Challenges Associated with Eradicating Invasive Rodents from Islands: Lessons Learned

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ABSTRACT: Removal of introduced rats from islands is a proven and powerful conservation tool that can help restore ecosystem functioning and/or processes. Haida Gwaii, British Columbia, Canada, is an isolated marine archipelago with distinct flora and fauna that have evolved during 14,000 years of isolation from the mainland. Approximately 1.5 million seabirds from 13 species nest on the islands of Haida Gwaii, including 50% of the global ancient murrelet population, a federally designated species at risk in Canada. Within Gwaii Haanas National Park Reserve and Haida Heritage Site (located at the southern end of Haida Gwaii) there are 9 designated Important Bird Areas (IBAs), established primarily to denote important seabird nesting sites. However, unintentional historical introductions of rats to islands within IBAs and throughout Haida Gwaii have led to the demise of several seabird nesting colonies. In September 2013, Parks Canada Agency, in partnership with Coastal Conservation and Island Conservation, implemented Canada's first aerial broadcast eradication of black rats from two islands within the Ramsay Island and Northern Juan Perez Sound Islands IBA, where seabird colonies and ecosystem processes have been negatively impacted by this species. The eradication of black rats from Murchison and Faraday Islands posed several challenges including ensuring adequate bait density to maximize the probability of eradication success while minimizing risks to native species. Our planning efforts focused on addressing bait competition by non-target species, the consequence of bait interception by the forest canopy, minimizing bait entering the marine environment, mitigating potential negative impacts to non-target species, and determining the ideal timing for the eradication operation. We present here a summary of these challenges and the measures that were implemented to address them.

KEY WORDS: aerial broadcast, brodifacoum, Canada, Haida Gwaii, invasive alien species, invasive species, island restoration, rat eradication, *Rattus rattus*, seabird conservation

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INTRODUCTION

Introduced invasive species, especially rodents, are one of the leading causes of species extinction on islands (Blackburn et al. 2004, Duncan and Blackburn 2007). Rats living in close association, or commensally, with humans have been introduced to 90% of the world's islands, resulting in a pronounced negative impact on island ecosystems. In addition, the extinction of many island mammals, birds, reptiles, and invertebrates has been attributed to the impacts of invasive rats (Andrews 1909, Daniel and Williams 1984, Meads et al. 1984, Atkinson 1985, Tomich 1986, Towns et al. 2006, Hutton et al. 2007). Given the widespread successful colonization of rats on islands and their impact on native species, rats are identified as key species for eradication in order to begin the process of ecosystem recovery (Howald et al. 2007).

Haida Gwaii, British Columbia, is an isolated marine archipelago renowned for its rugged coastline, temperate rainforest landscape, and distinct flora and fauna that have evolved during 14,000 years of isolation from the mainland during the last ice age. It is so disproportionately rich in rare and unique species that it is often referred to as the "Galapagos of the North." Approximately 1.5 million seabirds from 13 species nest on the islands of Haida Gwaii, including globally significant populations of ancient murrelets (*Synthliboramphus antiquus*; 50% of the global population), Cassin's auklets (*Ptychoramphus aleuticus*; 18% of the global population), and rhinoceros auklets (*Cerorhinca monocerata*; 4% of the global population), and regionally significant populations storm petrels [21% of the British Columbia population of fork-tailed storm petrels (*Oceanodroma furcate*) and Leach's storm petrels (*O. leucorhoa*)], and pigeon guillemots (*Cepphus columba*; 50% of the British Columbia population) (Harfenist 2003).

Black rats (*Rattus rattus*) or Norway rats (*R. norvegicus*) have been documented on at least 25 islands in the Haida Gwaii archipelago (Golumbia 2006). While quantified seabird nesting records for Haida Gwaii only date back to the early 1970s, the introduction of predators such as rats coincides with marked declines in many seabird populations. As an example, one of the world's largest populations of ancient murrelets, nesting on Langara Island, experienced a decline from a historical estimate of more than 200,000 breeding pairs (Gaston 1992) to less than 15,000 breeding pairs by 1993 (Harfenist 1994). Evidence indicates that rat populations are responsible for the drastic decline in seabird populations on several islands in the archipelago (Golumbia 2006).

In 2009, Parks Canada Agency launched its *SGin Xaana Sdiihltl'lxa* (translated from the Haida language as "Night Birds Returning") program. The program aims to protect and restore nesting seabird habitat and associated ecosystem processes on ecologically and culturally significant islands within Gwaii Haanas National Park Reserve and Haida Heritage Site on Haida Gwaii, British Columbia that have been impacted by invasive rats.

