to assess project condition.
Non-target and mitigation management	Effectively plan for, and implement aspects related to risks and non-target species.
GPS/GIS and technology management	Manage technology and assess data collected to support field operations.
Biosecurity management	Safeguard the investment of eradication.
Logistics management	Address logistical constraints to operating on a remote project site.
Communications management	Effectively plan for external communications and press related to the project.
Safety officer	Safeguard the safety of staff and community at the project site.
Pilot license	Operate essential equipment to distribute bait via aerial broadcast.
Field experience	Capable and experienced field hands to implement tasks prescribed in field trials and operational plan

12. FINANCIAL ESTIMATE TO ERADICATE MICE ON MANWR

Estimating the cost of an eradication of mice from MANWR is challenging, as many details and decisions around the project need to be determined and informed, in some parts by additional research. However, we can determine the factors that will influence the budget, which includes:

- Size of island and helicopter flight hours – will Eastern Island need to be treated or not?
- Complexity of treatment (Commensal infrastructure) – how much investment will be needed to treat the infrastructure effectively and confidently?
- Remoteness and access – the need to transport people, bait and helicopters to the island.
- Support infrastructure on island for staff and equipment – the island has a good support network in place, however, the housing and support costs are unclear at this time.

- Non-target species mitigation needs – the Laysan Duck mitigation strategy still needs to be determined.
- Environmental Compliance needs
- Outreach and engagement strategies

13. CONCLUSION

We evaluated the technical, environmental, social, political, and legal considerations for a proposed mouse eradication from Midway Atoll National Wildlife Refuge. The proposed mouse eradication project was found to be more complex than a project on an uninhabited island, yet no insurmountable constraints or challenges were identified, and the eradication of mice from MANWR is considered feasible. We believe that with the use of an aerial broadcast approach, supplemented by other mouse removal methods in the commensal infrastructure, necessary changes to the systems and processes to prevent mice from gaining access to human foodstuffs, and diligent efforts to protect native species, especially the Laysan duck, the project has a high probability of success if the identified issues are addressed during the planning stages prior to implementation (**Table 6**). The short term, one time use of the rodenticide to remove mice will have a net benefit to the ecosystem and people of MANWR and is expected to far outweigh the short-term impacts.

Table 6: Key issues and recommendations correlated to project feasibility.

Issue	Recommendation
1. Uncertainty regarding distribution of mice across the atoll.	a. Additional and ongoing monitoring for the presence/absence of house mice on Eastern/Spit Island is necessary before finalizing the geographic scope of the eradication. Biosecurity procedures should be put in place to prevent the inadvertent introduction of mice to Eastern Island from Sand Island.
2. Non-target species	a. The Laysan Duck will be one of the more complex species to mitigate risk. A team of species experts, and bird capture/handling expertise should be assembled to design and test the mitigation strategies before the implementation of the eradication.
	b. Migratory shorebirds may be at risk if individuals remain on island or return early from their winter grounds.
	c. Determine if Canaries are a cultural species, and will need protection and mitigation.
	d. Mynah birds are considered an invasive species and could be removed before, concurrently, or after a mouse eradication. The decision regarding how these non-native species are managed should be resolved early in the project planning
3. Commensal mice	a. A detailed treatment plan must be required for each inhabited space, abandoned structure and

	subterranean access point across the island which will involve hand positioning of baits, bait stations and the targeted use of other devices e.g. traps and glue boards. Detailed maps, photos, and outline of strategies for baiting, and a monitoring approach will be required.
	b. The variety of food stuffs, storage, cooking and consumption patterns on the island presents a real risk to a successful mouse eradication unless changes are made to how food is grown, delivered, stored, consumed, and disposed on the island. The pathway of human food as a food source for must be closed for mice buy. Food storage and transport systems along with the waste disposal system on Midway Atoll will need to be closely reviewed and revised to limit the potential for alternative food sources for mice. The abundance or lack of alternative, human origin, food sources will be a significant factor in determining the failure or success of an eventual eradication attempt; however, this food source can be controlled through adjustment of current systems, and requirements of how food is stored and transporte, how people consume food waste is handled. Additionally, the open dump must be removed and alternative disposal measures (e.g. incinerator) must be taken to remove this food source.
	c. The open sewer will require a detailed treatment plan, including maps of all known access points (manhole covers, pumphouses), treatment strategies and monitoring.
4. Presence of an active runway.	a. A mitigation strategy for preventing bait application on the runway (FOD) will be required.
5. Management of bait around water sources.	a. Mitigation will be required to prevent and minimize bait and rodenticide from entering the freshwater collection system. Rainwater collection should be maximized prior to the eradication, and the storage tanks topped off with as much water as possible. Grates should be covered prior to bait application. No additional rainwater collection should occur for an agreed upon period of time after bait application in an overabundance of caution.
6. Stakeholder support	a. The successful implementation of a mouse eradication from MANWRI will require that all partners, stakeholders, and users of the island understand the

	key elements of the eradication plan, and their role in the project. Alignment of all the partners begins at the feasibility stage where options are considered for applying the principles of rodent eradication in context of the physical, biological and social constraints of MANWR.
7. Uncertainty regarding presence of rats on MANWR	a. Monitoring for the presence of rats in commensal infrastructure should be considered. Broadcasting bait will intercept rats along with mice, but may intercepted in the commensal infrastructure where alternative mechanical tools designed for much smaller mice may be used.

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15. APPENDICES

15.1 Appendix A: Narrative for species of greatest concern

The following is a list species in a rough order of concern. Species with the greatest risk of impact via the toxicant or bird strikes are listed first.

1. Albatross (Laysan, Black-footed and Short-tailed) present on island late October building up into early November through to late June, with chicks present until mid-August. Whenever these birds are present on the island they present a flight safety risk to the helicopter. The level of this risk varies at different times/ stages in the life cycle depending on which age classes of birds are present and their activity patterns. It would be desirable to quantify this by doing observations of when/how many birds are flying at the different times of the day and the year.

