Pushing the Envelope in Paradise: A Novel Approach to Rat Eradication at Palmyra Atoll

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Abstract: Palmyra Atoll National Wildlife Refuge is a moist Central Pacific atoll that supports one of the best remaining tropical forest ecosystems in the region, including 10 species of breeding seabirds and a robust population of the world's largest terrestrial invertebrate, the coconut crab. Despite these riches, the atoll's ecosystem has been modified by introduced black rats that were inadvertently brought to Palmyra during WWII. Between June 1 and 30, 2011, a partnership between the U.S. Fish and Wildlife Service, The Nature Conservancy, and Island Conservation successfully implemented a project to remove rats from Palmyra. Independent monitoring of bait application and its environmental effects was undertaken by the USDA. Over the 28-day operation, a team of 41 people from 5 countries utilized 2 helicopters, 10 slingshots, 148 bait stations, and hand spreading to strategically apply 38,561 kg of rodent bait containing the anticoagulant brodifacoum (25 ppm) to Palmyra's 235 hectares of emergent land. Palmyra's challenging eradication environment demanded the development of a novel approach, such as broadcast application rates between 75 and 85 kg/ha and the use of "bolas" to bait coastal forest canopy to minimize bait drift into the marine environment. Initial findings show minimal non-target impacts as a result of the project, and post-eradication monitoring has failed to detect rats. Increased recruitment by at least 2 native tree species has been observed. By removing rats from Palmyra, the partnership aims to safeguard the atoll's indigenous flora and fauna, encourage the reestablishment of extirpated seabird species, and create an ecological refuge for species within the Central Pacific region that are at risk of extinction. This project is a conservation milestone for the Refuge, and it has established a benchmark for eradication campaigns on other tropical islands.

Key Words: aerial broadcast, black rat, brodifacoum, land crab, Pacific island, Palmyra Atoll, rat eradication, *Rattus rattus*, rodenticide, tropical, wildlife refuge

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INTRODUCTION

Invasive alien species are one of the greatest threats to the preservation of biodiversity on islands (Phillips 2010). To date, 1,159 whole-island eradication projects have occurred or are in process (IC 2011). Introduced predators, such as rats, cats, and mustelids directly impact native fauna (Cuthbert 2002, Nogales et al. 2004, Bellingham et al. 2010, Campbell et al. 2011), introduced herbivores directly impact native plants (Vitousek 1990, Campbell and Donlan 2005), and members of both groups disrupt or alter ecosystem processes and can cause lasting damage to island biota (Brown et al. 2001, Fukami et al. 2006, Traveset and Richardson 2006, Mulder et al. 2009). Lessons learned from decades of eradication attempts and subsequent advances in eradication technology have made the removal of invasive vertebrate species (IVS) from islands a highly effective conservation tool (Towns and Broome 2003, Veitch et al. 2011). The eradication of IVS is now recognized as a prerequisite to the restoration of insular ecosystems and the protection of native species (Bellingham et al. 2010). While IVS eradications share the common goal of removing targeted populations, the variation in eradication environments and the surrounding factors between projects preclude the development of a general recipe for eradication. Without a recipe, project implementers must understand the nuances of their particular project and adapt previously-tested tools to work with local conditions.

Palmyra Atoll National Wildlife Refuge is a moist Central Pacific atoll that supports one of the best remaining habitats for the broadleaf tree, *Pisonia grandis*, as well as 10 species of breeding seabirds and a robust population of the world's largest terrestrial invertebrate, the coconut crab (*Birgus latro*). Despite these riches, the atoll's ecosystem has been greatly compromised by introduced black rats (*Rattus rattus*) that were inadvertently brought

to Palmyra during WWII. In the presence of rats, several native tree species experienced limited or no recruitment (Wegmann 2009), and rats may have caused the extirpation of as many as 6 ground-nesting seabird species (USFWS 2011).

