PALMYRA ATOLL RESTORATION PROJECT -RAT ERADICATION: POST-OPERATIONS REPORT

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Technical Report

Island Conservation

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INTRODUCTION

The purpose of rat eradication phase of the Palmyra Atoll Restoration Project was to safeguard the atoll's indigenous flora and fauna, and create a refuge for species within the central Pacific region that are at risk of extinction. This project achieved a monumental conservation milestone for the Refuge, and established a benchmark for subsequent eradication campaigns on other tropical islands.

Palmyra is among the most isolated island systems in the world. It lies in the central Pacific approximately 350 nautical miles north of the equator: longitude 162 04' 59.05" W, latitude 005 52' 55.54" N (Figure 1). Palmyra is part of the chain of islands called the Northern Line Islands, along with Kingman Reef to its northwest and the Kiribati Line Islands to its south. Palmyra's emergent land area consists of 25 distinct islands ranging in size from < 0.1 ha to over 100 ha. The islands are separated by shallow channels or lagoon flats, some of which are emergent at low tide. Three deep lagoons run east-west between the two major island groups, and a thin (10-20m) wide causeway runs north-south between the Center Lagoon and Eastern Lagoon (Figure 1).

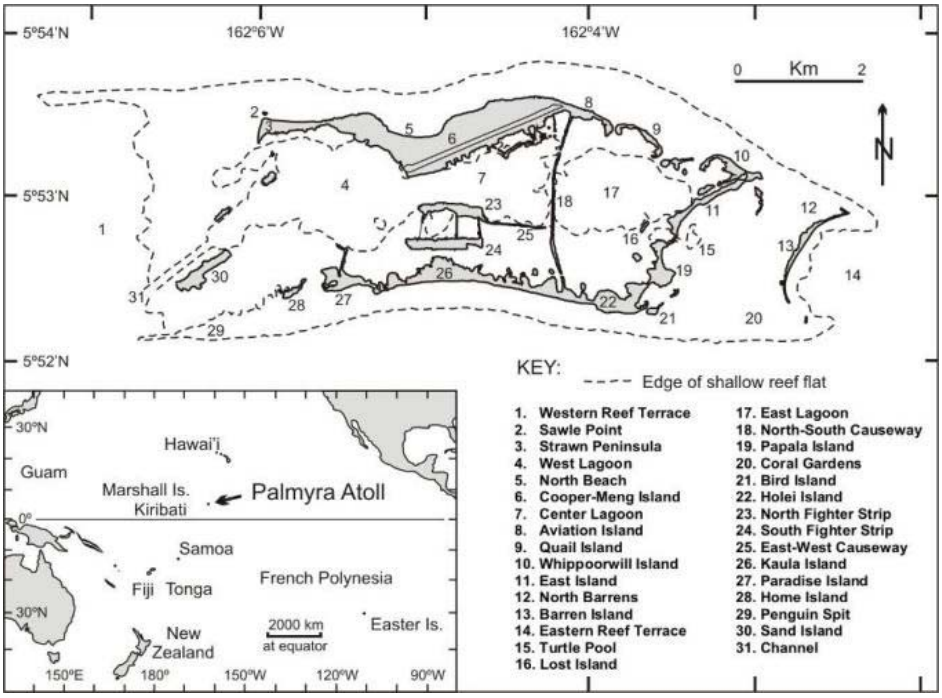

Figure 1. Geographic map of Palmyra Atoll (Collen et al. 2009).

Between June 3 and 30, the rat eradication project was implemented through a partnership between the U.S. Fish and Wildlife Service (FWS), The Nature Conservancy (TNC), and Island Conservation (IC); after 7 years of planning and scientific investigation. Over the 28-day period the team of 40 people from 5 countries utilizing 1 large ship, 2 helicopters, 6 small boats, 10 slingshots, bait stations, and hundreds of field hours systematically applied 38,560 kg of rodenticide per the Final Environmental Impact Statement and following Environmental Protection Agency supplemental label guidelines with 5 methods to every part of the atoll in order to eradicate the estimated 30,000 rats living on the 235 hectares of land. Amidst mechanical breakdowns, weather shutdowns, and extreme bird-helicopter hazards, this remarkable team of people came together to accomplish the highly complex mission with no major accidents or human injuries.