   Albatross chick are also at potential but unquantified risk of poisoning through their "pica" which involves chicks moving and often ingesting dirt providing a pathway for ingesting the toxicant. This occurs from June until the chicks depart in early to mid-August. A third risk posed by the albatross is when birds die and create a significant alternative food source for the mice. The biggest risk period for this is late July/ early August.

2. Laysan duck- are likely to be at high risk of primary and probably secondary poisoning. They are present on Sand Island all year a decision will need to be made as to whether mitigation for this species is required. As they are known to frequently fly between the islands any mitigation is likely to need to include the subpopulation on Eastern Island. Options include holding in captivity and wing clipping and holding them on eastern for the duration of the operation. The timing of the molt and when it is feasible to catch the birds before they become overly cryptic during the nesting season will need to be considered.

3. Migratory shorebirds- Bristle-thighed Curlew, Pacific Golden Plover, Ruddy Turnstone along with vagrants including Wandering and Grey tailed tattler, Long billed dowager, Wood sandpiper and others. While some young birds stay on Midway all year-round the bulk of the birds arrive in August and depart in May making the preferred window outside this period. We suggest investigating the feasibility of catching and holding as many as possible during the operation.

4. Monk seal. These can be present at all times of the year, generally hauling ashore to rest. The level of disturbance for individuals is likely to be low i.e. once or twice during each baiting application which is believed to not pose a significant risk. The exception is during the pupping season which is predominantly March through to June. There is little that can be done to mitigate this but as only 3 -4 animals pup on sand Island and most pupping will be completed before the baiting period it is not deemed a major issue.

5. Burrowing seabirds Bonin's Petrel, Wedge-tailed Shearwater, Bulwer's Petrel, Tristram's storm-petrel. While at least one species of burrowing seabird is present all year, often in large numbers, their daily activity pattern of arriving on the island in the evening and departing before dawn means that they will have minimal interaction with an aerial baiting operation. Also, there is no identified pathway for the birds to ingest the toxicant as they do not eat when on land.

food on land. There is however a major risk to birds in their burrows through any hand application- hand broadcast or bait station operation outside the buildings through the physical trampling of burrows.

6. Boobies –Red footed, Brown, Masked. Boobies are present at the atoll year-round with the Red-footed Booby being the most common of the three species on Midway. However, while they are frequently seen flying over or roosting on Sand Island the numbers are relatively low and they tend to flow at low altitude meaning the risk of air strike is very low. As the boobies predominately feed well offshore there is no recognized pathway for them to be exposed to risk of poisoning during the operation.

7. Frigate birds. Present on the atoll year-round but while they are frequently seen flying over and roosting on Sand Island they only breed on Eastern so will not be unduly disturbed by the helicopter operations. However, unlike the Boobies, Frigate Birds have been recorded catching and eating mice, so there is risk of secondary poisoning.

8. Cattle Egrets – These birds only breed on Eastern Island and there is already a control program under way for this species, so disturbance is not considered an issue. They do not fly very high and are a negligible risk to helicopter safety.

9. Sooty and Grey-backed Terns- these species present minimal risk to the operation and the operation to them as they do not breed on Sand Island.

10. White terns, Black and Brown Noddys – while these three species all breed on Sand Island there is no identified pathway for them to access the toxicant. White Terns predominantly breed March to August, while Brown Noddys June to October, and Black Noddys Decemeber to April. White Terns and Brown Noddys would be breeding during the proposed operational period however it is believed that disturbance is likely to be negligible. Their flight behavior may pose some BASH risk.0,[;’

11. Spinner Dolphin/ Green turtle- both species are present all year but there is no identified pathway for the toxicant. Turtles may be disturbed when loafing on the beach but as this is predominantly latter in the day disturbance should be minimal.

12. Mynas/ Canaries- while these species are at risk of poisoning they are of lower concern and are present all year-round therefore they are not a consideration in the timing.

15.2 Appendix B - Site visit trip report

Trip Report: House Mouse Eradication Assessment

Midway Atoll National Wildlife Refuge

Trip Dates: 25 October – 10 November, 2016

Gregg R. Howald, Pete McClelland, and Chad Hanson

ISLAND CONSERVATION
Preventing Extinctions

Executive Summary

1. This report summarizes the findings of the site visit made between October 25-November 10, 2016, to Midway Atoll National Wildlife Refuge, Battle of Midway National Memorial, in the Papahanaumokuakea National Monument, as part of the assessment of the feasibility of eradicating introduced house mice (*Mus musculus*).
2. The main objectives of the site visit were to:
   - Identify any physical and biological constraints to conducting a house mouse eradication.
   - Evaluate non-target species risk avoidance, minimization and mitigation strategies for the Laysan Duck (*Anas laysanensis*) and other species.
   - Identify additional research or monitoring needs to inform the feasibility assessment, eradication planning and non-target species mitigation measures.
3. House mice were not detected on Eastern or Spit Islands during our visit, suggesting that eradication efforts could be limited to Sand Island. However, additional monitoring will be necessary to confirm their presence/absence. Biosecurity measures should be instituted to prevent the inadvertent introduction of mice to Eastern or Spit Islands prior to the eradication attempt.
4. No insurmountable physical constraints to implementing a mouse eradication were identified. The primary constraint is the extensive and diverse commensal infrastructure found throughout Sand Island. The commensal infrastructure was divided into three categories: inhabited and abandoned buildings, and subterranean utility access points.
5. A number of potential non-target species were identified, including year round presence of the endangered Laysan Duck and introduced landbirds; seasonal presence of shorebirds and breeding seabirds including Laysan Albatross (*Phoebastria immutabilis*) and Black-footed Albatross (*Phoebastria nigripes*); and endangered Hawaiian monk seal (*Monachus schauinslandi*), green sea turtle (*Chelonia mydas*) and hawksbill sea turtle (*Eretmochelys imbricate*).
6. A feasibility assessment will be prepared independently of this trip report, with a detailed analysis of the options for eradication and mitigation strategies to minimize or eliminate risk.