In September 2013, Parks Canada Agency, in partnership with Coastal Conservation and Island Conservation, implemented Canada's first aerial broadcast eradication of black rats from Murchison and Faraday Islands within the Ramsay Island and North Juan Perez Sound Islands, a globally important bird area designated by Birdlife International. An aerial broadcast operation using pelleted bait containing the second-generation anticoagulant brodifacoum was chosen, due to the size of the islands and the presence of challenging topography. This technique has become the most common method of rodenticide delivery on large islands (greater than 100 ha) internationally and has been used in the majority of successful eradications (Howald et. al. 2007). Over the last 30 years, continued refinements to this technique have increased likelihood of success and have resulted in reduced negative impacts to non-target species (Towns and Broome 2003, Howald et al. 2005, Howald et al. 2007).

The successful eradication of black rats from Murchison (493 ha) and Faraday Islands (324 ha) posed several challenges, including bait competition by non-target species, bait interception by the forest canopy, minimizing bait entering the marine environment, potential negative impacts to non-target species, and determining the optimal timing for the eradication operation. We present here a summary of these challenges, their consequences, and the measures that were implemented to address them.

PROJECT DESIGN

The project design was guided by the fundamental principle of rat eradications: the delivery of a rodenticide bait into every rat territory on the target island at a density that ensures the bait is available to all rats and consumed in sufficient quantities to achieve lethal dosage. Overcoming the key challenges outlined above guided the design and ultimately the implementation of the eradication operation.

Bait Competition

The presence of non-native Sitka black-tailed deer (*Odocoileus hemionus sitkensis*) on Murchison and Faraday Islands presented two issues: bait competition with black rats (confirmed during pre-eradication bait uptake trials) (Parks Canada Agency 2012), which could impact eradication success through reduced bait availability for rats; and potential for primary poisoning of deer through the consumption of the rodenticide bait. Primary poisoning of deer increased the risk of secondary poisoning to native species such as bald eagles (*Halieetus leucocephalus*), common ravens (*Corvus corax*), northwestern crows (*C. caurinus*), black bears (*Ursus americanus*), and gulls, e.g., California gull (*Larus californicus*) and glaucous-winged gull (*L. glaucescens*).

Given the potential for bait competition by non-native deer, we agreed that removing the majority of the deer population from Murchison and Faraday Islands prior to the rat eradication operation using carefully planned culls would reduce bait competition and minimize the risk of secondary poisoning to scavenging species. (Due to the risk of reinvasion and the cost, it was not deemed practicable to undertake a deer eradication on the islands.) The deer cull was implemented in December 2012, with a total of 7 cull events taking place prior to bait application (opportunistic culls also occurred following bait application). All deer carcasses were removed from the island to avoid introducing an alternate food source for the rats, and also to avoid attracting large numbers of scavengers to the island. Most culls involved a small team of Parks Canada Agency staff (3 to 4 individuals) working with contract hunters and hunting dogs, using multiple techniques including shoreline hunting from boats, tree stand/blind hunting at attractant stations, ground hunting, and line drives (Parks Canada Agency 2013a).

A total of 153 deer were removed from the two islands in 727.4 hours of dedicated hunting time (Murchison Island: n = 98 individuals, Faraday Island: n = 55). To reduce the probability of immigration, an additional 8 deer were removed from the south shore of Lyell Island, the closest land point to Murchison and Faraday Islands. Monitoring techniques, including remote cameras and deer attractants, confirmed that the cull was effective at eliminating the majority of Sitka black-tailed deer from the island. We believe that this increased the probability of successful rat eradication by reducing competition for bait between deer and rats as well as the risk of secondary poisoning of scavenging species.

Bait Application

Forest Canopy Interception

Murchison and share the typical characteristics of a coastal temperate rainforest found within the coastal western hemlock wet hypermaritime biogeoclimatic subzone, including dense, mature forests comprised of Sitka spruce (*Picea sitchensis*), western red cedar (*Thuja plicata*), and western hemlock (*Tsuga heterophylla*).

Early in the eradication planning process, we anticipated that the high forest canopy closure present on the target islands could potentially intercept a portion of the bait. Bait interception by the coniferous forest canopy posed two challenges: 1) bait would not be immediately available to rats and 2) forest canopy interception would reduce the bait application rate on the ground. These issues appear to be primarily associated with forested islands (coniferous) in temperate latitudes and to our knowledge have not been encountered during any previous eradication operations globally.