Since the eradication, two in-depth monitoring efforts (6 weeks and 12 months after the initial bait application) failed to detect the presence of rats. The results from these detection efforts, and the absence of rat sightings despite year-round presence of FWS and TNC personnel at Palmyra, allow us to say with confidence that the atoll is now free of rats

The Palmyra rat eradication was the first phase of a three-part conservation expedition that utilized the same ship and major roll equipment (helicopters, bait buckets, etc.) for three separate rat eradication projects: Palmyra, Enderbury and McKean in the Phoenix Islands (the Government of Kiribati and EcoOceania), and Henderson Island (Royal Society for the Protection of Birds).

TIMETABLE

The R/V AQUILA, with helicopters aboard, left Seattle on 18 May 2011, and was based at Palmyra from 6 June to 1 July. It then travelled to Apia, Samoa to load supplies and exchange personnel for the Phoenix Islands project. The following table is a chronicle of the important operational milestones for the Palmyra rat eradication.

Date (2011)	Milestone
18 May	R/V AQUILA departs Seattle with equipment, supplies, and personnel
1 June	R/V AQUILA departs Honolulu with additional supplies and personnel; personnel fly to Palmyra
6 June	R/V AQUILA arrives at Palmyra
12 June	First bait application commences
19 June	First bait application is completed
21 June	Second bait application commences
26 June	Second bait application is completed
30 June	Personnel depart Palmyra for Honolulu via a chartered flight
1 July	Personnel depart Palmyra for Apia via the R/V AQUILA
6 July	R/V AQUILA arrives at Apia, Palmyra personnel disembark
30 September	R/V AQUILA arrives in Seattle (home port) after completing the Henderson Island project

PERSONNEL AND PROJECT MANAGMENT

The operations team for the Palmyra rat eradication contained 40 people (Table 1) who filled 50 positions, with most team members filling more than one position (Figure 2).

Table 1. Personnel directly involved in the Palmyra Atoll rat eradication – primary roles are presented

Affiliation	Personnel	Roles
IC	Alex Wegmann	Baiting Manager
IC	Aurora Alifano	Safety Manager
IC	Dan Grout	Hand Broadcast Crew
IC	Dave Sanderson	Helicopter Engineer
IC	Dave Will	GIS Manager
IC	Erik Oberg	Hand Broadcast Manager
IC	Graeme Gale	Broadcast Baiting Pilot
IC	Gregg Howald	Structure Baiting Manager
IC	Jake Bonham	Air Ops Manager
IC	Mike Fell	Bait Loading Assistant

Affiliation	Personnel	Roles
IC	Nick Torr	Bait Loading Manager
IC	Pete McClelland	Ops Planning and Intelligence Manager
IC	Peter Garden	Broadcast Baiting Pilot
IC	Richard Griffiths	Ground Ops Manager
IC	Rory Stansbury	Bucket Manager and Shorebird Capture Specialist
IC	Sean McKnight	GIS Assistant
R/V AQUILA	Anj Keeling-Garcia	First Mate
R/V AQUILA	Chris Johnson	Deckhand
R/V AQUILA	Damien Gramenga	Steward
R/V AQUILA	Gromyko Lekka	Deckhand
R/V AQUILA	Kale Garcia	Captain
R/V AQUILA	Mckenzie Keeling-Garcia	Hand Baiting Crew
R/V AQUILA	Rich Keeling	Engineer
R/V AQUILA	Sam Noble	Deckhand
R/V AQUILA	Tanner Keeling-Garcia	Assistant Engineer
TNC	Ben Buchwald	Maintenance Assistant
TNC	Bob Gooding	Galley Assistant
TNC	Dennis Davenport	Chief of Marine Operations
TNC	Jordan Jokiel	Structure Baiting Crew
TNC	Katie Stadler	Galley Manager
TNC	Ned Brown	Station Supervisor
TNC	Will Beyer	Maintenance Manager
USDA	Are Berensten	Monitoring Manager
USDA	Kacy Hayes	Monitoring Crew
USDA	Tom McAuliffe	Monitoring Crew
USFWS	Amanda Meyer	Monitoring Crew
USFWS	Beth Flint	Hand Baiting Crew
USFWS	Jim Breeden	Shorebird Mitigation Manager
USFWS	Lesanna Lahner	Shorebird Protection Specialist
USFWS	Susan White	Incident Commander
USGS	Stacie Hathaway	Monitoring Crew

