

Palmyra Atoll Rat Eradication Assessment Trip Report

August 2004

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SUMMARY

With funding from Mr. Ian Cumming, we studied the feasibility of rat eradication on Palmyra Atoll in August - September 2004. In August 2004, a team of nine people with representatives from Island Conservation, three US government agencies (USDA-NWRC, USDA-WS, USFWS-ES and USFWS Refuges) and the Department of Conservation New Zealand visited the atoll for eight days to initiate detailed research. Two Island Conservation staff remained on the atoll for one additional month to complete the planned research. The main goals of this expedition were to:

1) Assess the previous effort to eradicate rats from Palmyra Atoll both to learn why it was not successful and what experiences from that effort can be used to develop methods for a follow-up rat eradication.
2) Conduct site-specific research needed to develop a plan for a successful rat eradication.

Research was conducted on-island to answer questions critical to successful rat eradication. To determine if all rats would have access to rodenticide bait we asked:

- Do rats spend multiple days in trees without coming to the ground (will ground baiting suffice or must bait be available above ground as well)?
- What is the two dimensional (*planar*) movements of rats over a period of several days (how does bait need to be spatially distributed)?
- How much bait needs to be put out given bait loss to weather, land crabs and other invertebrates?
- Because land crabs are the main source of competition for bait, what is their distribution and density, and are there effective crab-proof bait station designs?

To make sure the rodenticide of choice, brodifacoum, was effective against the rats on Palmyra, we ran a small toxicity study in the field. Finally, to make sure the eradication could be conducted without harming other components of Palmyra's ecosystem, we identified potential non-target species that might require special mitigation.

We found that Palmyra's abundant rainfall and aseasonal environment were obstacles to successful rat eradication. They make it difficult to develop a bait that maintains its palatability over time and is more attractive to all rats than the abundant natural food resources. The abundant landcrabs compete with rats for the bait and make it difficult to ensure enough bait is available to all rats for an adequate time period.

Our rat range data indicate that the standard bait station spacing of 50 x 50 m may have been insufficient to get bait into every rat's ranging territory because the animals live in a three-dimensional habitat that includes the forest canopy. We recommend any bait station-based efforts require a distribution of stations with a maximum separation of 25 m to increase the proportion of rats coming into contact with bait stations, which still might not be adequate to intercept all rats.

Our initial estimates suggest that a broadcast application will require an application of 60-80 kg/ha to ensure that enough bait is available to the rats on the ground for four days, to overcome competition from landcrabs that are attracted to and consume the bait (but are not affected by the anticoagulant rodenticide). We were unable to precisely determine an effective broadcast application rate because of the high density of crabs and limited availability of placebo bait. We estimated the rate of bait application required to overcome crab consumption using measured crab densities multiplied by the mean and highest rate of bait consumption for each species of crab (measured in cage trials). We estimate that for the highest density of crabs in coconut palm forests, we would need to apply from as little as 3.34 kg/ha to as much as 47.74 kg/ha to overcome bait loss to crabs. Additional bait would be applied to ensure enough bait is available to rats. Further field testing to determine an appropriate application rate will be required.

Our resistance trials demonstrated that there is some tolerance or resistance to brodifacoum in the rat population, likely developed after long-term, chronic rat control. The build-up of resistance or tolerance may have contributed to the compromised original rat eradication effort and may suggest a need for an alternate toxin in addition to brodifacoum in future eradication efforts.

We tested six different bait types on Palmyra – CI-25, CI-25 Waxed, Ramik (8 g), Ramik (2 g), Weatherblock XT, and Final Blox. CI-25 proved to be the most palatable bait; however, it was unable to endure the wet climate on Palmyra. Ramik (8 g) retained its shape and firmness in Palmyra's climate for long enough, but the bait was not (relative to the other bait) palatable to the rats. Weatherblock XT and Final Blox survived well in Palmyra's environment; however, they contain Bitrex, a bittering agent that reduces palatability of the bait which may limit the success of the eradication. We identified the characteristics of the bait we need to deliver to the rats on Palmyra. We are currently working with Bell Laboratories of Madison, WI, to develop a bait for us to further test on Palmyra in 2005.

We believe that the most effective means to eradicate rats from Palmyra will be the use of baits containing brodifacoum and perhaps an additional bait containing a non-anticoagulant (such as bromethalin) rodenticide, either aerially broadcast or with an approach combining aerial broadcast and bait stations spaced at 25 m intervals. Because of the stringent regulatory environment in the US, which makes the approval of an aerial rodenticide broadcast a complex process, and the need to assure availability of bait both to rats in the canopy and on the forest floor, we believe that the combined use of bait stations (spaced at 25 m) and aerial broadcast may be the most effective method of eradication, but also the most logistically complex and costly. Rats with small territories, which may not encounter bait stations during foraging, should encounter the bait broadcast into the canopy and thus will not escape bait exposure. Bait station eradication can be implemented at any time during the year. Timing of the broadcast could be closely linked to the migratory patterns of non-target birds on the island, with little impact on the eradication.

We identified non-resident migratory shorebirds at risk of both primary and/or secondary exposure to the rodenticide. The primary species of concern are the Bristle-thighed Curlew *Numenius tahitiensis* and the Pacific Golden Plover *Pluvaialis fulva*. Both species are identified as species of high conservation concern in the US Pacific Islands Regional Shorebird Conservation Plan (2004) and the US Shorebird Conservation Plan (2000). Both species overwinter on the atoll, with some individual juvenile birds present throughout the year. The most effective mitigation for these species is to conduct the eradication when there are the smallest numbers of birds present on the atoll.

With $120,000 in funding from the USFWS, we recommend conducting a trial hand broadcast (to mimic an aerial application) application into representative habitat to test the efficacy, risks and logistics of eradicating rats from Palmyra Atoll coincident with the lowest numbers of migratory shorebirds.

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Introduction

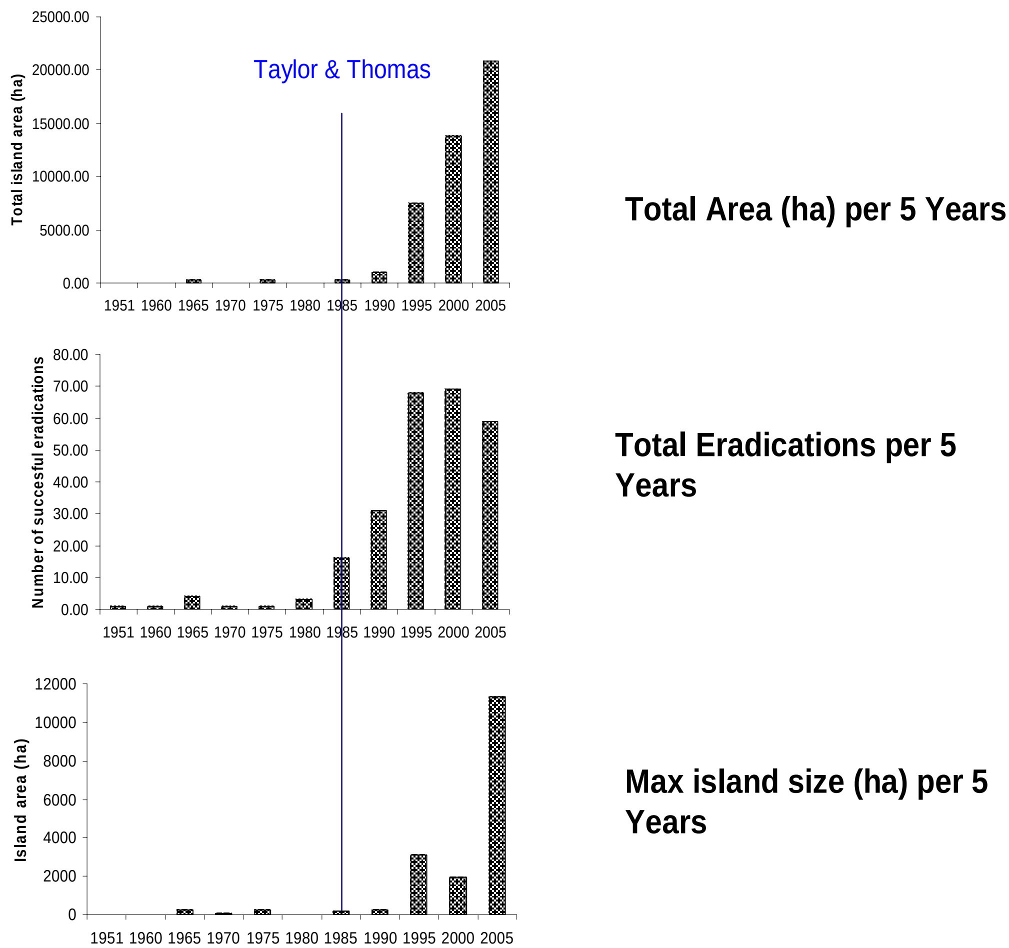
Island ecosystems, such as Palmyra Atoll, are key areas for conservation because they are essential habitat for seabirds, pinnipeds and sea turtles that range over thousands of square kilometers of open ocean, but depend on islands for breeding, raising young, and resting. In addition, islands tend to be rich in endemic species and are home to 15-20% of all plant, reptile and bird species, even though they make up only about 3% of the Earth's area (Whittaker 1998).

Unfortunately islands have been disproportionately affected by humans. More than 80% of all of recorded extinctions (excluding fish) have occurred on islands, and most of these were caused, at least in part, by invasive species (Island Conservation analysis of data from IUCN Global Red List and World Conservation Monitoring Center 1992).

One of the most significant invasive species on islands are rats in the genus *Rattus*. They have been introduced onto about 82% of the world's islands and/or island chains (Atkinson 1985), where they frequently have a quantifiable negative impact on the distribution and abundance of native flora and fauna. This is most pronounced on oceanic islands where native species have evolved in the absence of mammalian predators and thus have limited behavioral, morphological, and life-history defenses against rats (Brown 1997). Consequently, rats have been implicated in 40-60% of recorded bird and reptile extinctions since 1600 (Groombridge 1992). Fortunately, it is possible to eradicate rats from many islands, and in the last 20 years there has been a series of technological innovations in the field of rat eradication that have dramatically increased the power of this important conservation tool (Figure 1, Galvan *et al.* 2005). Briefly, rats are eradicated by distributing a bait containing a rodenticide, usually brodifacoum, into all rat territories. Bait can be placed in bait stations spaced on a grid of 25 x 25 m to 100 x 100 m, or can be broadcast evenly at a known density either by hand on small islands or with a helicopter using a bait-spreading bucket on larger islands.

Palmyra Atoll National Wildlife Refuge, located in the Line Islands of the central Pacific Ocean, approximately 1760 km south of the main Hawai`ian Islands, likely never supported native mammals because of its remoteness. However, non-native black rats (*Rattus rattus*) were introduced to Palmyra, likely during the US military occupation of the atoll in the 1940s. The establishment of rats on Palmyra is believed to have had a major negative impact on the ecosystem, especially on seabirds, invertebrates, and vegetation.

Figure 1. Total area, number and maximum island size of global rat eradications per five years (1951-2005). Taylor and Thomas (1989) developed a systematic bait station approach which facilitated a dramatic increase in successful eradications. The application of aerial broadcast by the early 1990's allowed much bigger and complex island rat eradications (Source: ***Unpub. data:*** *Island Conservation, IUCN, University of California Santa Cruz, Auckland University)*



The Nature Conservancy (TNC), in conjunction with the US Department of Agriculture's Wildlife Services and the US Fish and Wildlife Service initiated a rat eradication on Palmyra Atoll in 2001 in an attempt to restore the island ecosystem. However, the eradication effort was suspended in August 2003 after it became apparent that the rats could not be eradicated using the methods employed despite the ongoing efforts of island staff and volunteers.