To better estimate the potential bait interception rate, a forest canopy bait interception trial was conducted at a site with similar canopy closure and tree species composition, using a helicopter and non-toxic bait that was physically identical to the bait which would be used for the Murchison and Faraday Islands eradication (Coastal Conservation 2013). The results of the trial suggested a mean forest canopy interception rate of 22%.

Target sowage rates were consequently increased to account for the bait intercepted by the forest canopy (Parks Canada Agency 2013b).

There are several possible fates for the bait pellets that were intercepted by the forest canopy. Some of the bait was eventually dislodged by high winds and reached the forest floor (Parks Canada 2013b) where it was either consumed by target and/or non-target species or degraded as a result of water absorption. The bait remaining in the forest canopy likely degraded due to water absorption or wind desiccation, or it may have been ingested by arboreal rats and non-target species such as common raven.

Minimizing Bait Entering the Marine Environment

Bait application during rodent eradication operations must maximize eradication efficacy while minimizing potential environmental impacts. The aerial bait application on Murchison and Faraday Islands followed the standard practice in which parallel, overlapping flight swaths are flown over the entire land mass of each target island (e.g., Buckelew 2009, Howald et al. 2009, McClelland 2011, USFWS 2011, Broome et al. 2014). Overlapping flights lines minimize the risk of creating areas of low bait density and gaps in bait availability on the ground, which might result in eradication failure.

To minimize bait entering the marine environment, two separate bait zones were designated: interior and coastal. The flight swaths of the interior baiting zone began and ended approximately 50 m inland from the high water mark, while the coastal baiting zone began at the high water mark and used a directional deflector to distribute bait towards the target island (Figure 1). However, because one of the key principles of bait application is to ensure complete coverage of the target island (Cromarty et al. 2002), the coastal application swaths unavoidably overlapped the interior flight lines, resulting in localized higher bait application rates. This results in a higher than targeted net application rate due to overlapping flight lines at the transition between the interior baiting zone and the coastal baiting zone.

Overlapping flight lines where the interior baiting swaths and the coastal swath intersect ensures that there are no baiting gaps but results in higher than targeted bait densities on the ground compared to the target sowage rate of the bucket (Parks Canada Agency 2013b, Figure 2). This in turn results in a higher average bait application rate for the entire island when compared to the target sowage rate. While attempts were made to minimize overlapping baiting zones during the Murchison and Faraday Islands eradication, many factors can influence the degree of overlap, including wind, complex topography, and, most importantly, the need to avoid baiting gaps, especially in the coastal zone. To ensure that the minimum target bait sowage rate is achieved in every rat habitat on the target island, the actual average bait application rate will invariably be higher than the average target bait sowage rate. This is due to inherent inconsistencies in flow rate from the bucket, flight speed, flight line overlap, and bait gap coverage (e.g., Buckelew 2009, Howald et al. 2009, McClelland 2011, USFWS 2011).