Project Management

The Incident Advisory Group (IAG), led by the Incident Commander, was the primary decision making body during the operation. The Operations Advisory Group (OAG) led by the Deputy Incident Commander, relayed information between the IAG and the project teams. When the IAG decided to deviate from the Operational Plan, the deviation was recorded and signed by the representatives from FWS, TNC, and IC.

After all project personnel arrive at Palmyra and before the commencement of the first bait application, all hands briefings on the operation were held, and the different operations teams attended training sessions that were particular to their assignments.

On site, or "hot" debriefings occurred every evening of the operation. During the hot debriefings, the Incident Commander recounted the actions that occurred that day and fielded questions and statements from personnel regarding the day's activities. Following the hot debriefings, the IAG met to address issues discussed during the general debriefing. Each morning of operations, all personnel met at the command center and received the day's plans from the Incident Commander and the section chiefs.

With multiple moving fronts and overlapping authorities and responsibilities, management of this operation was difficult at the best of times. A greater level of experience in some positions and more emphasis on training project personnel in the Incident Command system would have improved the efficiency of decision making and effectiveness of the management structure used during the project.

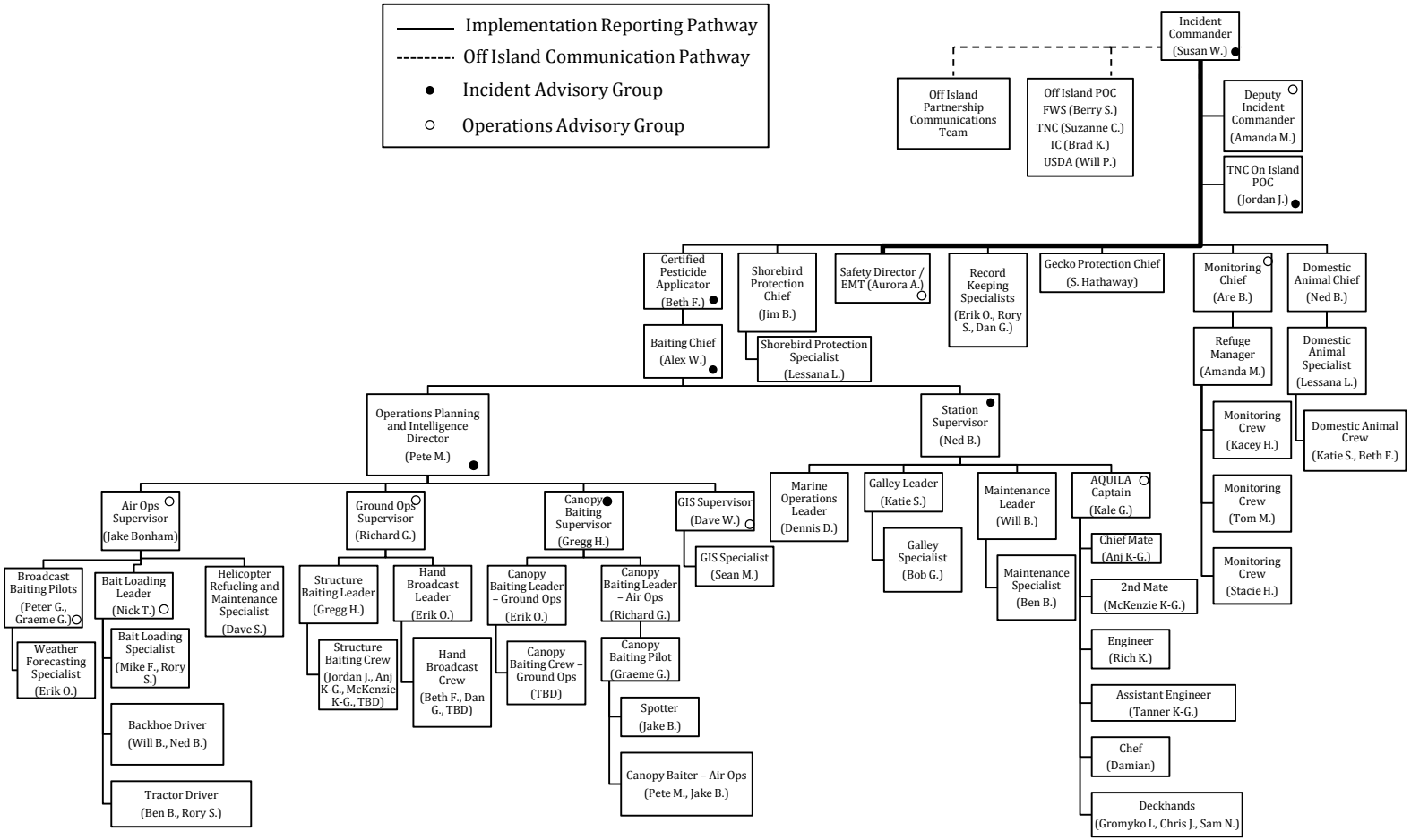

Figure 2. Command structure for the Palmyra rat eradication operations team.

BASE OF OPERATIONS

In 2004, TNC partnered with 10 academic institutions and government agencies in the establishment of the Palmyra Atoll Research Consortium (PARC). In 2005, a research station was constructed on Cooper Island (Figure 3). The station includes 16 small residential cottages, a galley, shower house, bathrooms, a research laboratory, a wharf for offloading supplies from large ships and barges, tractors (with forks) and flat-bed trucks, a backhoe, three 15' lagoon boats, a 25' offshore boat, and a large workshop area. The station is capable of housing and supporting 25 staff and researchers at one time. Fresh water is supplied through a refurbished 100,000-gallon rainwater catchment tank. Electric power is generated and transmitted by two 50 kW diesel generators, and a satellite dish was installed in 2006 to supply the station with internet connectivity and web-based telephones. Pre-existing infrastructure in use on Cooper Island includes a seaplane ramp, a crushed-coral runway, and several WWII era concrete foundations and bunkers used for storage of supplies.

The station's air-conditioned dry-lab was used as a command center for the eradication. Helicopter landing pads were constructed on the southwest corner of the wharf, and bait storage and loading zones were established in the center of the wharf area. Sixteen team members were housed in the station and 24 team members birthed and took meals on the R/V AQUILA.