In the spring 2004, Island Conservation and TNC secured funding from Mr. Ian Cumming to conduct a site assessment on Palmyra and develop specific recommendations, techniques and options to complete the eradication. In August 2004, a team of nine people with experience in island rodent eradication or control (Table 1) visited Palmyra Atoll to gather enough information to plan a trial eradication and begin planning eradication of rats from Palmyra Atoll.

Table 1. Eradication assessment team

Name	Organization	Expertise
Gregg Howald	Director, Island Conservation	Ecotoxicology/Eradication/Compliance
Brad Keitt	NW Project Director, Island Conservation	Avian Ecology/Eradication
Araceli Samaniego	Project Director, Island Conservation	Rodent Ecology/Eradication
Stacey Buckelew	Biologist, Island Conservation	Island Ecology/Conservation
Dan Vice	USDA-WS, Guam	Wildlife Biology/Control
Earl Campbell	USFWS-ES, Hawai`i	Wildlife Biology/Control
Will Pitt	USDA-NWRC, Hawai`i	Wildlife Biology/Control
Pete McClelland	New Zealand Dept. of Conservation	Island Mgmt/Rodent Eradication/Endangered Species Mgmt.
Alex Wegmann	PhD student, U. of Hawai`i	USFWS Palmyra Refuge Support

An initial eight-day site assessment was held to conduct basic studies and define site-specific research to be continued by two Island Conservation staff who remained on the island for an additional four weeks.

OBJECTIVES OF SITE VISIT

1. Evaluate the constraints of eradicating rats from Palmyra Atoll.
2. Review past eradication efforts.
3. Conduct site-specific research to aid in design of an eradication project, specifically:
    a. Evaluate the arboreal nature of rats and their *planar* movements, to determine if bait application into trees would be necessary.
    b. Determine an effective broadcast application rate that would deliver enough bait to the rats.
    c. Evaluate the presence of brodifacoum resistance in the local rat population from chronic control during past eradication efforts.
    d. Compare palatability of baits to natural foods and various alternative baits.
    e. Evaluate degradation rates of different types of bait in the Palmyra environment.
4. Assess presence of and risks to potential non-target species, and develop any necessary mitigation measures.

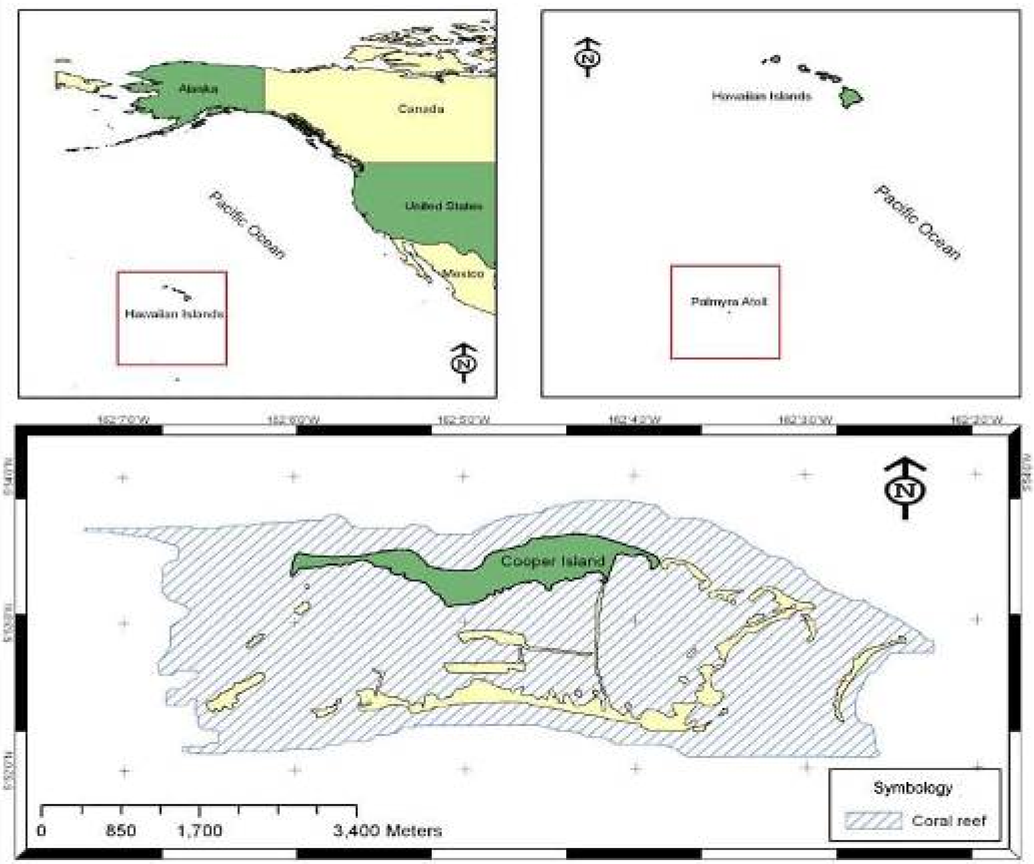
Field work was conducted from August 7 - September 11, 2004.

CONSTRAINTS

Access

Palmyra is approximately 1760 km south of Honolulu, in the Line Islands (Figure 2). Visitors to Palmyra can reach the atoll by either charter aircraft or by ship or boat. The atoll has a one-mile long coral rubble runway that is maintained by TNC staff. There is no regular air service to Palmyra, but TNC and USFWS regularly charter a small Gulfstream II twin turbo prop from Air Services Hawai`i, based on the south side of Honolulu International Airport. The aircraft can carry a maximum payload of 3300 pounds (both supplies and people). Maximum seating is for 18 persons. The cost for air charter is $20,000 for one round trip, typically with no overnight layovers.

Fig. 2. Location of Palmyra Atoll, Line Islands.



Ships and smaller pleasure craft visit the atoll regularly. The deepwater lagoon provides a safe, protected anchorage and can accommodate larger tugs and barges for deliveries of materials and supplies. TNC hires a tug/barge out of Honolulu to service the atoll yearly. The barge is able to tie up to Cooper Island near the old fish processing plant west of the main camp area. The cost of the barge/tug combination is a very expensive $150,000 per run.

Additional bareboat charters are available from the mainland and Honolulu, and the costs range from $2800 – $5500 per day, with some boats offering a maximum payload of 500,000 pounds.

Infrastructure

The developed portion of the atoll is on Cooper Island, and is owned and operated by TNC. TNC currently operates a full service tent camp capable of supporting 28 persons, with a generator for power and a rainwater collection system for drinking and wash water. Additional infrastructure includes old copra plantation buildings which provide shelter from the rain, a recreation facility, small dock, concrete bunkers, a well-maintained one mile long coral rubble runway for small aircraft and large propeller planes such as C-130s, and small boats to move personnel and gear between the islets. TNC charges users an access fee to fund the maintenance of these facilities.

Staff and guests are housed in groups of two in small weatherports. Two large weatherports support the communal kitchen/eating area, and shower/laundry facilities. The old fish plant and copra plantation buildings, and some additional weatherports, provide a workshop and ample storage space for equipment and supplies. Since the 2004 field work described in this report, TNC and a consortium of universities have completed construction of a new field research station on Palmyra.

Two small (about 18' long), plastic, open runabout boats are available to shuttle gear and people between islets as necessary. The shallow lagoon limits access to only a few landing points on the islets.

Weather

Palmyra lies within the Inter-Tropical Convergence Zone (ITCZ), the band of low pressure along the equator formed by the upward convection of warm, moist air from the Earth's surface. The climate of Palmyra is characterized by high humidity (>90%), warm temperatures (75 – 85 degrees Fahrenheit) with almost daily copious rainfall events associated with thunderstorms. Mean annual rainfall on Palmyra is 4.06 m.

Island Size and Topography

Palmyra Atoll is comprised of 54 islets encompassing 228 ha, rising to a maximum elevation of 2 m. The atoll is well within the size range of successful rat eradications (Figure 1). All of the land area can be accessed on foot, however, there are areas of thick vegetation, especially the *Scaevola* habitat, which precludes access without trail cutting. Although most of the islets are not connected, they can be reached by wading or swimming across the narrow channels that separate individual islets, or by boat.

There are potential safety concerns to eradication staff from unexploded ordnance, contaminated dump sites, hidden bunkers and marine wildlife (e.g. sharks), which could limit the successful implementation of a ground-based operation. Barrier and Quail Islands are inaccessible due to unexploded ordnance concerns. All areas of concern should be identified prior to implementation of the eradication.

Plants and Animals

The aseasonal climate on Palmyra supports dense vegetation of native and non-native trees and shrubs. A large portion of the atoll (approximately 48%) lies under a canopy of non-native coconut palm (*Cocos nucifer*a). Other habitat types include broadleaf forest composed of *Terminalia catappa,* the native *Pisonia grandi*s, and the shrub-like *Scaevola sericea* and *Tournefortia argenatea*. The *Pisonia* forest was once regarded as the best example of a pristine *Pisonia* forest in the American Pacific, but the trees are now dying due to stress response from introduced scale insects whose populations are inflated due to their symbiotic relationship with the introduced ant *Pheidole megacephala*. The decline of the *Pisonia* forest has caused dramatic changes in the Palmyra ecosystem.

The terrestrial habitats on Palmyra support 10 species of breeding seabirds. There are no breeding landbirds on Palmyra, but the island supports overwintering populations of Bristle-thighed Curlews (*Numenius tahitiensis*) and other shorebird including Wandering Tattlers (*Heterscelus incanus*), Pacific Golden Plovers (*Pluvialis fulva*) and Ruddy Turnstones (*Arenaria interpres*). The curlew and Pacific Golden Plover are designated by the US and Region 1 Shorebird Conservation plans as Species of High Conservation Concern because of limited breeding and non-breeding distributions, low relative abundance, and a decline in populations.

Palmyra supports a notably diverse assemblage of six landcrab species, including the large coconut crab (*Birgus latro*). The most abundant landcrab is the red hermit crab (*Coenobita* *perlatus*). Additional species include the purple hermit crab (*Coenobita brevimanus*), orange land crab (*Cardisoma carnifex*) and purple land crab (*Cardisoma rotundum*). These crabs compete with rats for access to the bait.

There are two terrestrial reptile species on Palmyra, an introduced house gecko (*Hemidactylus frenatus*) and a native mourning gecko (*Lepidodactylus lugubris*).

Palmyra supports a diverse collection of both native and non-native insects, including cockroaches and ants that are known to compete with rats for access to bait. During the first eradication attempt, it was noted that ants overwhelmed some bait stations, completely consuming the bait present in the stations within 24 hours.

Two domestic cats and a domestic dog are present as pets on the atoll, as well as one cat that is confined to a boat moored in the lagoon. We recommend that the pets be removed from the atoll prior to any eradication attempt. These animals would be at risk of exposure to any rodenticides used during an eradication effort.

REVIEW OF PAST ERADICATION EFFORTS

A review of the past eradication efforts was conducted in an attempt to identify why the eradication failed, so that some benefit can come from the time, energy and financial resources put into that project, and to ensure that any mistakes are not repeated in future efforts. This section summarizes the observations made by the crew that visited the island in August 2004. The review was designed to identify the processes or systems that failed.