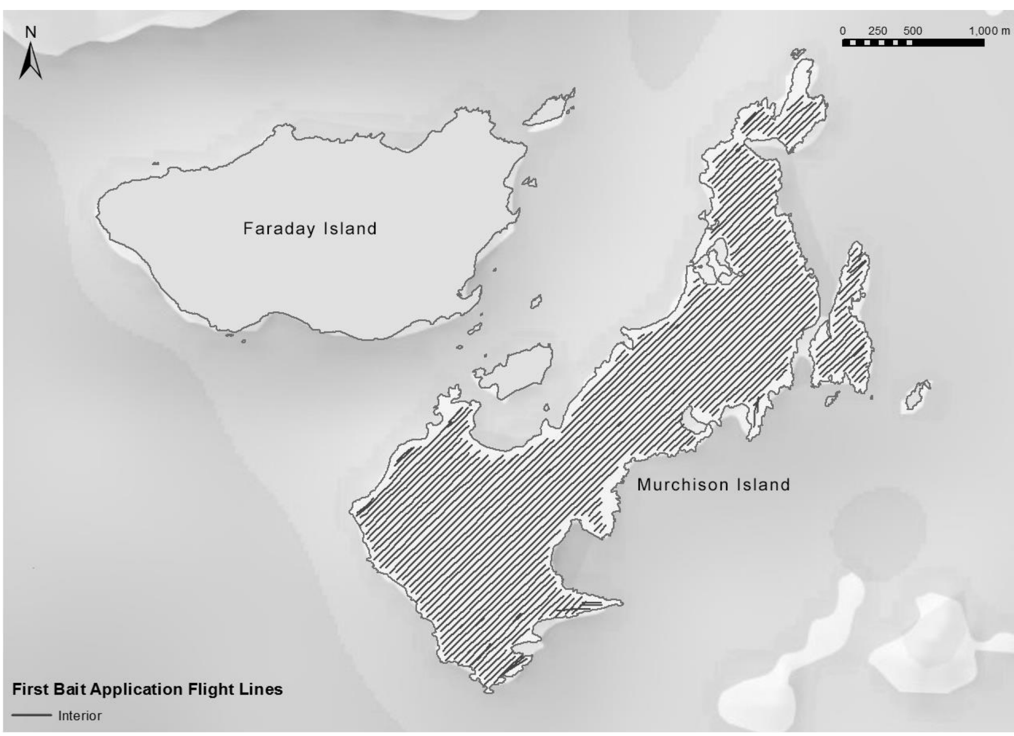

Figure 1. Interior flight lines during first bait application on Murchison Island showing potential baiting gaps in white created by starting and stopping approximately 50 m inland from the high water mark.

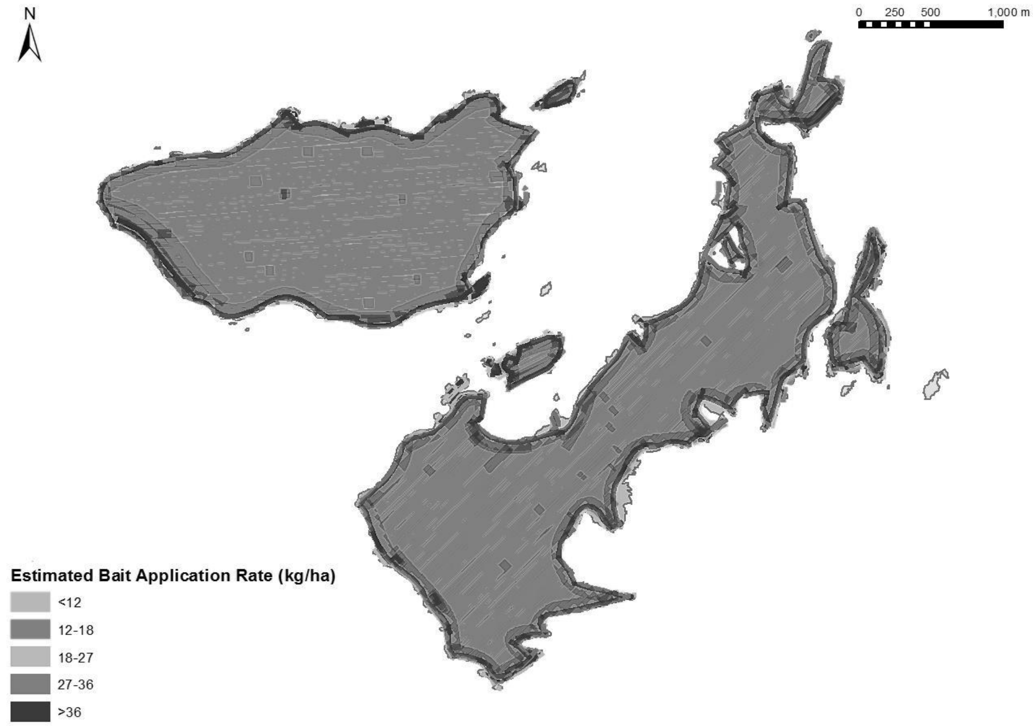

Figure 2. Estimated bait density map for Murchison and Faraday Islands during the first bait application based on bait used versus area sown (kg/ha). Target sowage rate (first application): 18 kg/ha; predicted average bait application rate on ground) accounting for overlapping flight lines): 20.1 kg/ha; actual average bait application rate on the ground: 22.1 kg/ha (Parks Canada Agency 2013b).

The Murchison and Faraday Islands aerial broadcast reflects the differences between the target bait sowage rate, predicted average bait application rate, and actual average bait application rate on the ground as a result of the abovementioned variables. For the first application, the bait bucket was calibrated to sow bait at 18 kg/ha (the target bait sowage rate), which resulted in a predicted average bait application rate on the ground of 20.1 kg/ha when the overlapping flight lines are taken into account. The actual average bait application rate, however, was 22.1 kg/ha (Parks Canada Agency 2013b). Similarly, for the second aerial broadcast, the target bait sowage rate was set at 13 kg/ha, resulting in a predicted average bait application rate on the ground of 14.5 kg/ha, and an actual average bait application rate of 14.3 kg/ha (Parks Canada Agency 2013b). The reduced application rate for the second broadcast accounts for an expected reduction in the rat population following the first bait application, and it targets any emerging juvenile rats still in the nest at the time of the first broadcast.