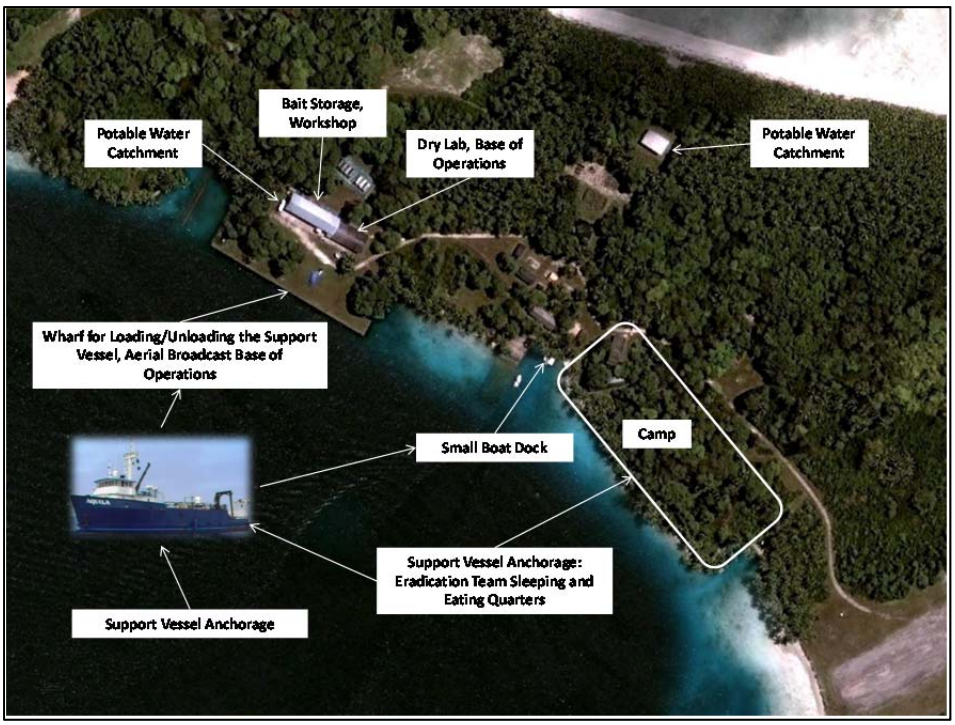

Figure 3. The base of operations for the Palmyra rat eradication project.

VESSEL

The R/V AQUILA, a 165 foot converted crabbing vessel from Seattle, WA, was contracted to transport equipment and supplies to and from Palmyra. The vessel transported all of the bait, equipment, both helicopters, and supplies in 20' and 40' freight containers secured to the deck and in the below-deck holds. Jet-A fuel (12,500 gallons) for the helicopters was transported in a below-deck holding tank. The vessel's captain had previously supported the Rat Island rodent eradication project, and several of the crew had been to Palmyra on previous voyages.

BAIT BUCKETS

Three spreader buckets, designed and built by Helicopters Otago, New Zealand, for the broadcast of pelletized bait were used. Empty weight of each bucket was 128 kg with a maximum internal bait capacity of 318 kg. Spare parts sufficient to rebuild the mechanical components of a bucket were taken to Palmyra.

The bait buckets used during the rat eradication at Palmyra were each calibrated for one of three bait application methods: full swath, directional swath, and narrow swath (Figure 4). During the bucket calibration, bait flow rate and helicopter speed (between 30 and 50 kts) were adjusted to reach the target bait application rates of 37.5 - 40 kg/ha for the Full Swath bucket (with 50% swath overlap to achieve the target application rate of 80 kg/ha), and 75 - 80 kg/ha for the Directional and Narrow Swath buckets. Also, the motor that drives the bucket's spinner was re-geared to produce 40m and 20m swath widths for the full swath and directional swath configurations, respectively. With the spinner removed, we achieved a 5m wide swath with the Narrow Swath bucket.