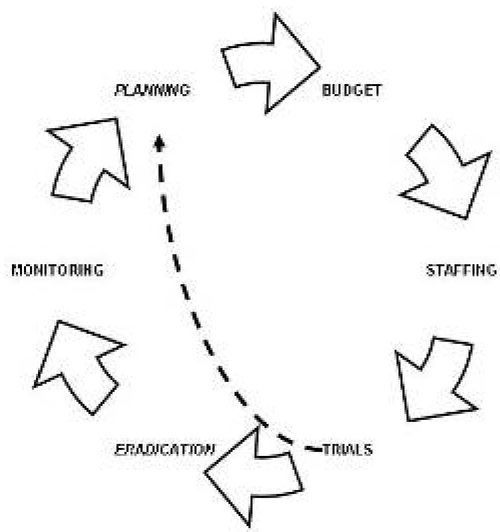
The three fundamental, and interrelated, parts of a successful rat eradication are:

1. exhaustive planning,
2. ongoing and effective communication between and among participants, and
3. adequate funding to implement the plan, including a contingency for unexpected costs or needed modifications to the eradication plan.

Planning

Based on the information that was provided, there appears to have been a lack of detailed planning, with only an Environmental Assessment that functioned as a written plan. No detailed plan was peer reviewed for potential problems, or shared with all participants to ensure continuity. Insufficient planning resulted in the use of techniques that proved inadequate to eradicate the rats. There was an ineffective management structure, use of volunteers and other staff with no expertise in rat eradication, poor communication between the involved parties and an inadequate budget to complete the eradication. The lack of a monitoring and communication plan led to poor data feedback to management and technical support that resulted in the continued use of inappropriate techniques and eventually contributing to a failed eradication (Figure 3).

Figure 3. A conceptual model of constant evaluation needed for a successful eradication project.



Communication

Initiating the eradication with an inappropriate approach or technique does not have to result in a failed eradication if there are adequately trained staff collecting data and making observations that are delivered to management and technical support staff, to troubleshoot and make modifications to the program as necessary.

There were many parties involved in the eradication, including USDA-Wildlife Services, US Fish and Wildlife Service, The Nature Conservancy management, TNC island managers and staff, a range of bait station technicians from previous projects and a series of inexperienced volunteers. There was no written communication plan that outlined either individuals' role or lines of communication for various aspects of the eradication. There appears to have been periodic communication breakdowns between the parties that led to strained relations between individuals and reluctance to share data or information. A detailed plan with an effective communication structure could have facilitated the relaying of information to appropriate support staff, who could have identified and rectified the problems with the eradication early and made the necessary changes.

Funding

The initial budget submitted to the National Fish and Wildlife Foundation was grossly inadequate to complete the project. The project appeared to be supply-driven, i.e., the project was constructed within the confines of the available funds. The project relied on the use of unpaid, inexperienced volunteer bait station technicians who were unable to identify subtle problems. Similarly, there was no contingency to modify the project as unanticipated problems arose.

The attempted eradication should not have been started given the inadequate funding. It is extremely important that eradication projects are adequately budgeted, with an appropriate contingency to respond to unexpected, unpredictable challenges. If only partial funding can be found, the project should be delayed until adequate funding is secured.

Eradication Technique

Successful eradication of rats from islands requires the use of techniques that:

1. Put every individual rat at risk from the proposed technique(s),
2. Remove/kill rats faster than they can replace themselves (breed), and
3. Prevent the in-migration by other rats.

Because of Palmyra's isolation, and the basic quarantine measures for ships and barges that regularly visit the atoll, the risk of rats immigrating to Palmyra is very low. Thus, the eradication efforts focus on steps 1 and 2.

The aseasonal, warm, humid climate and abundance of natural foods on Palmyra enable a sustained high density of rats that likely breed year round. Rats are capable of producing and weaning a litter every month. Thus, any technique that is used on Palmyra requires that the eradication be carried out intensively and as quickly as possible. The eradication attempt between 2001 and 2003 delivered bait in bait stations and could have killed the rats faster than they were breeding, assuming they had access to the bait stations, there was enough bait in the stations, and rats consumed the bait and were susceptible to the rodenticide.

Our assessment of the technique used in the previous eradication attempt focused on:

- **Bait availability** – Did all rats have access to bait stations and bait within the bait stations?
- **Bait palatability** – Did rats eat the bait?
- **Bait susceptibility** – Did all rats die after eating the bait?

Bait Station Design

The eradication of rats from Palmyra was initiated in 2001 initially with the placement of PVC tube bait stations placed on the ground. The stations certainly allowed rat access to the baits, but stations were readily overwhelmed by the abundant landcrabs and hermit crabs that were attracted to and consumed the bait. The stations were modified to elevated platforms with a small PVC tube that excluded some but not all landcrabs and hermit crabs from the stations. The final bait station design was made of empty 15 liter bait buckets modified to exclude crabs using a raised access hole (4.4 cm diameter, about 20 cm above ground) with bait suspended by wire near the bottom of the bucket. A baffle was put in place to prevent the large coconut crabs (which could not feasibly be excluded from the buckets) from "sweeping" the station, with a claw, for the bait. For rats to gain access to the bait, rats had to jump up to the hole, climb through the hole, jump down into the bucket and/or over the baffle. Bait blocks had to be chewed off a wire, which required rats to either consume part of the block in the station, or only remove part of the block from the station. To exit the station, rats had to jump over or onto the baffle edge, then jump up or over to the access/exit hole. The stations were secured in place with a large piece of coral rubble found in the vicinity of the station. Landcrabs, cockroaches, and ants competed with the rats for access to the bait in all bait station designs.

The third and final bait station design was successful in excluding the majority of landcrabs from gaining access to the bait within the stations (see Vice 2004,Appendix 1). However, there is a possibility, unconfirmed, that the modified bait stations design either physically or behaviorally excluded rats from the stations. Later in the project, personnel reported that rats routinely were observed to walk past armed bait stations, apparently ignoring the station. Similarly, there were reports of numerous bait stations that had no bait removed, yet live traps placed nearby or on top of the stations routinely captured rats. This indicates that some rats could not, or would not, enter the bait stations. It is unclear if it was a problem with the bait station design physically excluding the rats, or if the attractiveness of the bait was not high enough compared to the abundant natural foods. In other words, it is unknown if some of the rats simply chose not to enter the stations.

Bait Station Spacing

The stations were placed at approximately 50 m intervals laid along transects that were cut perpendicular to the axis of each islet. It appeared from the map of bait stations, and from a general walk around on the atoll, that the spacing was accurate, and all peninsulas and small islets had bait stations. The use of 50 m spacing of bait stations was based on the successful use of 50 m spacing of stations at Kure and Midway Atolls, and is typically the standard applied to island *Rattus rattus* eradication in the more temperate climates. (*Rattus exulans* were removed from Rose Atoll (6 ha) using bait station spacing at 30 m, in addition to live traps and snap traps at 10 m intervals.) The 50 m spacing was established to ensure that there are at least two or more bait stations in each and every adult rat home range or territory. An individual rat would require a minimum ranging area of 2500 m^2 to encounter at least one station within its territory.

Our radio telemetry data comparing the movements of rats live-trapped in coconut palms with rats trapped on the ground demonstrated that rats on Palmyra live in a three-dimensional environment, and regularly move between the tree canopy and the ground. The trees on the atoll, especially the abundant coconut palm, provide abundant food and shelter for rats. The ranging or *planar* movements of rats captured in coconut palms on Palmyra was particularly small, with a mean of 693 m^2 and a maximum of 1215 m^2. The *planar* ranging area of rats on Palmyra was measured to be smaller than typically measured elsewhere in more temperate climates, including Hawai`i. *R. rattus* in Hawai`ian forests were reported to have a mean home range of 3.6 ha (36,000 m^2) (range: 1.57-4.45 ha) (Lindsey *et al*. 1999) and *R. rattus* in New Zealand forests were noted as having home ranges as small as 0.3 ha (3,000 m^2) (Hooker and Innes 1995). The smaller *planar* movement measured on Palmyra is likely due to both the three-dimensional environment available and the abundance of natural foods. Thus, the rats could live in high densities and not have to move great distances to meet their life needs – food, water, shelter and mates to reproduce. Thus, we hypothesize that the rats, especially those with small territories, could have likely survived and either never encountered or infrequently encountered bait stations spaced at 50 m intervals. Some of these rats which did not encounter or avoided contact with the bait stations likely formed part of the residual population that repopulated the island after the eradication efforts were suspended.

Rat home ranges seem largely dependent on site-specific topography, rat density, habitat type, and food availability. Thus, to ensure a successful eradication, site-specific data must be relied upon as an indication of rat home ranges. Spacing of bait stations at 25 m intervals would ensure rats with territories as small as 625 m^2 would encounter at least one bait station within their territories.

Bait

For a successful eradication of introduced rats from an island, the fundamental requirement is that every last rat is removed or killed. Leaving even one pregnant female alive on the island, or failing to prevent future re-introductions, can negate the financial and time commitment devoted to eradicating rats initially. Thus, every effort must be made to get the last rat. The use of rodenticides for restoring islands is a powerful conservation tool. Used effectively, removal of the last rat is possible and rat eradications have been carried out over 250 times worldwide (Island Conservation, unpub. database).

To be an effective eradication tool, bait must:

- contain an active ingredient that is known to be highly toxic to the target population,
- be palatable and induce low or no bait shyness from the target population,
- be consumed in sufficient amounts by each rat to receive a lethal dose.

Of all known rat eradications worldwide, the vast majority have used the anticoagulant rodenticides, mainly brodifacoum (a second-generation anticoagulant), as the primary method of removal. The mode of action for brodifacoum is to prevent the production of active clotting factors by blocking the vitamin K-reductase enzyme in liver microsomes. The lack of active clotting factors leads to the inability of clot formation at sites of hemorrhage. The lack of clot formation leads to fatal hemorrhaging usually from a single point or multiple locations. Death typically results from complications due to hypovolemic shock. The major advantage of the anticoagulants is that the onset of poisoning symptoms is delayed until after consumption of a lethal dose. Thus, rats do not associate the symptoms of poisoning with the bait and bait shyness is avoided.

Over half of known rat eradications worldwide have used brodifacoum exclusively; the remaining projects used additional rodenticides or trapping as a secondary or tertiary means of removing rats (Figure 4). The introduction of an alternate rodenticide is used as a strategy to deal with individual rats that may have avoided the primary rodenticide through taste or behavioral aversion (e.g. USDA 2002). On other tropical islands (Rose Atoll, Kure Atoll, Sand Island, East Island, Midway Atoll), brodifacoum has been used as the primary rodenticide and occasionally bromethalin (an acute rodenticide) has been used as the secondary rodenticide. The mode of action for bromethalin is to uncouple oxidative phosphorylation in the mitochondria in cells of the central nervous system leading to a decreased production of ATP. Low levels of ATP inhibit the activity of the Na/K ATPase and lead to a subsequent buildup of cerebral spinal fluid. The increased cerebral spinal fluid results in high intracranial pressure, causing damage to nerve axons, inhibiting neural transmission and leading to paralysis, convulsions and death.

In the first rat eradication attempt on Palmyra, two baits containing two active ingredients were used. The bait used most extensively was Weather Block XT (Syngenta Crop Protection Inc.) containing 50 ppm brodifacoum. The bait was a 20 g blue wax block with a small hole in the center. The USDA (2002) reported 1,764.5 kg of Weatherblock XT had been applied on Palmyra by June 11, 2002. The total amount used after June 11, 2002 through August 2003 (end of eradication attempt) is not reported.

The second bait type was Fastrac All Weather Blox (Bell Laboratories, Inc.), containing 100 ppm bromethalin. The bait was a 20 g green wax block, tubular-shaped, with a small hole running through the longitudinal center of the block. The USDA (2002) reported that very little Fastrac bait containing bromethalin was used during the eradication attempt (25.3 kg) on "several islands" by June 11, 2002 during the first year of the eradication attempt. The amount of bromethalin used through the entire duration of the eradication attempt (through August 2003) was not reported.