During the month of June 2011, a partnership between the U.S. Fish and Wildlife Service (USFWS), The Nature Conservancy (TNC), and Island Conservation (IC) successfully implemented a project to remove rats from Palmyra while minimizing harm to the ecosystem. There have been 348 documented rat eradications worldwide, 88% of which have been successful (IC 2011). Eradicating rats from Palmyra is expected to result in measurable and significant biodiversity benefits for seabirds, plants, terrestrial invertebrates, and ecosystem processes (Wegmann 2009, Young et al. 2010). By removing rats from Palmyra, the partnership aims to safeguard the atoll's indigenous flora and fauna, encourage the reestablishment of extirpated seabird species, and create an ecological refuge for species within the Central Pacific region that are at risk of extinction.

While each rat eradication project is unique and requires methods that are appropriate for the given eradication environment, the governing principle for eradication success is the delivery of a lethal dose of rodenticide to all rats within the target population. A failed attempt at eradicating rats from Palmyra in 2001-2002 exposed several novel challenges (Howald et al. 2004). The second eradication attempt in 2011 was informed by a 7-year investigation of Palmyra's eradication environment and showcased innovative solutions to the challenges that likely caused the failure of the prior eradication attempt. This paper discusses the challenges faced by the eradication team, and the methods that were employed to overcome these challenges.

METHODS

Study Site

The rat eradication was conducted in June of 2011 at Palmyra Atoll National Wildlife Refuge (5° 53' N, 162° 05' W) in the Northern Line Islands. Palmyra consists of 25 low coral islands (emergent land = 235 ha) that support a regional flora that is typical of Central Pacific moist forests (Wester 1985). Palmyra's 25 islands encompass two large lagoons and are surrounded by shallow backreef. At the northern tip of the Line Island Archipelago and right in the middle of the Intertropical Convergence Zone, Palmyra receives approximately 500 cm (197 in) of rain each year.

Palmyra is a breeding refuge for 10 species of seabirds and is home to a robust community of land crabs comprised of 6 species and reaching mean densities of 460 crabs/ha (Howald et al. 2004). Palmyra's land crabs range in size from 100-g hermit crabs to the 5-kg coconut crabs. As omnivorous foragers, land crabs are the indigenous engineers of Palmyra's terrestrial ecosystem (Wegmann 2009), and that of most tropical Oceanic islands (Green et al. 1997, O'Dowd et al. 2003, Green et al. 2008). With ample food provided by Palmyra's aseasonal climate and heavy rainfall, and the absence of predators, Palmyra's rat population sustains high densities. Measurements of rat density in 1992 and 2008 found 90 to 120 rats/ha on Palmyra's islands, respectively (Flint et al. 1992, Wegmann and Middleton 2008).

Investigation of the Eradication Environment

In 2004, USFWS, TNC, IC, and the U.S. Department of Agriculture (USDA) – National Wildlife Research Center conducted a 6-week rat eradication feasibility study during which the team uncovered several challenging aspects of Palmyra's rat eradication environment that likely contributed to the failure of the previous (2001-2002) eradication attempt (Howald et al. 2004):

1. Extensive use of the coconut palm (*Cocos nucifera*) canopy by rats: Radio-collared rats spent a significant amount of time in the forest canopy, primarily in the crowns of coconut palms. Rats have access to water, food, and shelter in the palm crowns and it is possible that some rats rarely venture to the forest floor.
2. Year-round breeding by rats: Palmyra's aseasonal, wet tropical climate provided ample food resources to support year-round breeding.
3. Wet, tropical climate: Palmyra's persistent and often heavy rainfall can degrade bait pellets in a matter of hours.
4. Interference by land crabs: Land crabs are prodigious bait consumers and can eat up to 20 g of bait, or 3% of their body-weight, in a 24-hr period and rates of consumption do not decrease over time (Alifano and Wegmann 2010). Anticoagulant rodenticides have not been shown to harm land crabs; however, bait consumed by crabs is no longer directly available to rats and the crabs become a secondary pathway for the exposure of other non-target species to the rodenticide.