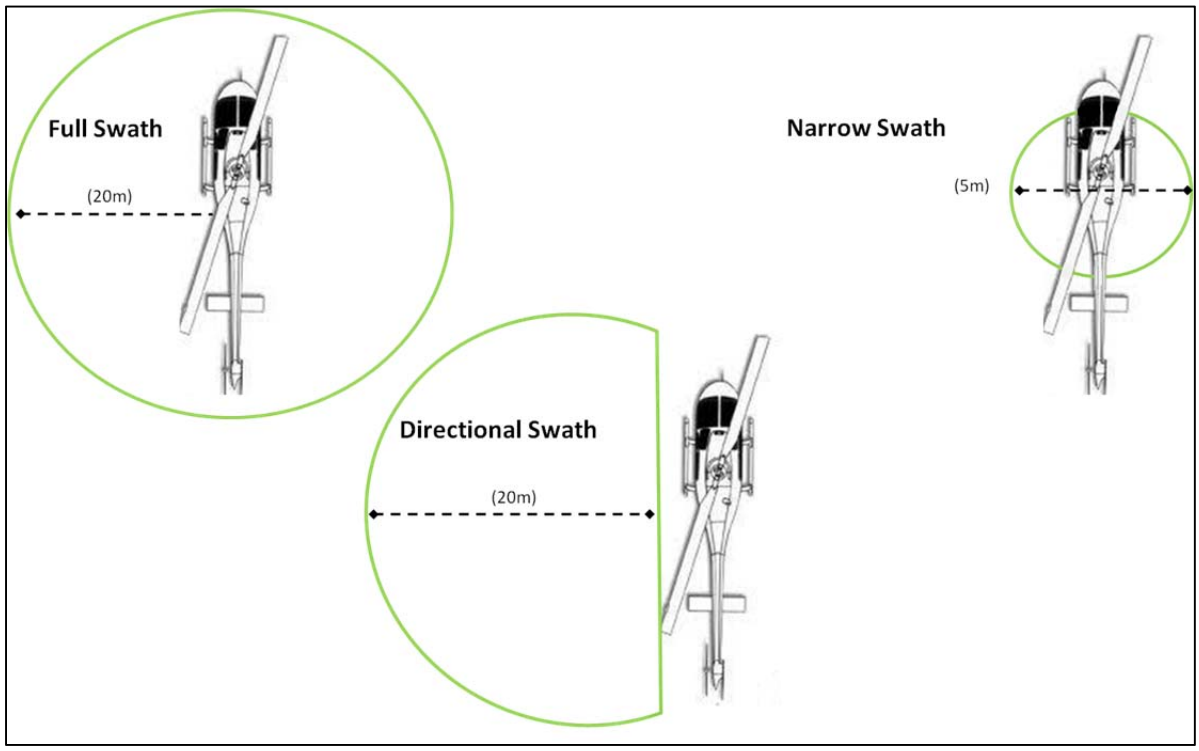

Figure 4. Bait bucket configurations for the Palmyra rat eradication project: full swath (40m), directional swath (20m), and narrow swath (5m).

For the Directional Swath configuration, a deflector was placed inside the aperture that feeds bait to the spinner. The deflector directed the bait flow to one half of the spreader resulting in a directional casting of bait. This configuration was used to treat the shoreline and most of the interior, with the exception of Cooper Island.

For the Narrow Swath configuration, the bait spreader was removed and a cone (point up) was fixed directly beneath the aperture at the bottom of the hopper. This bucket configuration was used to treat land areas that are less than < 40 m and >5 m wide.

Early in the operation, the rate of flow through the buckets proved too great for the original configuration of the Directional Swath bucket. The deflector was redesigned to withstand greater pressure from the flow of bait and we did not experience further problems with the mechanical operation of the buckets.

HELICOPTERS

We used two Bell 206 Jet Ranger III helicopters supplied by Pathfinder Aviation of Homer, Alaska for the aerial application of bait. One machine, N206PA, was owned by Pathfinder Aviation; the second machine, N5754K, was leased by Pathfinder. Total flying time was 59 hours: 34.7 hours for the first bait application, and 24.3 hours for the second application. Flight time is inclusive of reconnaissance flights and bucket calibration.

The pilots; Peter Garden and Graeme Gale, were chosen for this operation because they were both highly skilled baiting pilots with a large amount of experience using the type of aircraft and equipment in place at Palmyra. Both had been involved in previous rodent eradications and had a good understanding of what was involved and the levels of precision and accuracy required.

BAIT SUPPLY, STORAGE, AND TRANSPORT

Following manufacture, the bait used in the operation (25W Conservation brodifacoum bait produced by Bell Labs, Madison WI) was packed and shipped from Madison, Wisconsin to the support vessel in Seattle, Washington. One bulk bag (Flexible Intermediate Bulk Container custom manufactured by BulkLift®) containing 318 kg of bait was laced inside a large plastic bag, and then inside a Buckhorn® Fixed Wall container ("pod"): external dimensions (with lid in place) 47.9" x 43.8" x 31", internal dimensions 45.6" x 42.0" x 23.9". While inside the pod, each bulk bag was filled with 318 kg of bait. A desiccant pack was placed between the bulk bag and the large plastic bag, the plastic bag sealed sealed, and the pod's lid was secured in place. The pods were loaded into shipping containers for transport from Madison to Seattle. One 20' container (16 pods) and one 40' container (36 pods) were loaded directly onto the R/V AQUILA, and 80 pods (shipped in a 53' container) were placed in below-deck holds.