Contents

Background and Justification for a Feasibility Assessment

The islands of Sand, Eastern and Spit (Midway Atoll NWR, Battle of Midway National Memorial, Papahanaumokuakea National Monument (Figure 1), support 18 species of breeding seabirds. Most prominent are the ~1.3 million breeding Laysan Albatross (*Phoebastria immutabilis*) (LAAL), and ~28,000 Black Footed Albatross (*Phoebastria nigripes*) (BFAL). A few individual Short-tailed Albatross (*Phoebastria albatrus*) (STAL) have been observed annually on the atoll. In 2004, a population of critically endangered Laysan Duck (*Anas laysanensis*) was established on Sand and Eastern Islands.

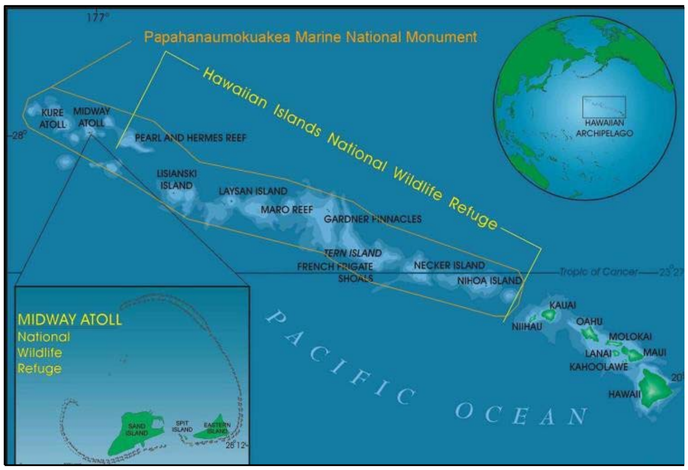

Figure 1. Midway Atoll National Wildlife Refuge, Battle of Midway National Memorial, Papahanaumokuakea National Monument, Northwest Hawaiian Islands.

Ship rats (*Rattus rattus*) were confirmed to be introduced onto the islands of Midway Atoll with the ramp up of military activities in 1943. It is unclear when house mice (*Mus musculus*) were introduced, however the massive construction and infrastructure maintenance projects (seawall, buildings, housing, and airport runway), suggest the possibliliy of multiple, inadvertent, introduction events over the last 75 years.

Rats were successfully removed from Midway Atoll in the mid 1990's, facilitating natural recolonization of the Bonin Petrel (*Pterodroma hypoleuca*) which recovered, going from non-detectable to hundreds of thousands by 2005 (B. Flint, pers. Comm.).

With the successful rat eradication, house mice were were subsequently released from rat predation and competition pressure, and the mouse population irrupted to densities not seen prior to the rat removal (Klavitter and Eggleston 2011). House mice appear restricted to Sand Island, and have not been observed on Eastern or Spit Island. While the loss of seabird populations due to predation by introduced rats has been well documented globally (see Atkinson 1985), until recently, house mice were not believed to have had an impact on breeding seabirds. The significance of the threat has likely been overlooked in the past (eg. Wanless et al. 2007), and impacts from house mice may be more significant when they are the only introduced mammal, possibly "triggering " predatory behavior (Wanless et al. 2007; Jones and Ryan 2009). For example, house mice on Gough Island are believed to be responsible for the high mortality of Tristan Albatross (*Diomedea dabbenena*) chicks (Cuthbert et al. 2004; Wanless et al. 2007; Davies et al. 2015), petrels and shearwaters (Wanless et al. 2007). On Marion Island, wounds consistent with mouse attacks have been found on chicks of Wandering Albatross (*Diomedea exulans)* and Dark-mantled Sooty Albatross (*Phoebetria fusca*) (Jones and Ryan 2010).

Figure 2. Adult Laysan Albatross with wounds caused by bites from house mice, Midway Atoll, 2016. (Photo: USFWS –MANWR.

At Midway Atoll, the 2015 annual survey of nesting Laysan Albatross documented bloodied and injured adult birds (Figure 2) in three localized areas on Sand Island. Rodents were suspected, and time lapse photography confirmed house mice repeatedly attacking nesting adult Laysan Albatross, crawling onto the head, neck and back of birds (Figure 3). The predatory behavior of mice started at a single location and then jumped to two additonal sites approximatley 100 m distant and then appeared to radiate out from these locations with each passing day, suggesting it was a learned behavior (M. Duhr-Schulz, pers. comm.). On confirmation of mouse impacts, the USFWS successfully initiated a mouse control program in the affected areas to curb the ongoing impact, and no additional wounded adults or chicks were subsequently detected as of February 2016. In total, 385 adult Laysan Albatross were confirmed to have injuries and wounds consistent with mouse bites (Figure 3). Nest abandonment was higher in the mouse impacted areas (M. Duhr-Schulz, pers. comm.). Of the forty two carcasses recovered, necropsy and histopathology results indicate that the proximate cause of mortality was sepsis (bacterial infection) originating in open wounds consistent with mouse bites (T. Work, pers. comm.). Therefore, mice are confirmed as the ultimate cause of death for Laysan Albatross during the 2015/2016 breeding season on Midway Atoll.

Figure 3. House mouse climbing on to the back of a Laysan Albatross, Midway Atoll, 2016. (Photo: USFWS-MANWR).

With conclusive evidence of mouse impacts on breeding albatrosses on Midway Atoll NWR, the USFWS commissioned an asessment of the feasibility of eradicating house mice from Midway Atoll. In the fall of 2016, USFWS and Island Conservation personnel visited Midway Atoll National Wildlife Refuge as part of assessing the feasibility of eradicating introduced house mice from the island.