When applied correctly, the use of bait containing brodifacoum and bromethalin has a high probability of successfully eradicating rats from islands. The rodenticide choice for Palmyra was appropriate and had a high probability of facilitating a successful eradication had the rats consumed lethal amounts of bait. However, Weatherblock XT contains Bitrex (a brand name for the bittering agent known as denatonium benzoate). The intent of the addition of Bitrex into rodenticide baits is to prevent the accidental consumption of rodent baits by children when used in urban settings. However, it is also known to reduce the acceptance of the bait to rats under laboratory conditions (Veitch 2002) and it is generally accepted that bait uptake declines with the addition of Bitrex into baits. Bait containing Bitrex is not recommended for use in island eradications due to the increased risk of bait shyness in individual rats potentially leading to eradication failure. On Palmyra, Bitrex may have caused some rats to avoid the bait (bait shyness) and not consume a lethal dose. Thus, Bitrex is another factor that may have compromised the success of the first eradication attempt.

The ongoing, chronic use of brodifacoum to control the rats on Palmyra may have led to the selection for individual rats that were physiologically more tolerant or resistant to the rodenticide. Over time, this can lead to the development of a resistant population, which makes it more and more difficult to control rats using that particular rodenticide. Although brodifacoum is highly toxic to rats, resistance to the second generation anticoagulants has been shown to develop in rodent populations in the United Kingdom (Cowan *et al.* 2004). Intensive baiting on Palmyra took place for a number of years (three years during the failed eradication attempt alone) around the camp complex on Cooper Island, primarily with brodifacoum, but also occasionally with diphacinone. The intensive rodent control may have been selecting for rats that are more tolerant of the rodenticides, either through the ability to metabolize and excrete the compound, or tolerance to higher doses. The investigation into resistance in August 2004 suggested that the early stages of brodifacoum resistance were present in the Cooper Island rat population (Pitt 2004, Appendix 2). Thus, ongoing baiting with brodifacoum alone could have led to the failure of eradication on Palmyra, even if all the additional biological problems were rectified. Ongoing use of 4-hydroxycoumarin anticoagulants may result in a population of rats that are resistant to the entire suite of anticoagulant rodenticides (Macnicoll 1986). Thus, to overcome resistance, a non-anticoagulant, possibly bromethalin, would have to be used.

CONCLUSIONS ON PAST ERADICATION EFFORTS

The benefit of looking back on a failed eradication attempt is that the problems identified can be rectified in a new eradication plan for Palmyra and raise awareness for other tropical and non-tropical island ecosystems in which rat eradication is desired. The eradication attempt on Palmyra Atoll between 2001 and 2003 violated the first two rules for eradication: all individuals were not at risk from the eradication technique, and the rats were repopulating the island at least as quickly as they were removed from the ecosystem in the latter stages of the baiting operation. There were problems with the planning, communication, and funding that were complicated by the local biological conditions, especially the competition from landcrabs and the small ranging territories of rats on the island. There was an assumption that the same management and eradication techniques applied successfully elsewhere could be applied on Palmyra without any background research or trials. A small scale trial would have revealed that the technique of eradication would not have been successful and could have allowed for research into new techniques, such as the effective bucket bait station that was ultimately designed and used. However, the bait buckets designed to exclude crabs could have excluded rats, the spacing of the bait stations physically excluded some rats from gaining access to the bait, the presence of Bitrex in the bait likely caused bait shyness in some individual rats, and the chronic baiting apparently resulted in slight brodifacoum resistance. Cumulatively, these problems presented insurmountable challenges to the eradication because there was no research/monitoring program built in to identify and then rectify problems. Had a project manager with expertise in rat eradication been involved with the project throughout, these problems could have been identified early, saving money, time, effort and frustration. Unfortunately it is unclear to what extent each of these problems alone or in combination caused the failure of the eradication.

The adaptive management approach is necessary in all eradication attempts, as each project presents its own unique set of challenges. Although Palmyra's ecosystem presents new challenges to rat eradication, they are not insurmountable and with the data collected during the site assessment in August 2004, an effective eradication plan can be developed. The eradication plan will need to be tested in a trial to identify potential problem areas and develop solutions to be implemented prior to the successful completion of an eradication on the atoll.

Studies Conducted on Pre-Eradication Trip Assessment

We conducted the following research during the site visit and assessment in August 2004 to support the development of a rat eradication plan.

Evaluate Arboreal Nature and Planar Movements of Rats on Palmyra Atoll

Methods

Since the movement, behavior, and canopy use by rats on Palmyra Atoll was unknown, we monitored a group of radio-collared rats within a palm forest (5 ha) on Cooper Island. Live traps baited with fresh coconut were set both on the ground (25 m apart) and in coconut trees (20-50 m apart). Traps were checked and reset daily for one week. Radio collars were put on nine rats captured on the ground and 12 rats captured in the tree traps. We only put collars on rats that weighed >100 g (collar weight approximately 5g). All rats were fitted with radio collars, observed over a 24-hour period, and released on their respective capture site. Directional Yagi antennas and digital receivers were used to monitor rat activity daily. The study area was visited nightly (2100-0000) and alternately in the dawn (0430-0700) and afternoon hours (1300-1500) to assess movement and refuge behaviors. Individuals were tracked an average of 12.9 days (s.d.=6.4). Data recorded for each individual included active/inactive status, specific spatial location (bearing and distance from a fixed marker location), and whether the animal was on the ground or in a tree. Signals determined to be inactive for >1 week were excluded from analysis. Daytime and nighttime locations for each individual were georeferenced from fixed marker locations using Garmin MapSource software and imported to ArcView for further analysis. Range areas were determined using a maximum-area calculation from peripheral locations encompassing the majority of central locations (assumed or confirmed refuge locations) including any stray or outlying positions. We believe this to be an adequate measure of ranging area for the purpose of determining an adequate spacing of bait stations to ensure that all rats have access to stations.

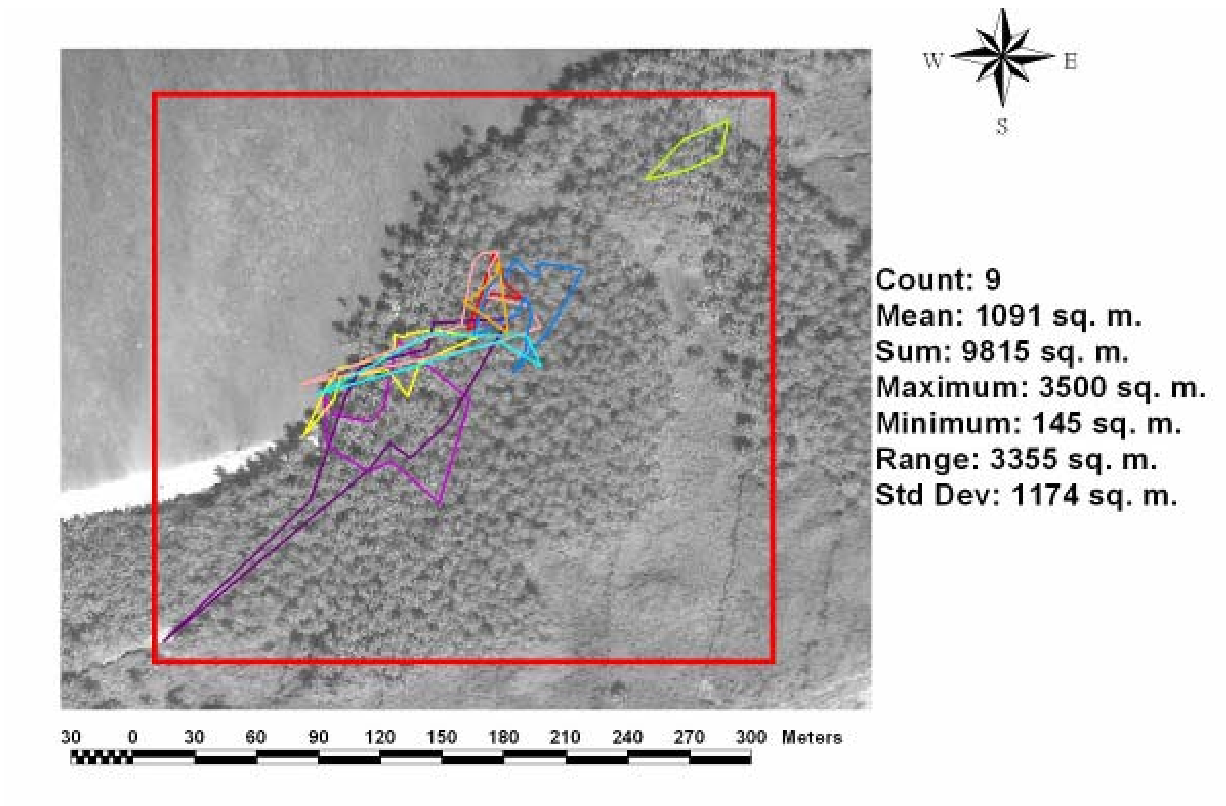
Results and Discussion

Mean ranging area for rats trapped in trees was 693 m^2 (s.d.=334) and 1091 m^2 (s.d.=1174) for ground-trapped rats (Figs. 5 and 6). Males, in general, covered a larger home range area (mean = 1317 m^2) than females (mean = 424 m^2), which is typical for this species (Table 2). Our results indicate that ranging areas were surprisingly small, but may be explained by the year-round availability of nesting and food resources. Small home range areas are also consistent with observations of high rodent abundances, which usually result in each rat having a smaller ranging territory (H. Gellerman, pers. Comm..) The information about rat movement therefore suggests that the distance between bait stations in previous eradication effort was likely too great to put all rats at risk of exposure.

All tree-trapped individuals ventured down and spent nearly 51% of the measured time on the forest floor. Inversely, ground trapped rats were observed in the canopy 29% of the measured time. This result suggests no rats are strictly arboreal, which is particularly favorable if a bait station eradication approach is implemented.

Although rats were more active during the evening hours, the Palmyra population showed a high level of diurnal activity compared to other populations. This may be related to the high

Figure 5. Ranging areas of 9 ground captured radio collared rats, Palmyra Atoll, August 2005.



percentage of foliage cover (both canopy and understory) and lack of predators, and/or the high density of rats competing for resources.

Figure 6. Ranging areas of 11 tree captured, radio collared rats, Palmyra Atoll, August 2005.