In addition to bait packaged in the bulk bags and pods, of bait was shipped in 20 l buckets, with 11.3 kg of bait in each bucket. Bait from the 20 l buckets was used to hand-bait areas of the atoll that could not be baited via helicopter, and to fill and refill bait stations. The buckets were strapped to pallets for secure transport and placed inside the 53'shipping container. A subset of the bait in 20l buckets was shipped to the IC headquarters in Santa Cruz, California, where personnel manufactured over 8,000 bait bolas for the operation.

MITIGATION OF RISK TO NON-TARGET SPECIES

Team members successfully captured and cared for 13 Bristle-thighed Curlews and 1 Pacific Golden Plover – the operation put both bird species at risk of primary and secondary exposure to the bait. Two curlews were confirmed to have been exposed to bait prior to capture but were successfully treated. All 14 birds were held in captive care and successfully released after bait was no longer available in the environment. Most of the captured birds have been resighted since the operation.

Thirty individuals of two native gecko species (one undescribed) were also captured, cared for, and successfully released. In addition, three domestic animals (one dog and two cats) belonging to TNC were kept in side buildings and away from primary and secondary pathways of exposure to rodenticide.

BAIT APPLICATION

Palmyra's 25 islets were divided into 12 baiting blocks (Figure 5). The boundary of each block represented a practical stopping point if time or conditions did not allow baiting to continue on an adjacent block. This system allowed the Baiting Manager to adaptively manage the baiting effort on an hourly basis, and proved to be an advantageous strategy given Palmyra's challenging environment.

The team applied bait using aerial and hand broadcast, bait stations, and thousands of specially designed canopy baits ("bolas") that were slung into palm crowns from the ground (with slingshots) and from the air by a team member harnessed to the end of a 15 m line attached to a helicopter. Application rates were within 5% of the targeted rate, and below maximum allowable limits (See Table 2). The first aerial bait application took five days to complete and the second required two days. In total, 875 person-hours were logged in addition to 59 hours of helicopter time to accomplish the bait application. Delays and interruptions in bait application were generated by frequent and occasionally heavy showers, mechanical problems with the spreader buckets, bird strike and safety considerations. The interval between first and second applications varied from 6 to 10 days, depending on the baiting block.

Criteria for selecting bait application methods

The following script explains the criteria by which different bait application methods were selected. The script uses the type of treatment area as the primary factor (underlined), and then describes the bait application process through an ordered presentation of the following factors: bait application method (e.g., hand broadcast), sowage rate (e.g., 80 kg/ha) and sowage features (e.g., 5 m swath, 0% overlap), treatment of gaps in the initial application, and exclusions from bait application. The aerial baiting components of this script pertain to the first bait application; for the second bait application, targeted sowage rates changed from 80 kg/ha to 75 kg/ha, and from 40 kg/ha, to 37.5 kg/ha.

1. <u>Land 1 – 10 m wide and the Camp area</u>
    a. Hand broadcast
        i. 80 kg/ha, 5 m swath, 0% swath overlap
            1. Follows aerial treatment of adjacent blocks - occurred within 24 hours of aerial treatment
        ii. Exclusions
            1. Active seabird nests on the ground
                a. 2 m exclusion of bait broadcast around each nest
            2. Water bodies
                a. 1 m exclusion of bait broadcast along the edge of the water body
                b. Exclusion of bait broadcast below the high water line
            3. Inhabited structures
                a. 1 m exclusion of bait broadcast around each inhabited building, no bait broadcast inside inhabited buildings