Site Visit Participants

The following people were directly involved in the site visit, and assessing the feasibility of mouse eradication from Midway Atoll NWR:

1. Meg Duhr-Schulz, USFWS-Refuges
2. Beth Flint, USFWS-Refuges
3. Chad Hanson, Island Conservation
4. Gregg Howald, Island Conservation
5. Anne Humphrey, USFWS-Refuges
6. Susan Hunter, USFWS-Refuges
7. Pete McClelland, Private Contractor to Island Conservation
8. Jon Sprague, USFWS-Ecological Services

Site Visit Objectives

A team of USFWS and Island Conservation staff visited Midway Atoll National Wildlife Refuge between October 25-November 10, 2016 to consider options for the eradication of house mice from Midway Atoll.

The goals of the site visit were to:

1. Identify any physical and biological constraints to conducting a house mouse eradication.
2. Evaluate non-target species risk avoidance, minimization and mitigation strategies for the Laysan Duck and other species.
3. Identify additional research or monitoring needs that inform the final feasibility assessment, eventual eradication planning and non-target species mitigation.

The site visit to Midway Atoll, National Wildlife Refuge focused on:

1. Defining the **geographic scope** of the eradication, i.e., determine if mice are present on Eastern and Spit Islands,
2. Characterizing the extensive, and diverse **commensal infrastructure** (buildings, airport, active and abandoned subterranean utility access) and considering treatment options to maximize probability of a successful eradication.
3. Considering options to avoid, minimize and **mitigate any risks** (disturbance and ecotoxicological) to non-target species, with an emphasis on the Laysan Duck. In addition, we considered possible **impacts of native species on the operation** e.g. bird airstrike hazard from flying albatross or another species.
4. **Evaluating systems and processes** that are used to support personnel that work and live on the island, and consider changes that could be implemented to maximize probability of a successful eradication, minimize real or perceived human health risks from an eradication operation, and sustain the eradication into the future (i.e., biosecurity),
5. **Evaluating logistics** for an eradication implementation.
6. Building a **shared platform of knowledge** between the key project partners of the USFWS Refuges, Chugach Corp., and Island Conservation, to best inform a possible mouse eradication feasibility for Midway Atoll NWR.

1. Defining the Geographic Scope of a House Mouse Eradication at Midway Atoll NWR

- Midway Atoll has three emergent islands – Sand (452 ha), Eastern (136 ha) and Spit Island (6ha) (Figure 1).
- House mice are confirmed extant on Sand Island. All evidence to date (anecdotal and primarily observation) strongly suggest that mice are absent from Eastern and Spit Island. The ~1km wide channel separating Sand from Eastern/Spit islands is very likely sufficient to act as a natural barrier to mice moving between the islands (unassisted by people).
- If mice are absent from Eastern and Spit Islands, the islands can be excluded from the logistical planning for the eradication, thereby simplifying the project. However, additional monitoring is necessary to confirm mouse presence/absence.
- During our two day visits of Eastern and Spit Islands, no mice or mouse sign was incidentally observed on the islands. No mice were detected on automatic cameras set to passively detect movement from mice (or other species) (69 camera nights; Appendix 1).

Figure 4. Aerial View (from left to right) of Sand, Spit and Eastern Island, Midway Atoll NWR. Inset photo of Eastern Island. October 2016. (Photo: G. Howald)

- In comparison, on Sand Island, house mice were regularly observed at all times of the day and night and in all habitat types, often in seemingly high numbers. They were regularly photographed with automatic cameras (Appendix 1), and easily trapped on Sand Island during our visit.
- If mice were present on Eastern Island, it is reasonable to expect that we would have observed/detected mice as frequently as on Sand Island. However, the habitat differences between Eastern and Sand are distinct, and habitat-type influence on mouse population dynamics is unknown. Eastern Island is dominated by low lying puncture vine/nohu (*Tribulus*

cistoides) vs. Sand Island (Figure 4), which has multiple habitat types including an extensive commensal environment, and natural areas with a mix of native and non-native grasses, shrubs, and non-native ironwood (*Casuarina equisetifolia*) forest stands, with no understory.

- USFWS personnel and contractors travel from Sand to Eastern Island by boat, on an almost daily basis, for habitat restoration work. The transportation of gear and personnel by open boat presents a risk of introducing mice to the island and that introduction pathway should be closed as soon as possible with basic biosecurity procedures. We made recommendations to the USFWS staff on options and ideas for preventing mice from boarding boats while at the dock (bait stations, traps/glue boards on the docks and boats), and/or becoming inadvertently transported in supplies and gear including backpacks (i.e., inspections before departure).
- The worst-case scenario is that mice are unknowingly extant on Eastern Island while the mouse eradication implementation is focused exclusively on Sand Island. Inadvertently leaving mice on Eastern Island would be a significant missed conservation opportunity, and a future biosecurity risk to a mouse-free Sand Island.

Recommendation: Additional and ongoing monitoring for the presence/absence of house mice on Eastern/Spit Island is necessary before finalizing the geographic scope of the eradication. Biosecurity procedures should be put in place to prevent the inadvertent introduction of mice to Eastern Island from Sand Island.