The discrepancy between the target bait sowage rate and actual bait application rate is commonly misunderstood when calculating the average bait application rate for the entire island, particularly for those new to the subject, as it is simple to focus on the bucket's target sowage rate and intended minimum ground application rate without accounting for planned overlaps between interior and coastal baiting zones (D. Will, pers. comm.). Thus, when planning future rat eradication operations, it is recommended that eradication managers discuss the nuances of the baiting strategy with project partners and in supporting documentation (e.g., operational plans, environmental impact assessments), with particular emphasis on the differences between the target bait sowage rate, predicted average application rate on the ground, and actual average application rate on the ground.

Minimizing Impacts to Non-target Species

Bait Pellet Design

Brodifacoum 25W Conservation Pellets™, developed by Bell Laboratories, Inc. (Madison, WI) were used for the Murchison and Faraday Islands eradication. This product is comprised of a grain matrix compressed into approximately 2-g pellets containing brodifacoum at a concentration of 25 ppm. The pellets also included a non-toxic pyranine biomarker, which fluoresces green under ultraviolet (UV) light, allowing confirmation of ingestion through the examination of carcasses or feces with a UV light. The bait pellets were designed to be highly attractive to rats, but also to maintain their integrity in the wet maritime conditions of Haida Gwaii for a time period that both maximized the probability of bait availability for rats and minimized the risk of exposure to non-target species. The bait pellets were designed to be too large for small passerines such as song sparrows (*Melospiza melodia*) to easily consume, and they were dyed green, which appears to make the pellets less visible, and presumably less attractive, to some bird species (Pank 1976, Buckle 1994, Tershy and Breese 1994). Attempts were also made to minimize chaff in the bait (smaller pieces that break off the pellets and can be easily consumed by granivorous birds) during production and packaging.

Carcass Searches

Unintentional poisoning of endemic, non-target species, especially scavengers such as bald eagles, common ravens, northwestern crows, and black bears, is a potential consequence of rodent eradication projects (e.g., Howald et al. 2007, Salmon and Paul 2010). Although carcass searches generally have a low success rate, as a result of the efficiency with which scavengers remove the carcasses and the low efficiency of human searches (e.g., Stutzenbaker et al. 1984, Blackcomb 1986, Brown et al. 1988, Mineau and Collins 1988), they are still considered an important mitigative measure for eradication operations to reduce the potential for secondary and tertiary poisoning of non-target scavengers.

During the Murchison and Faraday Islands eradication operation, quantified, systematic, and intensive searches were undertaken by field personnel on all treated islands. Any animal remains (rat and non-target species) that were found were collected in order to minimize the risk of secondary and tertiary poisoning of non-target species as a result of scavenging, and they were tested for brodifacoum exposure. Personnel began conducting carcass searches 3 days after the first broadcast and continued until the remaining team members departed the project site, 11 days after the second bait application following the onset of inclement weather conditions and high winds (personnel safety risks). Additional carcass searches were conducted on the islands in the spring and summer of 2014.

More than 480 km of search tracks and 418 hours of search time were completed, resulting in the recovery of 79 rats and 120 non-target carcasses, which included 14 common native species and one Sitka black-tailed deer (Parks Canada Agency 2013b). Northwestern crows comprised 50% of the total carcasses recovered (n = 60). The next-most-common species to be recovered were common raven (9.2%, n = 11), dark-eyed juncos (*Junco hyemalis*; 8.3%, n = 10), varied thrush (*Ixoreus naevius*; 7.5%, n = 9), fox sparrows (*Passerella iliaca*; 6.7%, n = 8), and hermit thrush (*Catharus guttatus*; 5.8%, n = 7). The fresh carcasses collected during these searches will be tested for brodifacoum exposure at a later date by an approved laboratory.

The majority of carcasses were found within 150 m of the coastline and individually, with the exception of northwestern crows. This species is sociable, roosting and foraging in large flocks along the coast. They are also opportunistic and quickly take advantage of new sources of food through social interaction. These traits explain the high mortality rate for northwestern crows during the eradication, and also why field personnel often found more than one dead individual at a particular location.