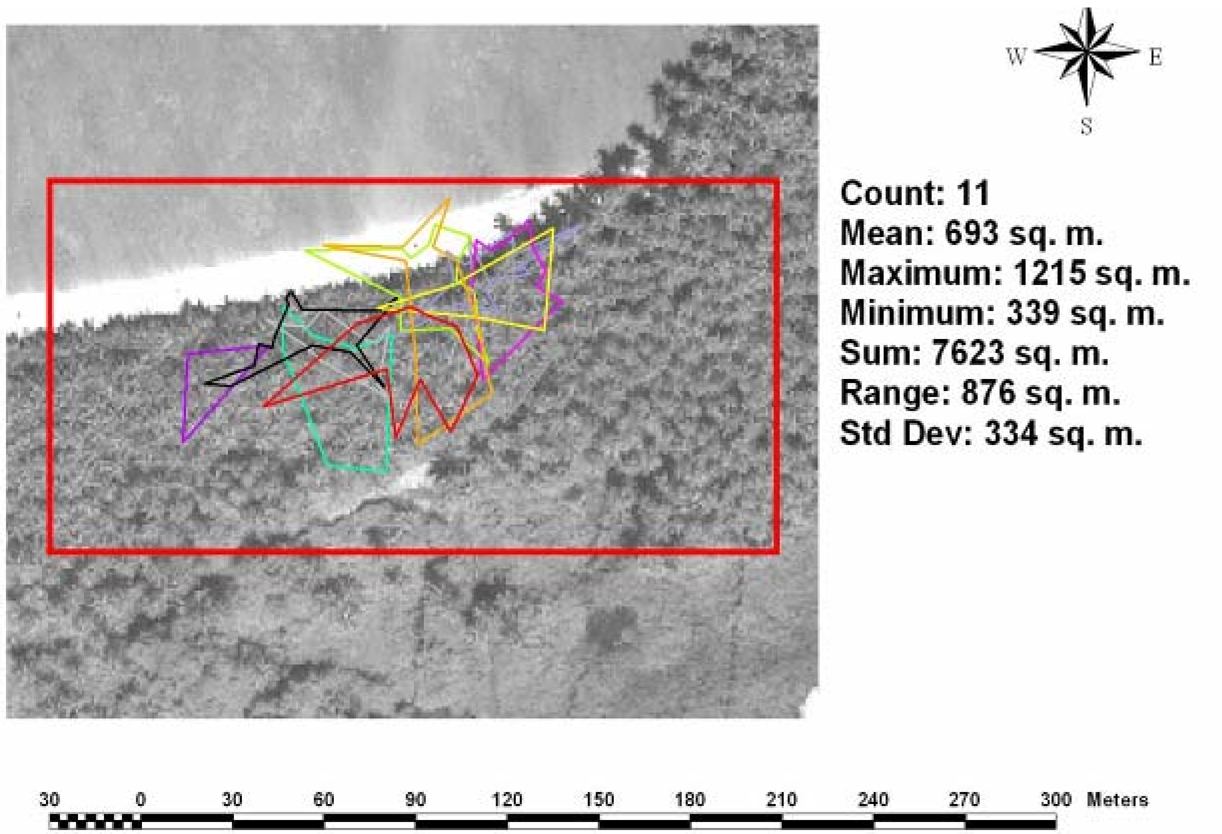


Table 2. Mean, minimum, maximum and median ranging areas (m^2) of rats on Palmyra Atoll (2004). Median home ranges represent territory sizes.

	Mean	Min	Max	Median
Male (10)	1317	429	3500	1008
Female (11)	424	145	744	367

Assuming that the ranging area data collected in August, 2004, is representative of rat ranging distances, it is clear that a very tight bait station spacing would be required to ensure delivery of bait to all rats. Using the lowest ranging territory measured, approximately 68 bait stations per hectare would be required to capture every rat territory, or about 15,436 stations atoll-wide. Installation of 15,000 bait stations may not be feasible because it would likely be expensive to install and maintain.

Calibration of a Broadcast Application Rate

If an aerial or hand bait application is used it is essential to apply enough bait so that it is available to rats for about four days. To calculate the appropriate bait application rate, one must consider both the uptake of bait by rats and by other species. In tropical systems such as Palmyra, land and hermit crabs would play a significant role in removing bait from the environment. Although crabs and other invertebrates are not susceptible to anticoagulant rodenticides, they are attracted to and compete with rats for bait. Thus, the total estimated uptake of bait by both rats and crabs must be considered for accurate bait application rate estimates.

During the field assessment, bait uptake at various application rates was initially measured using placebo bait (bait without brodifacoum added) in a plot with an unmonitored buffer zone. The buffer zone was intended to reduce the attraction of crabs to the bait in the uptake plot. This method was abandoned after initial results demonstrated artificially high crab densities even with large buffer zones. Although there was an obvious edge effect to the measured bait uptake, the required bait application rate using this method was approximated to be in excess of 60 kg/ha.

Because of the complications associated with the uptake plots, we estimated the potential uptake of bait loss by crabs using daily bait consumption rates of crabs in large cage trials multiplied by the density of crabs measured in the field. We acknowledge that this is a limited estimate and may not reflect true bait loss. It does, however, allow for "ballparking" a broadcast application rate. To estimate crab uptake across the atoll two factors were measured: 1) bait consumption for each species, and 2) number of individuals by species per unit area (crab density). Individual consumption rates for the four most abundant land crab species (*Coenobita perlatus* (N=3), *Coenobita brevimanus* (N=3), *Cardisoma carniferex* (n=5), *Cardisoma rugosa* (n=5)) were measured in captivity. All crabs were fed CI-25 placebo bait and consumption was measured using a digital balance every 12 hours over a four-day period. In collaboration with Alex Wegmann (University of Hawaii), an atoll-wide crab density survey for all five species was conducted. Five percent of the emergent land area across the major habitat types was surveyed and 250 m transects (2.5 m x 50 m) were randomly chosen from a geo-referenced Palmyra Atoll 25 m survey grid. All *Coenobita*, *Cardisoma,* and *Birgus* crabs encountered on the transects were counted with tally-counters to ensure accuracy. Prominent habitat type was recorded for each transect, and for transects that spanned more than one habitat type the habitat composing the majority of the transect was recorded. In addition, the time of day and weather conditions were recorded at the start of each transect. The survey results for each habitat type were used to extrapolate an atoll-wide population estimate for each species.

Crab density data were not normal (left-skewed) when tested with normal probability plots. Square root transformation of the data solved this issue. Thus, density estimates were square-root-transformed to perform descriptive statistic analyses of the mean, standard deviation, upper and lower confidence intervals. Once descriptive statistics were performed, data were back-transformed to yield corrected density mean, standard deviation, and upper and lower confidence intervals.

Major habitat types and their extension on Palmyra Atoll are described in Table 3, below:

Table 3. Area (ha) of major habitat types on Palmyra

Palm forest	Open ground	***Pisonia*** **forest**	***Scaevola*** **forest**	***Terminalia*** **forest**	ATOLL
98.2	20.8	23.8	65.5	19.2	**227.6**

Results and Discussion

The statistical estimates of the crab densities on the atoll are presented in Table 4. Red hermit crabs (*Coenobita perlatus)* were measured as the most abundant crab species on the atoll.

Using the captive crab consumption/density approach to bait application estimate, we estimate the highest bait application required to overcome crab consumption over four days to be between 3.34 and 47.74 kg/ha, in addition to the application required to deliver bait to rats (Tables 5 and 6).

Our results indicate both land and hermit crabs are important competitors with rats for bait. Hermit crabs consume less than land crabs, but are more abundant on the atoll. Due to logistical difficulties during the experiments (such as potential captive stress-level effects and weather conditions) the consumption rates by crabs may be underestimated.

Table 4. Estimated crab densities per hectare. Means, standard deviation, upper confidence intervals (Upper CI), and lower confidence intervals (Lower CI) for Palmyra Atoll, 2004.

	Purple hermit crab	Red hermit crab	Orange land crab	Purple land crab	All crabs
Forest Type	***Terminalia* forest (19.2 ha)**				
Mean (crabs/ha)	139	185	18	26	368
Standard Dev	19	68	1	0	88
Upper CI	205	296	33	40	574
Lower CI	87	99	7	15	209
Forest Type	***Scaevola* forest (65.5 ha)**				
Mean (crabs/ha)	14	179	46	9	248
Standard Dev	0	113	7	2	122
Upper CI	24	312	77	15	428
Lower CI	7	82	23	4	116
Forest Type	***Pisonia* forest (23.8 ha)**				
Mean (crabs/ha)	7	116	55	54	231
Standard Dev	8	39	17	13	76
Upper CI	9	190	97	93	390
Lower CI	4	60	25	26	115
Forest Type	**Open (20.8 ha)**				
Mean (crabs/ha)	5	15	4	5	30
Standard Dev	6	0	13	4	23
Upper CI	8	29	5	9	51
Lower CI	3	6	3	3	14
Forest Type	**Coconut palm forest (98.2 ha)**				
Mean (crabs/ha)	67	416	44	47	574
Standard Dev	6	182	4	5	197
Upper CI	100	631	69	75	874
Lower CI	40	246	24	26	336
Grand Total Means	**232**	**910**	**166**	**142**	**1450**

Table 5. Predicted crab bait consumption (kg/ha) (mean, std. dev, upper and lower confidence intervals) by species and habitat type over four days assuming mean consumption rate, Palmyra Atoll, 2004. Value highlighted in yellow indicates highest probabl application rate to overcome crab bait loss.

	Purple hermit crab	Red hermit crab	Orange land crab	Purple land crab	Pooled
Forest Type	***Terminalia* forest**				
Mean	0.53	0.71	0.07	0.1	1.41
Standard Dev	0.07	0.26	0	0	
Upper CI	0.78	1.13	0.13	0.15	2.19
Lower CI	0.33	0.38	0.03	0.06	0.8
Forest Type	***Scaevola* forest**				
Mean	0.05	0.68	0.18	0.03	0.95
Standard Dev	0	0.43	0.03	0.01	
Upper CI	0.09	1.19	0.3	0.06	1.64
Lower CI	0.03	0.31	0.09	0.02	0.44
Forest Type	***Pisonia* forest**				
Mean	0.03	0.44	0.21	0.21	0.88
Standard Dev	0.03	0.15	0.06	0.05	
Upper CI	0.04	0.73	0.37	0.36	1.49
Lower CI	0.02	0.23	0.09	0.1	0.44
Forest Type	**Open**				
Mean	0.02	0.06	0.02	0.02	0.11
Standard Dev	0.02	0	0.05	0.02	
Upper CI	0.03	0.11	0.02	0.03	0.19
Lower CI	0.01	0.02	0.01	0.01	0.05
Forest Type	**Coconut palm forest**				
Mean	0.25	1.59	0.17	0.18	2.19
Standard Dev	0.02	0.7	0.01	0.02	
Upper CI	0.38	2.41	0.26	0.29	**3.34**
Lower CI	0.15	0.94	0.09	0.1	1.29

Table 6. Predicted crab bait consumption (kg/ha) (mean, std. dev, upper and lower confidence intervals) by species and habitat type over four days *assuming maximum consumption rate,* Palmyra Atoll, 2004. Value highlighted in yellow indicates application rate to overcome crab bait loss.

	Purple hermit crab	Red hermit crab	Orange land crab	Purple land crab	Pooled
Forest Type	***Terminalia* forest**				
Mean	1.03	12.19	0.71	0.92	14.85
Standard Dev	0.14	4.5	0.03	0	
Upper CI	1.51	19.54	1.31	1.41	23.77
Lower CI	0.64	6.57	0.29	0.53	8.03
Forest Type	***Scaevola* forest**				
Mean	0.11	11.8	1.81	0.31	14.03
Standard Dev	0	7.5	0.27	0.06	
Upper CI	0.18	20.62	3.05	0.53	24.37
Lower CI	0.05	5.43	0.89	0.15	6.53
Forest Type	***Pisonia* forest**				
Mean	0.05	7.65	2.15	1.89	11.74
Standard Dev	0.06	2.55	0.66	0.44	
Upper CI	0.07	12.58	3.81	3.25	19.71
Lower CI	0.03	3.95	0.97	0.9	5.85
Forest Type	**Open**				
Mean	0.04	1	0.16	0.18	1.38
Standard Dev	0.04	0.03	0.5	0.15	
Upper CI	0.06	1.89	0.21	0.31	2.46
Lower CI	0.02	0.39	0.12	0.09	0.62
Forest Type	**Coconut palm forest**				
Mean	0.49	27.47	1.72	1.65	31.34
Standard Dev	0.04	12.02	0.14	0.18	
Upper CI	0.74	41.67	2.71	2.62	**47.74**
Lower CI	0.3	16.22	0.96	0.91	18.39

Brodifacoum Resistance

We conducted two trials evaluating the susceptibility and potential resistance of rats to brodifacoum from long-term use on Cooper Island. The details of the study and results can be found in Pitt 2004 (attached).