2. Characterizing the Commensal Infrastructure

- Under the leadership and guidance of the on island USFWS and Chugach staff, we toured/examined the diversity of the on-island commensal infrastructure including every type of standing building – whether currently in use, abandoned or decommissioned to underground utility access points. Appropriate PPE (hard hats, masks, pants, shoes) were worn when accessing older, abandoned, and decommissioned buildings (Figure 5).
- After conducting a visual inspection of representative buildings across Sand Island, Chad Hanson gave a brief presentation to USFWS and Chugach staff to outline our initial understanding of building types and potential treatment options. The intention of this meeting was to receive feedback from island personnel to identify

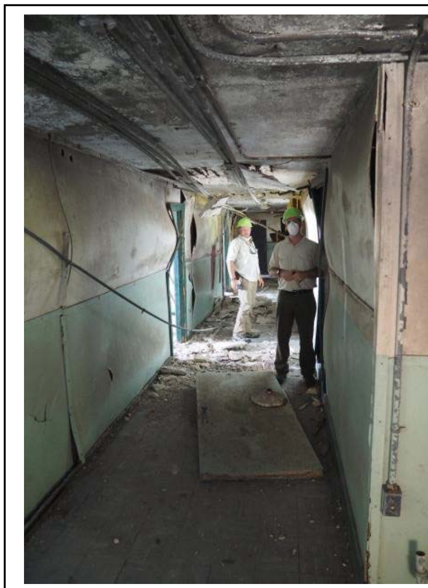

Figure 5. Inspection of a WWII era, abandoned building, Midway Atoll NWR. November 2016. (Photo: G. Howald).

any key structures or categories of structures that may have been overlooked, as well as encourage discussion regarding proposed options that could be used to address infrastructure during a potential eradication (Appendix 2).

- Mice were either observed, or evidence of mice was found (e.g. droppings/food cache) in the clear majority of buildings that we visited.
- House mice were reported on the second floor of the Charlie Hotel (barracks), and were observed on the second floor of the NAF building, confirming that the structures and how these buildings are treated to intercept any free-ranging mice will be critically important for the eradication planning.
- Structures remaining on Sand Island vary in condition and can be described in whole, or as a combination, of the following three categories:

    1. Inhabited spaces
    2. Abandoned structures
    3. Subterranean utility access points

Figure 5. Example of free standing housing, and shadehouse/greenhouse, Midway Atoll NWR. November 2016. (Photo: P. McClelland).

2.1 Structure Categories on Sand Island

2.1.1 Inhabited Spaces

- Living spaces -housing and dining facilities, food storage and food preparation sites (Figure 5).
- Work spaces -offices, utility buildings, covered storage, recreation facilities, covered garden / nurseries, docks and wharfs

2.1.2 Abandoned structures

- condemned structures where access is restricted or not permitted due to safety or other conditions (Figure 6)

2.1.3 Subterranean Utility Access Points

- high voltage service boxes
- electrical conduit junction sites
- sewer system access points (Figure 6)
- waterline junction sites and valves

2.2 Airport

- Sand Island has an active Part 139 certified airfield with a 7,900 ft. long by 150 ft. wide runway. The runway and taxiway is maintained as an emergency landing site for extended twin-engine operations (ETOPS) flights across the Pacific Ocean.
- We introduced the purpose of the feasibility site visit to Mr. Timothy Deike, airfield/runway manager, including a description of several treatment options that could occur in the event of an eradication. This was followed by a guided tour of the airfield which delineated limitations associated with working around an ETOPS airfield. We were provided access to subterranean utilities and navaid buildings. Additional information was provided regarding where water collection grates were located. This information was collated into a narrative and provided to Mr. Deike for review of accuracy.
- Several subterranean utility access points exist adjacent to the runway (not on the runway). There are tight controls on baiting the runway, but due to the lack of refugia for mice, baiting of this area will not be necessary.
- Mice have infested the building used to support the airport crew, and are actively controlled through trapping and poisoning.

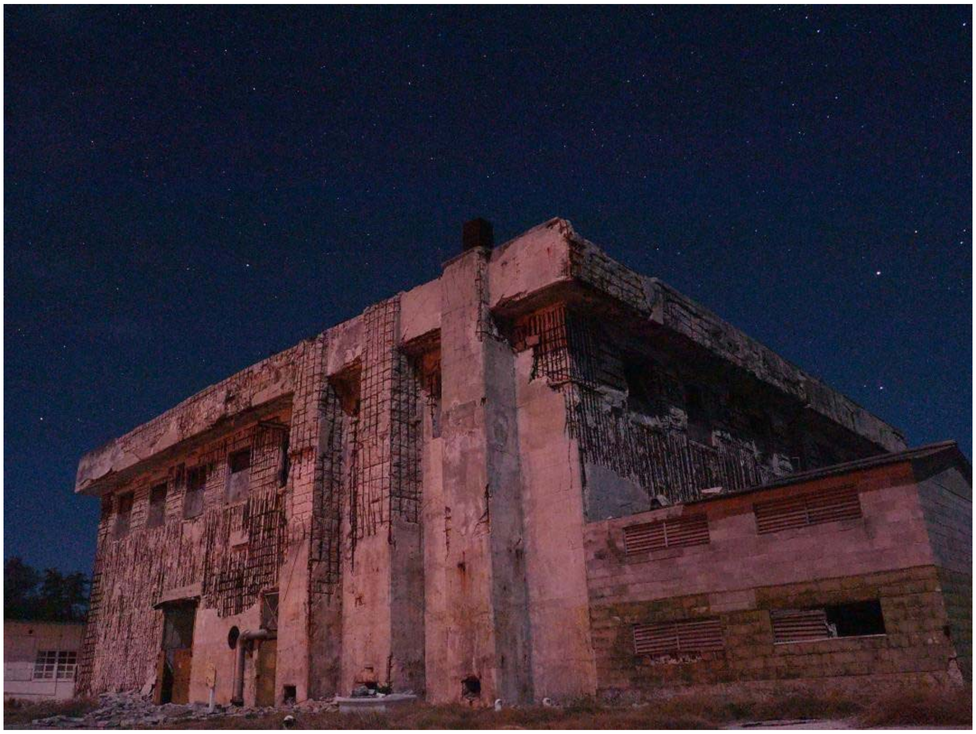

Figure 6. Abandoned WWII era structure (the Command Center) and sewer system access point, Midway Atoll NWR. November 2016. (Photo: G. Howald)