No bald eagles were recovered, which is a direct contrast to the results of the 2008 Rat Island eradication in Alaska (Buckelew et al. 2010). The lack of bald eagle mortalities both during and after the eradication operation could be attributed to: 1) the eradication timing (September coincides with the completion of the bald eagle breeding season and many birds leave their territories to forage on spawning salmon in nearby rivers); 2) limited scavenging opportunities resulting from the carcass search activities; and 3) the effectiveness of the deer cull at reducing deer numbers on the project islands (reduced risk of secondary poisoning from scavenging deer that had died as a result of rodenticide exposure).

During the eradication operation, large numbers (~100-200) of glaucous-winged and California gulls roosted on several rocky islets near Murchison and Faraday Islands; however, only 2 glaucous-winged gulls were found dead during the eradication operation despite daily visits to the gull roosts during the search period. Neither individual exhibited obvious external signs of brodifacoum poisoning (i.e., bleeding around the mouth and nares). Furthermore, only a limited number of gull feces on the rocky islets tested positive for the pyranine biomarker present in the bait pellets. These observations suggest that the majority of the gulls present during the Murchison and Faraday Islands eradication operation did not recognize the bait pellets as food, despite pellets being present in moderate to high quantities at or near their nightly roost sites, which were also baited during the eradiation operation. Instead, the gulls appeared to be focused on naturally occurring marine food sources such as bait fish during the eradication operation (for example, approximately 1,000 birds were seen foraging in Faraday Passage in one day). This result is in direct contrast to the 2008 Rat Island eradication, during which 320 glaucous-winged gull carcasses were recovered, and toxicology tests implicated brodifacoum in 24 of the 34 tested samples (Salmon and Paul 2010).

Eradication Timing

The preferred time of year to undertake a rat eradication operation is a function of target species biology, non-target species biology, environmental factors, and logistical constraints (Howald et al. 2007). Ideally, an eradication operation should be undertaken when rat populations are in decline or during lows in the annual food dependent population cycle (a scarcity of natural food items translates to increased foraging effort and a higher probability of bait encounters and consumption) (Howald et al. 2007). However, the timing of the eradication must also minimize potential impacts to non-target species, while taking into consideration seasonal weather patterns (personnel safety) and low public presence on the target island(s). Rarely do the aforementioned factors perfectly align, and thus eradication timelines are almost invariably a compromise.

The Murchison and Faraday Islands eradication was no exception; operational implementation occurred in September 2013, which coincided with:

- a seasonal reduction in food supply for rats;
- the completion of the migratory and non-migratory bird breeding cycles (minimizing disturbance and the number of individual non-target impacts);
- a reasonable likelihood of suitable weather conditions generally favourable for ground, water, and aerial operations and personnel safety; and
- a low public presence near the project area.

Although September 2013 was chosen for the eradication, black rat populations may not have been in decline, possibly due to the favourable weather conditions that were encountered, as well as previous evidence of rat breeding in September 2012 during the bait uptake trails (Parks Canada Agency 2012). To maximize the probability of eradication success, we took into consideration the potential status of rat populations by incorporating a delay between the first and second bait applications of approximately 3 weeks, in order to target any emerging juvenile rats still in the nest at the time of the first broadcast. The time delay also ensured that any deer remaining on the islands during first application would either succumb to the rodenticide bait or be removed by the ongoing culling activities prior to the second bait application.

CONCLUSION

The eradication of invasive rodents from islands is a powerful tool that can be used to prevent extinctions or local extirpations and restore ecosystem processes, often with a high return on investment both in terms of monetary cost and conservation returns (Howald et al. 2007). However, the specifics of every rodent eradication are unique, including the factors that influence eradication success and the degree of impact to native species. Conservation practitioners must take all variables into consideration when planning an eradication operation rather than focus exclusively on maximizing the probability of eradication success.

The eradication of black rats from Murchison and Faraday Islands posed several challenges including bait competition by non-target species, bait interception by the forest canopy, potential negative impacts to non-target species, and determining the ideal timing for the eradication operation. Each challenge was addressed systematically and often with the "worst case scenario" in mind. This approach likely contributed to the efficient implementation of an eradication that, based on our initial assessments, appears to have been a success.

The Murchison and Faraday Islands black rat eradication was the first aerial broadcast operation attempted in Canada to date. The valuable lessons learned during the eradication, and particularly the challenges posed by forest canopy interception of bait, can be applied to future rat eradications in Gwaii Haanas and also to global eradication projects to both maximize the probability of eradication success and minimize impacts to non-target species.

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