In summary, one of the rats, dosed at four times the LD50, died 21 days post-dosing and showed no symptoms characteristic of anticoagulant poisoning. This situation suggests that slight resistance to brodifacoum may occur within the population, and/or vitamin K (an antidote to brodifacoum) is abundantly available and consumed on the atoll. Vitamin K is contained in coconut fruit, particularly in young green coconuts, but its relative importance in the diet of the rats on Palmyra is unclear.

Rat Bait Preference

Methods

Potential baits for use during an eradication on Palmyra were tested for palatability in paired trials against other bait types or natural foods. Individual rats were live-trapped and held a minimum of 24 hours pre-trial. Trials consisted of 10 individuals each presented with paired food types. Food types were presented in random locations within the cage to reduce spatial selectivity. Trial results were determined by observation of first bait/food type selected. Thus, the first bait tasted by a rat was considered preferred. Each rat was observed for an additional period after the animal made its first choice to see if the rat switched and consumed the alternative bait/food type. The time to selection was recorded for each individual in addition to any switches made to the alternate bait/food choice during the trial. Three main trial types were conducted: 1) commercial bait vs. competing commercial bait to assess bait preference; 2) bait vs. bait of the same type at various stages of degradation to determine if bait exposed to environmental conditions was palatable; and 3) bait vs. natural foods known to be consumed by rats on Palmyra.

Results and Discussion

The results (Table 7) indicate that CI-25 (the bait developed by Bell Labs and Island Conservation for use on Anacapa Island, Channel Islands National Park, California) was the most preferred bait when compared to both natural foods and other baits. Ramik (2 g) was preferred to Ramik (8 g) and natural *Terminalia* fruit but not Weatherblock XT. As has been found in other studies (Howald *et al.*2005), bait exposed to environmental conditions and lightly covered with mold was preferred to fresh bait.

Table 7. Results of rat preference trials, Palmyra Atoll, 2004.

Baits in Trial	Preferred	Preference (%)
Paired Bait Trials		
CI-25/Ramik (8g)	CI-25	90
CI-25/Ramik(broken 8 g)	-	50
CI-25/Ramik (2 g)	CI-25	60
CI-25/CI-25 (wax coat)	CI-25	60
Ramik (8 g)/Ramik (2 g)	Ramik (2 g)	100
Ramik (8 g)/Weatherblock	Weatherblock	100
Degraded Bait Trials		
Wblk/ Wblk (mold – 1 wk)	Moldy Wblk	70
Wblk/ Wblk (mold – 2 wk)	Moldy Wblk	60
Natural Food Trials		
CI-25/Coconut	CI-25	100
Ramik (2 g) /*Terminalia* fruit	Ramik (2 g)	60

Bait Degradation

In order to ensure effective bait delivery to rats on the island, the bait must be able to withstand the island's climate and retain its size, shape and consistency. The rate of bait degradation is related to weather conditions, and is more rapid under the hot, humid, and wet climate of Palmyra.

Methods

To determine how well different types of bait retain their consistency in the Palmyra environment, degradation trials were conducted in natural conditions and in bait stations. Details of the degradation trial can be found in McClelland (2004) (Appendix 2).

Results and Discussion

The degradation rate for each type of bait in natural conditions was very similar among habitat types, indicating that type of bait is more important than microhabitat (Tables 8 and 9). The most preferred bait, CI-25, could not withstand the humid conditions and disintegrated rapidly (mean = 3 days). In addition we observed that insects, especially ants, proved to be moderate consumers of all baits when .the bait was on the ground for more than 10 days.

In bait stations, Weatherblock withstood environmental conditions similarly among habitat types and resisted mold for one week longer than when fully exposed to the environmnent (Tables 8 and 9).

Our results demonstrate that the Weatherblock bait and the large (8 g) Ramik placebo broadcast baits proved to be effective in withstanding degradation (mold/moisture).

Table 8. Results of degradation trial by habitat type and fully exposed to the environment, Palmyra Atoll, 2004.

Bait type	Days to mold/crack	Days to disintegration
	Scaevola	
CI-25	1	3
Ramik (2 g)	2	5
Fastrac	4	>20
Generation block	4	>20
Weatherblock	7	>20
	Grassland	
CI-25	1	3
Ramik (2 g)	3	4
Fastrac	3	>20

Generation block	6	>20
Weatherblock	6	>20
	Terminalia	
CI-25	1	3
Ramik (2 g)	2	5
Fastrac	3	>20
Generation block	7	>20
Weatherblock	6	>20
	Pisonia	
CI-25	1	3
Ramik (2 g)	2	3
Fastrac	3	>20
Generation block	7	>20
Weatherblock	7	>20
	Cocos	
CI-25	1	3
Ramik (2 g)	2	4
Fastrac	3	>20
Generation block	5	>20
Weatherblock	5	>20
	Mean degradation	
CI-25	1.0 (s.d.=0.0)	3.0 (s=0.0)
Ramik (2 g)	2.2 (s.d.=.71)	4.2 (s=.84)
Fastrac	3.6 (s.d.=.89)	>20
Generation block	5.8 (s.d.=1.3)	>20
Weatherblock	6.2 (s.d.=.84)	>20

Table 9. Results of Weatherblok XT degradation trial in bait stations by habitat type, Palmyra Atoll, 2004.

Bait type	Days to mold/crack	Days to disintegration
	Scaevola	
Weatherblock	13	> 20
	Grassland	
Weatherblock	15	> 20
	Terminalia	
Weatherblock	13	> 20
	Cocos	
Weatherblock	13	> 20
	Pisonia	
Weatherblock	20	> 20
	Mean degradation (days)	
Weatherblock	14.8 (s.d.=3.03)	> 20

Non-Target Species and Mitigation Measures

Palmyra supports several species that may be at risk of disturbance or exposure to rodenticide if basic mitigation measures are not adopted. The range of species includes landcrabs (if bromethalin is used), breeding seabirds, migratory shorebirds, two species of sea turtles and possibly the Hawai`ian Monk Seal (*Monachus schauinslandi*). In addition, the two domestic cats and a dog on the island will require specific mitigation to prevent exposure to the rodenticides used.

Specific mitigation measures will need to be developed for each species to minimize the impact of disturbance and/or rodenticide exposure. The primary mitigation is the timing of the bait operation to minimize the numbers of individuals of each species of concern on the island during baiting operation. Specific mitigation measures adopted are dependent on the eradication strategy used and will be developed further in a separate recommendation report.

CONCLUSIONS FROM PRE-ERADICATION STUDIES

- Eradication of rats from Palmyra Atoll is quite feasible, however it is by no means trivial and there are several technical challenges.
- No rats are exclusively arboreal
- The *planar* movements of rats were relatively small, indicating that the distance between bait stations in previous work was too great for eradication.
- Broadcast application rates may need to be in excess of 60 kg/ha to compensate for loss of bait to the high density of crabs found in various habitats throughout the atoll.
- Possible mild resistance to brodifacoum exists within the rat population.
- Palmyra rats prefer CI-25 bait over both other available baits and key, naturally abundant and available foods.
- CI-25 bait degrades rapidly on Palmyra and does not last more than a few days.

MANAGEMENT IMPLICATIONS FOR FUTURE ERADICATION EFFORT

- Both bait station and aerial application approaches could be used (and/or required) on Palmyra Atoll.
- Broadcast application in excess of 60 kg/ha may be needed to compensate for crab uptake and competition for the bait, ensuring enough bait on the ground for 3-4 days.
- Both brodifacoum and a secondary rodenticide, such as bromethalin, could be used in the eradication attempt. Bromethalin should overcome any brodifacoum-resistant individual rats, but landcrabs are susceptible to bromethalin and would require specific mitigation if bromethalin is used, to prevent population level exposure.
- A bait should be developed that is as palatable as CI-25 and that can withstand the Palmyra climate.

- A bait is in development currently and will be in degradation/palatability tests on Palmyra in February 2005.

RECOMMENDATIONS

1. Carry out specific research to conduct a trial eradication and refine a plan for eradication of rats from Palmyra Atoll, including:
    - Confirming broadcast application rate.
    - Developing a broadcast bait that can withstand the climate on Palmyra.
    - Testing rat use of elevated bait stations.
2. Conduct a trial broadcast eradication on Palmyra Atoll, with two rodenticides.
3. Review results and modify the approach to eradication as necessary; then begin planning the eradication of rats from Palmyra Atoll.

ACKNOWLEDGEMENTS

We wish to thank Mr. Ian Cumming for supporting the site assessment of Palmyra Atoll. We thank TNC Palmyra staff – Nancy Mackinnon, Matt Lange, Elizabeth Lange, Dacia, Danny, Joanne MacIsaac, and Chuck Cook for their assistance, guidance and support for our site visit to the atoll. Steve Barclay, Beth Flint, Don Palawski provided USFWS support. Jacob Sheppard, Nancy Ogle, Virginia McDermott and Holly Jones of Island Conservation assisted with logistics and provided general support. We acknowledge Jim Murphy of the USDA-WS for his moral support of this assessment and sharing data and insight into his experience on Palmyra Atoll. We thank Peter Dunlevy, Beth Flint, Gary Witmer and Lee Ann Woodward for reviewing an earlier draft of this trip report.

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Toxicant Delivery Stations and Terrestrial Crab Exclusion

Project Summary – Palmyra Atoll
August 2004

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INTRODUCTION

Successful delivery of anticoagulant poisons to every animal is the fundamental premise behind complete eradication of rats (*Rattus* spp.) from islands. In the absence of non-target species, bait delivered via aerial or hand broadcast can be made available to every animal in a defined time frame. However, non-target species often prevent the use of broadcast techniques, as primary and secondary uptake may adversely impact unintended targets and/or may limit bait availability to rats. On many tropical islands, terrestrial crabs occur in great abundance, and may consume bait directly, competing with rats and subsequently reducing bait availability. Additionally, crabs that have ingested toxicants become secondary hazards to migratory shorebirds, other native wildlife, and potentially, humans. To mitigate such hazards, anticoagulant toxicants are frequently delivered in secure bait stations. An ideal delivery device excludes all non-target hazards and allows free access to all sizes and species of rats.

Beginning in 2000, Palmyra Atoll, the northern most island in the Line Island chain, was the site of a black rat (*R. rattus*) eradication attempt, utilizing brodifacoum delivered in bait stations. Initially delivered in 12" long, 1 ½" diameter PVC pipes, hermit crabs (*Coenobita* spp.), land crabs (*Cardasoma* spp.) and coconut crabs (*Birgus latro*) consumed large volumes of toxicant. To further exclude crabs, several modifications were made to the delivery device, including anchoring the pipe to the ground or a raised platform, as well as capping one end of the pipe. These modifications were not successful at eliminating bait take by crabs. Following approximately 6 months of use, these devices were abandoned. The use of an alternative design, consisting of a covered 4-gallon plastic pail, with a 1 ½" diameter hole cut into the side approximately 8" up from the bottom of the pail, was implemented. This device provided some degree of exclusion for hermit crabs, land crabs, and coconut crabs. During this effort, at least one bristle-thighed curlew (*Numenius tahitiensis*), a species of concern, was killed through secondary toxicant uptake after eating hermit crabs that had ingested anticoagulant bait. Despite intensive poisoning over a 24 month period, the eradication effort at Palmyra was unsuccessful.

Future eradication attempts on Palmyra may require the development and use of delivery devices that provide complete crab exclusion as well as accessibility to all rats. In support of this need, a series of *in situ* and *in vitro* bait station experiments were initiated on Palmyra. The primary objective of this project was to assess the ability of different bait delivery stations to exclude terrestrial crabs.