3. Considering Options to Minimize Risks to Non-Target Species

3.1 Overview of Non-Target Species Present on Midway Atoll NWR

- Much of our efforts on island were focused on identifying the diversity of species that utilize Midway Atoll NWR islands, lagoon and near shore marine environment, their legal status, and understanding the significance of Midway Atoll for each species.
- There are no endemic species on Midway Atoll, however, the Atoll is of high significance for numerous species, including:
    - The **endangered** (non-migratory) **Laysan Duck**;
    - Significant breeding populations of **LAAL and BFAL**;
    - An introduced population of **Canaries (*Serinus canaria*) that may have cultural significance**;
    - A **resident population of spinner dolphins** (*Stenella longirostris*);
    - **Overwintering shorebirds** such as the Bristle-thighed Curlew (*Numenius tahitiensis*), a species of special concern.
    - **Endangered** green (*Chelonia mydas*) and hawksbill (*Eretmochelys imbricate*) sea turtles use the beaches for resting with no known nesting areas.
    - **Endangered** monk seals (*Neomonachus schauinslandi*) use the beaches and foreshore vegetation for breeding and resting, and can be found on the island yearround.
- No native mammals are known from Midway Atoll. No domestic animals – pets or livestock - were present during our visit. Rats were previously documented on the three islands, but were successfully removed in 1995 (B. Flint, pers. comm.). House mice were confirmed as the only non-native mammal on the island during our site visit.
- There were incidental reports of rats on Sand Island, possibly introduced from an infested ship that was tied up to the island in September 2016.
- We were unable to confirm the presence of rats using remote cameras (Appendix 1). If rats have been re- introduced to Sand Island and are present in low numbers at the time of the eradication, the design of the mouse eradication would eliminate rats as well.
- Non-native birds including Mynahs (*Acridotheres tristis*) and Canaries were confirmed present and abundant on Sand Island.
- Cattle Egrets (*Bubulcus ibis*) have colonized Midway Atoll NWR by island hopping through the NWHI. Documented to be breeding on Eastern Island, egrets regularly use both Eastern and Sand Island, and are actively managed due to their predatory behavior on nesting seabirds.

3.2 Laysan Duck

- The Laysan Duck is protected under the US Endangered Species Act, and as part of the Species Recovery Plan. A second population of ducks was established on Midway Atoll beginning in 2004.
- The population established quickly, and population estimates are ~300-500 individuals on Sand Island and Eastern Island.
- We observed Laysan Duck in every habitat type across Sand Island, including around buildings, around standing water sources (guzzlers and seeps), open grassland habitat, under the ironwood canopy and the landfill. Ducks were observed at the water bodies on Eastern Island.

- Botulism has emerged as a problem for ducks on Midway Atoll, and mortality has occurred even with intervention by the USFWS (capture and treatment, hold and release).
- Based on their foraging strategy, it is assumed that ducks are at high risk of both primary and secondary exposure to the rodenticide during a mouse eradication. It is assumed they will consume bait, and contaminated prey items.
- The consequence of that exposure is presumed to be significant i.e., without mitigation, individual ducks present on the island during the eradication will very likely succumb to primary or secondary rodenticide exposure. Therefore, **reducing or eliminating the pathway of exposure** will be a key mitigation strategy.
- We discussed options for minimizing, reducing and avoiding rodenticide exposure to ducks that included:
    1. Live capture, hold in captivity until the risk period passes.
    2. Live capture, clip wing feathers, and translocate to Eastern Island IF mice are confirmed absent from Eastern and Spit Island.
    3. Live capture, and translocate birds to another island, either supplementing the population on Kure Atoll or establishing a new population.
    4. A combination of the above strategies.
- We held extensive discussions with the USFWS Ecological Services lead on island about the regulatory mechanisms and consultation process required before any management action can move forward. It was recognized that there is a vehicle for the USFWS-Refuges to consult under Section 7 of the US Endangered Species Act and any proposal must have no net negative impact to the species.

Recommendation: Of all the species, the Laysan Duck and shorebirds will be one of the more complex taxa to mitigate for risk. A team of species experts, and bird capture/handling expertise should be assembled to review, design and test the mitigation strategies before the implementation of the eradication.

4. Evaluating Systems and Processes that are Used to Support Personnel that Live and Work on Midway Atoll

- Midway Atoll has the capacity to support ~40 full time staff and personnel, with additional support for outside visitors and researchers that visit the island throughout the year.
- With the assistance of Chugach staff, we evaluated the systems and processes that are used to support people living on the Atoll. Much of the emphasis of our assessment focused on how people may compromise the likelihood of success of a baiting operation (food and waste as an alternative, more attractive food to mice than bait), and risks an eradication operation may pose to people living on the island.
- We investigated the risk of human food and waste, as an alternate food source to mice, by following the pathway of foodstuffs from delivery to storage, cooking and consumption, to ultimately waste disposal at the landfill.

4.1 Human Grade Food

- Food for human consumption is a mix of fresh, frozen, canned, and dry food supplies delivered by ship and the scheduled plane service to the island, and supplemented by freshly grown produce grown in the shade houses, community gardens and private gardens at residences.
- Food is stored under a variety of conditions including loose, in boxes, and in sealed containers in reefers (sealed refrigerated; freezers; dry/ambient temperature), and open store rooms with shelving (Clipper House, private residences, office spaces) found across Sand Island.
- Food is moved in boxes and bags − either by bicycle, by hand or golf cart − between the reefers and the Clipper House on as-needed basis by dedicated kitchen staff.
- Most of the food is prepared and consumed in the Clipper House (common area), however, food preparation and consumption can occur at private residences, or in other common areas such as the bowling alley, Captain Brooks, and Charlie Barracks.
- Packaged frozen, refrigerated and dry food stuffs are available for purchase at the Ship Store (a convenience store).
- The mouse control activities around the food stores were reported to be working. However, there have been periodic breaches and mice are known to gain access to and contaminate foodstuffs.
- Waste foodstuff is disposed into either open compost piles or into garbage containers (destined for the landfill).