With these challenges identified, the USFWS, TNC, and IC returned to Palmyra in 2005 to conduct a trial broadcast eradication on 5 of the 25 islands. The team succeeded in removing rats from all 5 islands (Buckelew et al. 2005). In 2008, USFWS, TNC, and IC formed a partnership focused on planning and implementing a second rat eradication campaign at Palmyra. From 2008 through 2010, the partnership conducted more studies to determine:

- An appropriate bait application rate and assess bait migration pathways (Wegmann et al. 2008),
- Rodenticide migration from bait pellets to topsoil (Alifano et al. 2012), measure rodenticide concentrations in the excrement of land crabs that had consumed bait, and assess rat preference for different bait products when presented side-by-side with natural food items (Alifano and Wegmann 2010)
- Crab-resistant bait station designs, and test a novel tool for baiting the crowns of coconut palms (Alifano et al. 2010).

Implementation of the Rat Eradication

Over the 28-day operation (2-30 June 2011), a team

of 41 people used 2 helicopters, 10 slingshots, 148 bait stations, and hand spreading to strategically apply 38,561 kg (85,012 lbs) of Brodifacoum-25W Conservation Bait (Bell Laboratories, Madison WI) to Palmyra's 235 hectares (581 acres) of emergent land. The successful implementation of the rat eradication relied on the results of studies conducted during the investigation of Palmyra's eradication environment. Following is a discussion of the challenges that we faced and the innovations we employed to overcome them.

Rat Use of the Coconut Palm Canopy

Coconut palm is the dominant canopy tree at Palmyra, covering 45% of the land area (Wegmann 2009). Because rats were frequently found in the palm canopy (Howald et al. 2004), the treatment area was extended to include the crowns of coconut palms as well as the emergent land area. To ensure that bait was delivered to all potential rat territories, the project partnership decided to apply bait aerially using a helicopter with an under-slung bait spreading bucket. Prior studies at Palmyra showed that most pellets that were aerially dispersed landed on the forest floor, yet a few would become lodged in palm crowns creating small pockets of bait that were not available to land crabs; land crabs do not typically climb more than a meter or two above the ground (Burggren and McMahon 1988).

Most of Palmyra's lagoon and ocean-facing shoreline is overhung with vegetation, and coconut palms lean far out over the water. Rats were regularly observed running up and down the trunks of overhanging coconut palms, yet this important rat habitat could not be treated by aerial broadcast, as this would unavoidably place bait pellets into the marine environment. An estimated 5,670 palm trees overhang Palmyra's shoreline (USFWS 2011). To deliver bait to the overhanging palms that were excluded from the aerial bait application, IC developed a "bola"-style canopy bait. The bola canopy bait consisted of two cotton-gauze sacks connected by 20 cm of twine, each containing 12.5 g of bait (Figure 1). Two small corks were added into each sack so that the bola could be retrieved from the water if it fell out of the palm crown. The entire bola assembly is biodegradable. Bola canopy baits can be slung by hand or with a sling-shot, or dropped into the palm crowns by a brave sole suspended beneath a helicopter – known as the "Dope-On-A-Rope" method. At Palmyra, we used all three methods to bait the overhanging palms.

Wet, Tropical Climate

Heavy, consistent rainfall at Palmyra leads to rapid bait degradation (Howald et al. 2004). To ensure that bait remained uniformly available to rats for at least 4 days, the project partnership chose the 25W-Brodifacoum Conservation Bait product manufactured by Bell Laboratories (Madison, WI). The 25W bait is specially designed for use in wet environments and holds up well when wet or even submerged by heavy rainfall.

Year-Round Breeding by Rats

On temperate, subarctic, or subantarctic islands, rat eradication projects can take advantage of seasonal shortages of food and cessation of breeding, by applying bait when rats are most likely to consume novel food items and are least likely to produce litters that might not emerge until after the bait availability period. This could not be done on Palmyra because, as with other wet tropical island ecosystems (Strecker et al. 1962), Palmyra's aseasonal climate allows for constant availability of food for rats, and rats breed year-round. To minimize the risk of missing weanling rats that were not out foraging during the short bait-availability window, two bait applications across all 25 islands were conducted. The bait applications were spaced 6-10 days apart, depending on the island, and bait was applied at similar rates for each application to provide a high probability that weanling rats emerging between the two applications would encounter bait.