METHODS

Prototype toxicant delivery stations were constructed of materials available on Palmyra Atoll. Three general station types were developed. The first, a platform station, consisted of 2" outside diameter PVC pipe, fitted with a 12" x 12" x3/8" plywood square on top of the pipe. Affixed to the plywood was a Protecta© toxicant delivery box (11 ½" x 12" x 6 ½", 2 entry box). The PVC pipe was cut to provide an above-ground height of both 24" and 18". This device will be referred to as the "box" station.

The second station type was constructed of ½" inside diameter electrical magnetic tubing (EMT; steel pipe) with a lid from a 5 gallon bucket firmly affixed to the pipe via a ½" hole drilled in the center of the lid. A second lid, to provide some protection from environmental conditions, was affixed approximately 10" above the first lid. The lower lid was set to provide an above-ground platform height of both 24" and 18". This device will be referred to as the "pipe" station.

The third station type consisted of a 4 gallon plastic bucket, fitted with a lid. A 1 ½" diameter hole was cut in the side of the bucket, approximately 8" from the bottom of the bucket. To further facilitate rat entrances and reduce crab damage to the bucket, a variation on this design was constructed, which included a 2" outside diameter, 4" length PVC pipe sleeve, inserted into the hole on the side of the bucket. This device will be referred to as the "bucket" station.

Evaluations of bait station crab exclusion were conducted inside a warehouse formerly utilized by a commercial fishing enterprise on Palmyra. Crabs were housed in 4' x 4' x 2.5' rigid plastic "totes" which are widely used in the commercial fishing industry. The smooth inner surface of the bins prevented crabs from climbing out. A single trial was defined by the same population of crabs in the same tote with a single bait station design (Table 2). Any change in crab number, individuals, or bait station design constituted a new trial. The number of exposure hours represents the total hours of individual crab exposure to a given bait station (e.g., 5 crabs in a single trial for 24 hours = 120 crab exposure hours).

Terrestrial crabs were grouped in three taxonomic categories for evaluation: 1) Hermit crabs (*Coenobita perlatus* and *C. brevimanus*), 2) Coconut crabs, and 3) Land crabs (*Cardasoma carnifex* and *C. rugos*). Live crabs were hand captured on Palmyra, placed inside totes, and exposed to bait stations. Hermit crabs were initially placed in groups of 55, with 35 adults and 20 sub-adults in each tote. Hermit crab densities were doubled to 110 individuals (70 adult and 40 sub-adults) following 2 full days of trials. These densities were established to mimic the "piling" behavior that hermit crabs exhibit when a valuable food source is found. Hermit crabs were considered adults if they were using a Hawai`ian turban shell *(Turbo sandwicenis)*; sub-adults were smaller crabs in any other shell. Land crabs were placed in groups of 5, and coconut crabs were held individually (this was done to reduce the probability of competitive interactions and subsequent injuries while in captivity). A single bait station was placed inside each tote. Stations were baited with placebo Ramik© bait (20 gram pellets) and roasted coconut mixed with peanut butter. Bait in each station was captivated with steel rods or tie wire to prevent removal. Entries into the pipe and box bait stations were documented through bait consumption. Entries into the bucket station were documented through bait consumption and crabs stuck inside the bait station. Because the number of nightly entry events could not be established through bait consumption, total entries were not documented. Exclusion capabilities are reported as "yes" or "no". Crabs were provided *ad lib* water and alternate natural food items during the duration of the trials.

Following the initial lab trials, a small number of field trials using the three bait station types were initiated. Seven bait stations (2 – 24" box stations, 1 – 18" box station, 2 - bucket stations without a PVC insert, 1 - bucket station with a PVC insert, and 1 – 18" pipe station) were placed in field use for three days, to assess crab exclusion and rat accessibility. Devices were baited in the same manner as in the lab trials. Crab and rat entrances were assessed using bait consumption and ink tracking boards.

RESULTS

Lab Trials

Thirty five separate lab trials were initiated during this effort, with a total crab exposure time of 41,175 hours (Table 1). Of the three primary stations evaluated, only the pipe station was accessed by crabs, and coconut crabs were the only group that entered the station and consumed bait. The bucket stations excluded all crab entries across each taxonomic group, although coconut crabs easily accessed the top of the bucket station. As well, the box station excluded all crab entries across each taxonomic group. Coconut crabs were able to climb the PVC pipe that supported the box and reach the delivery device, but were unable to access the secured bait inside the box.

Hermit crabs were able to climb the support pipe for both the pipe and box stations, but were unable to access bait as the platforms on both stations precluded entry. Only large adult hermit crabs were observed climbing the PVC pipe supporting the box station. Both adult and larger sub-adult hermit crabs were able to climb the ½" EMT supporting the pipe station. In several instances, sub-adult hermit crabs were observed clinging to the shell of adult crabs as they climbed, and were therefore capable of reaching higher on the stations than if climbing unaided.
Land crabs were not observed making any entry attempts into any of the bait stations. It is apparent that land crabs will be a greater impact to eradication efforts if broadcast methodologies are incorporated.

Field Trials

Given the small number of stations available and the short duration of testing, field evaluations provided limited information on crab exclusion and rat accessibility. In three nights of field use, only a single bucket station, without the PVC insert, received a rat visit. All stations were free of any indication of crab entries.

TRIAL	CRAB TYPE	# CRABS /TRIAL	# TRIALS	# EXPOSURE HOURS	CRAB ENTRIES
Bucket	Land Crab	5	2	1195	No
Bucket	Coconut Crab	1	4	101	No
Bucket	Hermit Crab	55	3	8629.5	No
Bucket	Hermit Crab	110	1	5170	No
24" Pipe	Coconut Crab	1	2	36	Yes
18" Pipe	Hermit Crab	55	2	2585	No
24" Pipe	Hermit Crab	55	2	2585	No
18" Pipe	Land Crab	5	2	115	No
24" Pipe	Land Crab	5	2	120	No
18" Pipe	Hermit Crab	110	1	5170	No
24" Box	Coconut Crab	1	4	101	No
18" Box	Land Crab	5	2	495	No
24" Box	Land Crab	5	2	500	No
18" Box	Hermit Crab	55	2	2585	No
24" Box	Hermit Crab	55	3	6617.5	No
18" Box	Hermit Crab	110	1	5170	No

Table 1. Exposure time and crab entrances for toxicant bait stations evaluated on Palmyra Atoll, August 2004.

DISCUSSION

The ideal toxicant bait station for use on Palmyra would have 100% crab exclusion, 100% accessibility to all rats, be cheap to build/purchase, and be simple to apply in the field. The three different bait station types evaluated here all appear to have significant crab exclusion qualities, and were constructed of readily available materials. The pipe and bucket stations would be easier to apply in field use than the box station, as the box station would require the use of rebar or some other support material for attachment to the ground. However, given the apparent repellency to coconut crabs offered by the box station, it may be the device of choice on islands with substantial coconut crab populations (i.e., Sand Island).

Prior to implementing wide-scale use of any delivery device, the accessibility of the station to rats must be assessed. Each of these devices appears to have complete accessibility to rats, but this has not been verified. An important next step will be to complete lab trials using captive rats exposed to the delivery devices, to assess accessibility.

A challenge for the application of any large-scale eradication attempt using bait stations will be quality control in field use. Any vegetation, litter, or other materials around a station may enhance the ability of non-targets to enter the station. Both hermit crabs and coconut crabs are extremely adept climbers, and small hermit crabs can support themselves on extremely thin branches or leaves. In addition, bait stations that are not well supported or anchored can be knocked over by coconut crabs, making bait subsequently available to non-target species. Mitigation for these potential hazards must be developed and implemented at the outset of any eradication attempt and frequent quality assurance reviews should be conducted at regular intervals to ensure field application techniques are meeting the prescribed use patterns.

APPENDIX 2. BRODIFACOUM RESISTANCE STUDY, W. PITT.

Study Title:

Resistance in roof rats (Rattus rattus) from Palmyra Atoll

Prepared by:

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Introduction

This field study is one component of continuing research to evaluate the reasons for an unsuccessful rodent eradication program and to determine the feasibility of future eradication efforts on Palmyra Atoll. Previously, the Nature Conservancy attempted an island eradication effort using bait stations with brodifacoum based baits. Baiting continued for more than two years and not all the rats were removed. Further, baiting around the housing complex has continued for 4 or more years with brodifacoum primarily but also with diphacinone baits. One possibility for the failed eradication effort is that a segment of the rat population was resistant to brodifacoum and thus not susceptible to control. The purpose of the current study was to evaluate if any portion of the rat population is resistant to brodifacoum due to previous baiting efforts. The rats most likely to show signs of resistance would be rats near the housing complex on Cooper Island where baiting with brodifacoum has been ongoing for the longest period of time.

Methods and Results

General Methods:

Black rats (Rattus rattus) were captured on Cooper Island near the base camp between August 7-14 2004. This area has had the longest history of brodifacoum use and if rats had developed resistance it would likely come from this population. All rats were sexed, weighed, and housed in individual cages. Rats were maintained under outdoor ambient conditions, but under a roofed structure to prevent wetting by precipitation or overheating by direct sunlight. Water was available ad libitum. CI-25 placebo bait was used as food and was always available for control animals and available to treatment animals after all treatment bait had been consumed.

For treatment animals, an LD 50 of 0.7 mg/kg was used as the LD 50 based on the published range of 0.65 – 0.73 mg/kg for black rats.

All rats were examined daily and the condition of the rats and any mortalities were recorded. Dead rats were weighed, sexed, and necropsied for signs of anticoagulant poisoning as described by Stone et al. (1999). The bait would be submitted for analysis if < 50% of the treatment rats are dead or appear moribund by the end of the feeding trial. This chemical analysis of the % active ingredient would have been done to assure that the low mortality rate was not a result of insufficient concentration of active ingredient.

<u>Resistance Trial A:</u>

Twenty rats were used in resistance Trial A with equal numbers of males and females randomly placed into control and treatment groups (Table 1). Each treatment rat was fed 1 Final block (50 ppm Brodifacoum) on two consecutive days (2 Final blocks total). The LD 50 dose varied according to weight of rats (0.014 g Final block per gram of animal).

The rats were initially dosed on 8 August 2004 (1200 hrs) with 1 Final Block and again on 9 August 2004 with a second Final Block. All treatment rats died 5-10 days after initial exposure to bait (13 – 18 August, 2004).

Resistance Trial B:

Twenty-eight rats (14 males, 14 females) were used in resistance Trial B (Table 2). Rats were captured 8 - 10 August 2004 on Cooper Island near the research complex. Each rat was randomly placed into one of four treatment groups limited by having at least 3 of each sex in each treatment group. The treatment groups were control, LD 50 dose, twice LD 50 dose, and four times LD 50 dose. Each LD 50 dose was normalized based on mass of the rat. Each treatment rat was fed a single dose of CI -25 (25 ppm brodifacoum).

The rats were initially dosed on 11 August 2004 (1300 hrs). All treatment rats died 5-21 days (mean = 8.7 days) after initial exposure to bait (16 August – 1 September, 2004). Four treatment rats persisted after 10 of the initial dose with death occurring on days 11, 11, 13, and 21 after initial dose.

Necropsy

Two control rats (#13, 17) and one treatment rat (#32) were necropsied to document signs of bleeding or other abnormalities (Table 3). The control rats had been euthanized on 3 September and the treatment rat had been found dead on 1 September, 2004. Necropsies included a gross physical examination, removal of the fascia, and internal examination of the organs to detect signs of bleeding.

No obvious signs of bleeding were observed in any of the rats. Rat #32 had a small hematoma on the right front leg but this appeared to be a minor injury that had previously healed. Rat #32 had external trauma to its head but it was unclear if this happened pre or post mortem. The injuries to the head were sufficient to cause death.