4.2 Waste Management

- Waste on the island is supposed to be separated into recycling (glass, metal, cardboard) and garbage. However, recycling is not always separated from garbage.
- Collected recycling is separated by type, and stored in a WWII era building and shipped off island approximately yearly.
- On inspection of the recycling center, much of the canned, glass and some cardboard was contaminated with foodstuff which attracted mice. Mice were observed to be foraging in the recycling bins during daylight hours.
- The garbage collection procedure was identified as follows (Figure 7):
    - Garbage destined for the landfill is placed into a mix of rodent proof and open garbage containers, lined with plastic bags.
    - Garbage is collected weekly or as needed, with containers emptied into open barrels, and transported by trailer to the open landfill near the east end of the airport runway.
    - Garbage is dumped into an open landfill, and when accumulations are significant, the garbage is periodically burned, and later buried under sand. On inspection, the open burning was not complete, likely due in part to wet compost and other foodstuffs in containers and how densely the garbage was packed/stacked, leaving a potential food source for mice.
- During visits to the landfill at dusk, Laysan Duck (upwards of 40 were counted), and mice were very abundant, foraging throughout the garbage pile.
- During our visit, the Refuge was in the process of moving over to oil/gas fueled incinerators which will make disposal more complete, and limit alternative food sources.

Figure 7. Waste management system (Landfill, trailer with garbage containers, and recycling), Midway Atoll NWR. November 2016. (Photos: P. McClelland)

4.3 Fresh Water Supply

- Rainwater is the source of all potable freshwater on the island.
- Pooled rainwater is collected via surface run off at five points adjacent to the airport runway, and pumped into 3 large storage tanks (Figure 8) during high rainfall events. Maximum capacity of freshwater storage was reported to be enough to support the island community for approximately 7 months.

Figure 8. Freshwater storage tanks, Midway Atoll NWR. November 2016.

Figure 9. Freshwater storage and water filtration system. Midway Atoll NWR. November 2016.

- Freshwater is pumped through underground pipes to two underground storage tanks near the USFWS building (Figure 9). Water is then filtered through a series of micron filters prior to being stored in large rubber bladders for delivery through underground pipes to the housing, dining and other facilities on demand.
- No information on the number of filters, or size of filters was available at the time of site visit.
- Drinking water is filtered at selected tap sources.

4.4 Sewage

- We evaluated the sewage treatment on Sand Island.
- All waste water enters into a gravity sewer system with access points (manhole covers) across Sand Island wherever buildings have been or currently exist. Not all access points were identified.
- A pump house adjacent to the Chugach office collects and pumps the sewage through a closed pipe system, to another pump house adjacent to the old north/south runway.
- Sewage is pumped into septic tanks, and gravity fed into an extensive leach field.

5. Evaluating the Logistics for an Eradication Operation

- We evaluated the capacity of Sand Island to support either an aerial based eradication approach, or ground based (bait station/hand broadcast) approach.
- The on island facilities are adequate to host personnel needed for a mouse eradication, regardless of a ground or aerial based approach. The housing, and supporting systems are adequate to keep a crew working comfortably for extended periods of time.
- Bait, supplies, and even a helicopter can be shipped direct to Midway Atoll via airlift (e.g. military or USCG airlift support) or by ship, with facilities to offload and stage the equipment and supplies for the eradication.

6. Building a Shared Platform of Knowledge

- Over the 16 days on island, we worked closely with USFWS Refuge and Chugach corporation staff to understand the workings of Midway Atoll, and share how the principles of rodent eradication are applied on islands worldwide, and could be applied on Midway.
- In addition to touring the island infrastructure and natural environment, a total of eight (8) PowerPoint presentations were shared, and facilitated communication of the principles of rodent eradication, and how they may be applied on Midway Atoll.

- The presentations included:

i. Midway Atoll orientation presentation by the USFWS-MANW Refuge (M. Duhr-Schulz)
ii. Introduction and History of Rodent Eradications (G. Howald)
iii. Rat Eradications in New Zealand (P. McCelland)
iv. Rat and Mouse Eradication Planning, Floreana Island (C. Hanson)
v. Evaluation of the Eradication Timing for Midway (P. McClelland)
vi. Observations and Mouse Eradication Options for Inhabited, Abandoned, and Decommissioned Commensal Infrastructure (C. Hanson)
vii. Section 7 Consultation Process and Options for Mitigating Risks of the Eradication to the Laysan Duck (J. Sprague)
viii. Close Out Presentation: Summary of Observation and Options to be Considered for the Feasibility of Eradication of House Mice from Midway Atoll (G. Howald)

- Midway Atoll is managed by the USFWS National Wildlife Refuge, however, most of the day-to-day operations are managed by the Chugach Corporation. The vast majority of the staff on island are from Thailand, many with limited ability to speak English. Both the language and cultural barriers were significant; we were unable to engage in effective or meaningful discussion with the entire Midway community.
- While engagement is necessary to complete the necessary on island work, any official requests for support must go through appropriate communication channels. Typically, the communication is through the USFWS MANWRefuge management to the Chugach Corporation management and down to the community leaders (and vice versa).
- The Midway Atoll Thai operational staff provided support and gave us access to the lesser known workings of Midway Atoll. They hold much of the detailed knowledge of the day-to-day operations of the island (utilities/food/housing/transportation/maintenance) and will be key to the success or failure of the mouse eradication.
- Key Chugach staff (lead for the Chugach management, and Thai community leaders) that oversee the operations were not present during our site visit. **Consultation with these individuals will be required to validate our observations and conclusions.**

6.1 Timeline of On-Island Activities

October:

- 25th Arrival and general orientation of the island and accommodations, discussion amongst assessment team and initial schedule planning
- 26th Received a Briefing on island and acquired background documents accompanied by a thorough bike tour including assessment of old fuel farm, bunkers, and waste pump house. Participated in a training on how to properly walk through petrel burrow habitat
- 27th Visited Henderson airfield and met with airport manager Timothy Deike. Assessed subterranean manhole covers near NAF building and USFWS offices. Gregg Howald delivered a presentation on eradication. Visited water processing plant and received a tour by the facility management. Assessed buildings including seaplane hangar.
- 28th Boated to Eastern and Spit Island and set nine camera traps with rodent attractant. Participated in a discussion with John Sprague and Beth Flint regarding buildings and rodenticide use.
- 29th Engaged in discussion regarding report format. Met on timing for biological drivers (Meg, Ann, John, Beth, Alli). Joined in the holiday festivities at the Captain Brooks Halloween party.