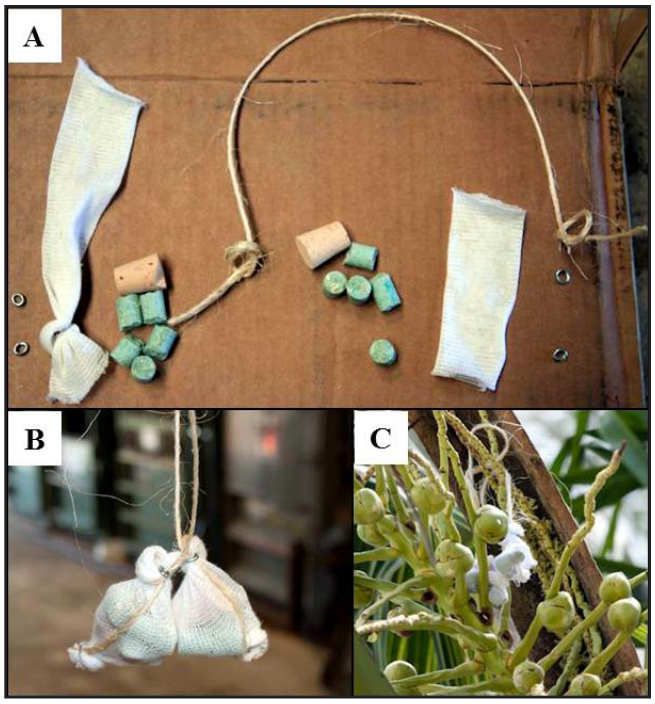

Figure 1. Photographs of a "bola"-style canopy bait, designed to deliver rodenticide to the canopy of a palm tree: A) The components of a bait bola, B) an assembled bait bola, C) A bait bola entwined in the inflorescence of a coconut Palm (*Cocos nucifera*) at Palmyra Atoll.

Interference by Land Crabs

Tropical oceanic islands pose a further challenge to eradication projects, and especially eradications targeting rodents, where indigenous land crabs compete with target species for bait and interfere with traps and detection devices (Wegmann 2008, Griffiths et al. 2011). Because current eradication practices are inherited from successful temperate or subantarctic campaigns, time-tested methods for effectively managing land crab interference were not available to the Palmyra project team, and a novel approach was required.

While unaffected by anticoagulant rodenticides, land crabs compete with rats for bait applied to the ground; land crab influence on bait availability was the most serious challenge faced by the project team. During the failed eradication attempt at Palmyra, land crabs compromised the effectiveness of bait stations. Station designs that were

resistant to the long reach and crushing and slicing claws of coconut crabs were, by design, also less accessible to rats (Howald et al. 2004). Broadcasting bait across the treatment area allowed the project team to overstep the land crab interference with bait stations, yet consumption of bait by land crabs remained a problem.

During the 2005 trial eradications conducted at Palmyra, bait availability was reduced from the initial application rate of 90 kg/ha to 50 kg/ha within a 24-hour period, to 30 kg/ha within 2 days, 15 kg/ha within 3 days, and to 10 kg/ha within 4 days. To maximize the probability that all rats will encounter and consume a lethal dose of bait, bait should be made uniformly available for at least 4 nights when using a single-dosing 2nd-generation anticoagulant rodenticide (Schneider and Hitch 1982, Pitt et al. 2011). To achieve 4 nights of bait availability, bait would need to be applied at rates upwards of 90 kg/ha for both applications, since crab consumption of bait increases rather than decreases over time (Wegmann et al. 2008).