Discussion

The eventual death of all rats suggests the majority of black rats on Palmyra Atoll are susceptible to the effects of brodifacoum. Seven rats died with a single dose at the LD 50 level for black rats. Further, 28 of 29 rats died within 2 weeks of the initial dose (one rat escaped). These results indicate that there is not a large portion of the population resistant to the effects of brodifacoum. Further, it is likely that there is not a significant source of Vitamin K in their diet to counteract the effects of the rodenticide.

The length of time between initial dose and death of at least one rat suggests that a portion of the population may be resistant to effects of brodifacoum. This conclusion is further supported by the lack of hemorrhaging observed during the necropsy of a rat that persisted 21 days after the initial dose. The rat received 4 times the LD 50 dose and did not show obvious signs of hemorrhaging.

Rats survived an average of 7 days and 8.1 days (removing rat #32) after receiving the initial dose in resistance trials A and B respectively. Although rats did not die quickly from the high doses of brodifacoum provided, the survival duration after the initial dose is similar to other studies of brodifacoum (Gill and Redfern 1980). This length of survival after initial dosage is unremarkable.

Recommendations

1. A second baiting with another anticoagulant would be necessary to ensure complete eradication, if brodifacoum based bait is used to remove rats from Palmyra Atoll.
2. Another anticoagulant could be used instead of brodifacoum due to little chance of cross-resistance among anticoagulants (Apperson et al. 1981).
3. Continued haphazard baiting around the research station with brodifacoum should be terminated as soon as possible, if brodifacoum based baits will be used in an Atoll wide eradication effort.
4. An intensive evaluation of the efficacy will be necessary to ensure complete eradication, if brodifacoum based baits are used.
5. The brodifacoum LD 50 suggested for roof rats (0.65 – 0.73 mg/kg) appears to be adequate for rat eradication efforts on Palmyra Atoll.

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Table 1. Black rats (Rattus rattus) mass, sex, treatment, and fate in resistance trial A on Palmyra Atoll. August 2004.

Rat #	Mass (g)	Sex	Treatment	8Aug bait Mass (g)	9Aug bait Mass (g)	Total Bait (g)	LD 50 bait mass normalized	Multiple of LD50	Date of death
2	150	Female	Control	NA	NA	NA	NA	NA	NA
3	105	Female	Control	NA	NA	NA	NA	NA	NA
4	200	Female	Control	NA	NA	NA	NA	NA	NA
7	200	Female	Control	NA	NA	NA	NA	NA	NA
8	215	Female	Brodifacoum	20	20	40	3.01	13.3	8/14/2004
9	155	Female	Brodifacoum	21	20	41	2.17	18.9	8/14/2004
10	220	Female	Brodifacoum	20	20	40	3.08	13.0	8/15/2004
12	190	Female	Brodifacoum	20	21	41	2.66	15.4	8/13/2004
13	205	Female	Brodifacoum	21	20	41	2.87	14.3	8/15/2004
15	165	Female	Brodifacoum	NA	NA	NA	NA	NA	NA
16	115	Female	Control	NA	NA	NA	NA	NA	8/18/2004
20	230	Male	Control	NA	NA	NA	NA	NA	NA
21	210	Male	Brodifacoum	20	20	40	2.94	13.6	8/16/2004
22	155	Male	Brodifacoum	20	20	40	2.17	18.4	8/18/2004
24	190	Male	Control	NA	NA	NA	NA	NA	NA
25	200	Male	Brodifacoum	19	20	39	2.8	13.9	8/16/2004
26	170	Male	Brodifacoum	20	20	40	2.38	16.8	8/15/2004
27	210	Male	Control	NA	NA	NA	NA	NA	NA
28	140	Male	Brodifacoum	20	20	40	1.96	20.4	8/14/2004
30	275	Male	Control	NA	NA	NA	NA	NA	NA
31	200	Male	Control	NA	NA	NA	NA	NA	NA

Table 2. Black rats (Rattus rattus) mass, sex, treatment, and fate in resistance trial B on Palmyra Atoll. August 2004.

Rat Mass (g)	Sex	Treatment Group	LD 50 multiple	Brodifacoum (mg)	Bait (g)	Date of death
245	Male	3	2	0.343	13.72	8/21/2004
195	Male	4	4	0.546	21.84	8/20/2004
195	Male	2	1	0.1365	5.46	8/20/2004
155	Female	2	1	0.1085	4.34	8/19/2004
155	Female	4	4	0.434	17.36	8/16/2004
160	Female	2	1	0.112	4.48	8/16/2004
140	Female	4	4	0.392	15.68	8/18/2004
220	Female	3	2	0.308	12.32	8/20/2004
160	Male	2	1	0.112	4.48	8/19/2004
195	Male	3	2	4	10.92	8/22/2004
195	Male	1	NA	0	10	NA
230	Male	1	NA	0	10	NA
140	Male	1	NA	0	10	NA
100	Female	3	2	0.14	5.6	8/23/2004
130	Female	1	NA	0	10	NA
155	Female	1	NA	0	10	NA
145	Female	4	4	0.406	16.24	8/20/2004
170	Female	1	NA	0	10	NA
145	Female	3	2	0.203	8.12	Escaped
170	Female	2	1	0.119	4.76	8/16/2004
155	Female	3	2	0.217	8.68	8/19/2004
160	Male	2	1	0.112	4.48	8/20/2004
225	Male	3	2	0.315	12.6	8/18/2004
190	Male	4	4	0.532	21.28	8/18/2004
225	Male	1	NA	0	10	NA
175	Male	3	2	0.245	9.8	8/17/2004
135	Female	2	1	0.0945	3.78	8/19/2004
225	Male	4	4	0.63	25.2	8/22/2004
175	Male	4	4	0.49	19.6	9/1/2004

Table 3. Necropsy results of rodents captured on Palmyra Atoll, August 2004.

ID Number	Sex	Date dead	Body weight (g)	Head-Body length (mm)	Tail length (mm)	Right hind foot length (mm)	Right ear length (mm)	Dorsal pelage color	Ventral pelage color	Reproductive status
Control (13)	Male	9/3/2004	214.30	196.3	223.3	36	24.3	Long black guard hairs & grayish hairs with orange tips	Grayish color with white cream tips	descended testes
Control (17)	Female	9/3/2004	129.85	172	203.7	34.2	22	Long black guard hairs & grayish hairs with orange tips	Grayish color with white cream tips	Vagina perforate
LD50X4 (32)	Male	9/1/2004	154	147	219.7	34.3	Not taken	Long black guard hairs & grayish hairs with orange tips	Grayish color with white cream tips	descended testes

Necropsy Notes:

All the rats were classified as *Rattus rattus* by their morphological characteristics.

When peeling of the entire fascia from the three rats, rat # 32 had signs of previous bleeding on the right front forelimb.

The remaining muscle color throughout the rats' bodies was pink and healthy.

Rat # 17 had green color stains on its paws, tail, and near the anus.

Rat # 32 had both its ears torn apart, missing both its eyes, and the left side of its rostrum had been scraped away.

Rat # 32 had green color stains on its ventral pelage, paws, tail, and in the anus region.

Overall, no obvious signs of hemorrhaging were seen.

BAIT WEATHERING TRIAL

Prepared by: Pete McClelland, New Zealand Department of Conservation

September 2004

Summary

In order to ensure that bait is available for rats for the desired three nights following a broadcast operation the two available bait types were placed under rat and crab proof exclosures and their degradation monitored for four days. The small (1-2g) CI-25 baits broke down rapidly while the 8g Ramik bait was still in good condition at the completion of the trial.

Methodology

The trial used five exclosures – approximately 50cm square with 15cm high sides, a 15cm foot coming out from the base to try and prevent rats or crabs digging under and 1cm square wielded wire mesh on the top to five the bait full access to the weather. These were placed in the 5 major habitat types found on the Island namely,

a) Pisonia – tall forest with an open understorey, approximately 80% canopy cover and with a well drained storey substrate.
b) Coconut Palms – tall forest, open understorey, approximately 80% canopy. Moderately drained sandy substrate.
c) Terminalia – tall forest, approximately 95% canopy heavy fern ground cover, approximately 1m high. Leaf litter substrate.
d) Open grass – no canopy, 100 % ground cover, compacted substrate
e) Pandonas – low "forest" 100% canopy and heavy understorey of same vegetation. Fine gravel substrate and leaf litter.

The sites were checked every 24 hours within 3 hours (after) of the rainfall being record for that period, and the condition of the bait recorded. Specifically the physical shape of the bait i.e. solid → soft → crumbly , retaining shape, degree of water absorption. Also, amount of mould on the bait, likely palatable (very subjective) and ant activity.

Results

Rainfall

11 August

12 August

13 August

14 August

Bait Condition

11 August

Plot A) **CI-25** - swollen and crumbly, 100% moisture penetration, moderate ant activity

Ramik – outer layer flaking 50% moisture penetration, no ant activity

Plot B) **CI-25** - swollen and crumbly, 100% moisture penetration, moderate ant activity.

Ramik - outer layer flaking – 50% moisture penetration, no ant activity

Plot C) **CI-25 -** all bait eaten by crabs

Ramik – 100% moisture penetration, outer layers flaking

Plot D) **CI-25** – swollen and mushy, just holding shape, moderate ant activity

Ramik – 100% moisture penetration, outer layer flaking (can crush with two fingers) still palatable.

12 August

Plot A) **CI-25** – disintegrating but still in general shape

Ramik – continued flaking – 2 layers

Plot B) **CI-25** – all eaten by crabs

Ramik – 1st layer flaking – 100% moisture penetration

Plot C) **CI-25** – all bait eaten by crabs

	Ramik – all bait eaten by crabs
Plot D)	**CI-25** – disintegrating – wet mush
	Ramik – 1st layer flaking
Plot E)	**CI-25** – (new yesterday) 100% moisture penetration, bait swollen and crumbly
	Ramik – flaky 1st layer

13 August

Plot A)	**CI-25** – most bait eaten by crabs , rest mush **Ramik** – no change
Plot B)	All bait eaten by crabs
Plot C)	All bait eaten by crabs
Plot D)	**CI-25** – 50% bait gone, not whole pallets – wet mushy – high ant numbers
	Ramik – still holding shape but 50% flaking
Plot E)	**CI-25 –** disintegrating but still holding shape
	Ramik – flaked 1st layer

14 August

Plot A)	All bait eaten
Plot B)	No bait
Plot C)	No bait
Plot D)	**CI-25** – 75% bait gone (ants?)
	Ramik – no change

Plot E) All bait gone

DISCUSSION

Keeping crabs out of the exclosures was more difficult than predicted as they tunnelled under the foot. In some cases 50+ crabs would be inside the enclosure overnight. There was no evidence of rats taking the bait so when bait was missing and crabs present it is assumed the crabs ate the bait. When bait was missing but no crab activity was found it was always when the CI-25 bait had gone mushy and its loss was attributed to ants.

Even when the CI-25 bait was replaced it was always wet through and starting to breakdown by the next day. It is very unlikely, given the rainfall on Palmyra, that 1gm CI-25 baits would last three nights in a presentable state, even if the crabs/ants didn't eat it. A large bait would have a reduced surface area: volume ratio and is likely to last better. The Ramik bait weathered well, even though it started flaking after one day it appeared to still hold its shape after three nights and may in fact have become more palatable as it got softer.

CONCLUSION

The 1gm CI-25 bait is not suitable for use on Palmyra. The 8 gm Ramik bait does have the desirable weathering properties, but does have issues with sowing rate and possibly palatability. Therefore other bait types need to be explored and tested.

RECOMMENDATION

That as many different bait types/sizes be tested for weathering as well as palatability etc to see if one that meets the tight requirements of Palmya can be found. If a suitable bait can be found – field trials should be carried out.