- 30th Explored the north side of Sand Island to look at seeps and guzzlers. Assessed sites of possible rat presence.
- 31st Arranged for two cameras to be pulled from Eastern Island. Planned and set up range-finding bait uptake exercise to assist in gauging application rate for bait availability trial. Met with JR of Chugach Corporation from 2:30 – 3:30. Received cameras from Eastern Island and reset one camera at a concrete storage site near the "bone yard" and reset one camera outside the north door of the bowling alley, both locations of possible rat sightings.

November:

- 1st Met with refuge manager to discuss the feasibility of mouse eradication and associated details on Midway Atoll NWR. Continued the abandoned building assessment. Assessed: abandoned barracks, mess hall, command center, theater and surrounding buildings, radar, electric WWII building. Collected results from range-finding study. Pete McClelland gave a presentation on Campbell Island at an evening session within the USFWS visitor center.
- 2nd Set up a 25m x 25m bait availability plot behind Clipper House with non-toxic bait spread at 40 kg/ha. Assessed Cable House structure. Initiated discussion on building strategy. Presented building strategy and timing and initiated discussion on duck management with feasibility assessment team and on-island USFWS management.
- 3rd Checked bait availability plot. Participated in a commensal tour with JR to inspect buildings and sewer. Moved a single camera from bowling alley to shipping container by NAF building.
- 4th Checked bait availability plots. Held a team discussion to set timeline for rest of the trip. Participated in a discussion regarding Laysan ducks led by John Sprague. Completed a tour of the NAF building.
- 5th Checked bait availability plots. Joined a trip to go snorkeling at "reef hotel". Explored more sites and habitats across Sand Island.
- 6th Checked bait availability plots. Began developing feasibility plan narratives, reports, and presentations.
- 7th Checked bait availability plots. Participated in meeting with Chugach management and refuge manager. Developed final presentation. Placed biomarker traps within bait availability plot. Chad Hanson presented on Floreana Island at evening session within the USFWS visitor center.
- 8th Checked bait availability plots. Conducted necropsies on three captured mice. Worked on final report. Gregg Howald presented general wrap-up (final presentation) to island team.
- 9th Collected remaining bait availability plot markers after plot went to zero. Conducted necropsies on three additional mice. Revisited Eastern and Spit Island to collect cameras.
- Collected cameras on Sand Island. Reviewed camera images and prepared camera equipment for storage on Sand Island. Progressed trip report outline.
- 10th Conducted coastal habitat assessment. Departed island to HNL on evening G3 flight.

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Appendix 1: Summary of Remote Camera Monitoring

Objective: Assess presence/absence of mice from Eastern/Spit Islands

Methods:

The team used cameras to conduct an introductory assessment of presence or absence of mice on Eastern and Spit Islands. We opportunistically used cameras to assess if rats may be present on Sand Island after a recently docked ship was found to have been harboring a rat on board. During the visit, a total of nine trail cameras were used to monitor for rodent presence: Four Reconyx Hyperfire 950 cameras, three Bushnell Aggressor No-Glow cameras and two Bushnell Aggressor Low-Glow cameras. Memory cards installed had a minimum of 8 gigabits of memory. Energizer brand lithium AA batteries were utilized in all cameras. Cameras were installed in place accompanied by one, or a combination of the following bait lures: Formula 3 inert bait pellets (1g, 9.5mm, green dye, dry formula), Provoke mouse attractant, Provoke rat attractant, Pro-pest professional rodent lure, and/or fresh coconut.

Cameras were initially installed on the 28th of October on Eastern Island and Spit Island. Three days later, cameras were rebaited while two cameras were collected and reinstalled on Eastern Island near the "bone yard" and outside of the bowling alley north entry. Three days later, the bowling alley north entry camera was moved to a shipping container behind the NAF building. On average, cameras were rebaited every three to four days.

Results:

A total of 99 camera nights occurred with 69 camera nights on Eastern Island, 12 camera nights on Spit Island, and 18 camera nights on Sand Island. No mice or other rodent species were detected on Eastern or Spit Islands. No rats were detected on Sand Island, while mice were readily detected within these photos until bait was depleted. One Bushnell camera was removed from Eastern Island early in the trip due to a loss of battery power. This camera was not reinstalled.

Appendix 2: Summary of Inspections

Objective: Assess the diversity of commensal infrastructure on Midway Atoll

Buildings and Utility Access Inspected (not exhaustive):

Charlie and Bravo Barracks, residential structures (duplexes, multi-story homes), Clipper House, Captain Brooks bar, ship store, food storage containers, shade garden hydroponics, old cold storage, FWS office, FAA building and firehouse + navaids, pump houses (Water/Sewage), transport and bike shop, barber shop, bowling alley and gym, bunkers used for storage, dive shop + chemical storage, Thai temple, cargo pier, fuel pier, three fingers docks, seaplane ramp and boathouse, fuel farm, recycling building, library, chemical shacks, NW demolition connex boxes at NAF hangar, Ava Maria shrine, seaplane building, native plant shade houses, staged vehicles, staged equipment, boats, theater and associated buildings, old dining hall, communications building, radar building, cable house, command center, All-hands club, NAF Building, bunkers, random buildings by old fuel farm (e.g. mechanics shop, generator house), buildings adjacent to dive shop, abandoned boats in bone yard, manholes, high-voltage service boxes, valve junction access boxes, and sewer leach field.