The pesticide use label for 25W sets the upper limit for broadcast bait applications at 18 kg/ha for the first application and 9 kg/ha for the second application. A biomarker-based bait exposure study conducted at Palmyra in 2008 (Wegmann et al. 2008) demonstrated that the maximum application rates specified by the label achieved, at best, a 2-night bait availability period and left more than 30% of the rat population unexposed to bait. Less than an hour after bait was applied to the study sites, every land crab encountered had secured at least one bait pellet. Faced with this challenge, the project partnership worked with the USDA (the registrant for 25W) and the U.S. Environmental Protection Agency to develop a supplemental bait label that allowed bait to be applied at or below 90 kg/ha, with target application rates set at 80 kg/ha for the first application and 75 kg/ha for the second application.

During the implementation, the project team applied bait at 84 kg/ha for the first application, and 79 kg/ha for the second. Both applications exceeded target application rates by a small margin but were well within the maximum rate specified by the supplemental label. While bait persisted in places for more than 4 days after each application (Pitt et al. 2012), bait was not uniformly available to rats beyond 4 days in most areas, despite the high bait application rate.

RESULTS AND DISCUSSION

During the course of the rat eradication campaign at Palmyra, the project team encountered challenges that were not typical of past rat eradication attempts on other islands. Results from carefully designed studies were combined with innovation to overcome the challenges posed by Palmyra's wet aseasonal environment. Despite significant effort to detect rats since bait application, rat sign has not been observed. It is too early to say that the eradication was successful, but all indications point towards this conclusion. Many of the solutions to the challenges listed above, e.g. the "bola" bait, played a dual role, increasing the probability of eradication success while minimizing harm to species at risk of exposure to the rodenticide.

While Palmyra's plant and invertebrate communities were at negligible risk of harm from exposure to the rodenticide used to remove rats from the atoll, the active compound in the bait matrix (brodifacoum) is toxic to birds (Eason and Spurr 1995). As marine foragers, seabirds lack a direct pathway of exposure to brodifacoum; however, shorebirds, which forage in Palmyra's emergent habitats, were at risk of direct (consumption of bait) and indirect (consumption of invertebrate prey that consumed bait) exposure to brodifacoum. To minimize harm to Palmyra's migratory shorebird populations, the project was implemented during the breeding season (May-August), when breeding adults had returned to their northern-hemisphere nesting grounds. Only 80 of the 300 or more bristle-thighed curlews (*Numenius tahitiensis*) that overwinter at Palmyra were present during the eradication project. Of the 5 species of shorebirds that overwinter at Palmyra, 2 were at high risk of exposure to brodifacoum due to their foraging habits: bristle-thighed curlew, and Pacific golden plover (*Pluvialis fulva*) (USFWS 2011). Thirteen bristle-thighed curlews and one Pacific golden plover were captured prior to bait application. All of the birds survived the captive-holding period and were released when no further risk of exposure was apparent.

Hundreds of hours were spent searching for shorebird carcasses during and after the operation. The following carcasses were found: 8 bristle-thighed curlews, 2 Pacific golden plovers, 2 ruddy turnstones (*Arenaria interpres*), and one wandering tattler (*Tringa incana*). The Migratory Bird Special Purpose permit issued to this project authorized take of 182, 62, 35, and 48 of these species, respectively. Exposure to the rodenticide applied during the eradication was likely the cause of death for these specimens (Pitt et al. 2012).

More time is needed to accurately measure the response of Palmyra's flora and fauna to the removal of rats; however, results from preliminary monitoring and observations suggest that many, if not all, of the anticipated benefits will be realized. Since the eradication, biologists have observed wedge-tailed shearwaters (one of the species that was likely extirpated from Palmyra by rats) on the ground and vocalizing. Also, Palmyra's plant community showed a quick response to the rat removal, with a significant increase in seedling establishment for the native tree *Pisonia grandis* (Wolf 2011); *Pisonia* provides the preferred nesting habitat for Palmyra's tree-nesting seabirds (Young et al. 2010).

Palmyra is the only moist tropical atoll ecosystem in the Central Pacific that is entirely protected, as well as the only atoll ecosystem in this region that is not experiencing exploitation of both marine and terrestrial natural resources by burgeoning human populations. This project is a monumental conservation milestone for the National Wildlife Refuge System as well as for Palmyra NWR, and it has established a benchmark for eradication campaigns on other tropical islands.

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