2. <u>Land > 10 m wide</u>
    a. Aerial broadcast
        i. Land 10 – 25 m wide
            1. Narrow swath bucket

a. 80 kg/ha, 5 m swath, 0% swath overlap

ii. Land > 25 m wide except for Cooper Island
    1. Coast & Interior
        a. Directional swath bucket
            i. 80 kg/ha, 20 m swath, 0% swath overlap
    2. Gaps
        a. Narrow swath bucket
            i. 80 kg/ha, 5 m swath, 0% swath overlap

iii. Cooper Island (Section 2 in Figure 5)
    1. Coast
        a. Directional swath bucket
            i. Outside pass
                1. 80 kg/ha, 20 m swath, 0% swath overlap
            ii. Inside pass
                1. 40 kg/ha, 20 m swath, 0% swath overlap, 50 % overlap with Interior passes - assuming 20 m "throw-forward" at the beginning and end of each Interior line
    2. Interior
        a. Full swath bucket
            i. 40 kg/ha, 40 m swath, 50% swath overlap
    3. Gaps > 5 m wide and 10 m long
        a. 0 kg/h recorded
            i. Narrow swath bucket
                1. 80 kg/ha, 5 m swath, 0% swath overlap
        b. 40 kg/ha recorded
            i. Narrow swath bucket
                1. 40 kg/ha, 5 m swath, 0% swath overlap

iv. Exclusions
    1. Cooper Island Runway
        a. Full swath bucket
            i. 40 kg/ha, 40 m swath along outside edge of runway, 50% overlap starting 20 m out from edge of runway
        b. Directional swath bucket
            i. 40 kg/ha, 20 m swath along the outside edge of the runway, 100% overlap with the 20 m of the full swath described above
    2. Camp
        a. Full swath bucket
            i. 40 kg/ha, 40 m swath centered on the camp exclusion boundary, 50% overlap starting 20 m inside the camp exclusion boundary
                1. 50% overlap with the hand baited area
    3. Inland water bodies
        a. Land 10-25 m wide
            i. Narrow swath bucket
                1. 80 kg/ha, 5 m swath around the edge of the water body
                    a. 1 m exclusion of bait broadcast around the

edge of the water body
4. Land > 25 m wide except Cooper Island
    a. Directional swath bucket
        i. 80 kg/h, 20 m swath along the edge of the water body
            1. Gaps > 5 m wide and 10 m long
                a. Narrow swath bucket
                    i. 80 kg/ha, 5 m swath, 0% overlap
5. Coast
    a. Exclusion of bait broadcast below the high water line

3. <u>Abandoned structure</u>
    a. Hand Broadcast
        i. Up to 200 g of bait broadcast into structures less than 2,500 ft^2, up to 450 g of bait broadcast into structures greater than 2,500 ft^2.

4. <u>Palm crown overhanging water</u>
    a. Canopy bait
        i. Crown overhanging ocean-facing shoreline that is inaccessible by foot
            1. Air
                a. 50 g bait bola dropped into every stand-alone crown, or every 3rd interconnected crown
        ii. Crown overhanging lagoon-facing shoreline
            1. Ground
                a. 50 g bait bola shot into every stand-alone crown, or every 3rd interconnected crown
5. <u>Inhabited structure</u>
    a. Bait Stations
        i. Inside
            1. 1 station for every 19 sq m of building space, 120 g of bait per station
        ii. Outside
            1. 1 station for every 37 sq m of building space, 120 g of bait per station
6. <u>Shorebird roosting islets not treated by broadcast baiting (Rust, Pillbox, Dadu, Curlew)</u>
    a. Bait Stations
        i. 1 - 2 stations per islet, 120 g bait/station
    b. Canopy bait
        i. 50 g bait bolas placed in canopy when bait stations were not practical

Following the discovery of a juvenile rat on July 10 in the camp area on Cooper Island (18 days post the second bait application); bait was applied by hand in the vicinity of the rat detection (Table 2).

Altogether, 43,000 kg of bait was transported to Palmyra; and of that, 38,560 kg was applied. The legal consent for the operation allowed for 47,000 kg of bait to be applied.

Commensal Environment
Food stores, food scraps from the kitchen, and inhabited buildings (buildings in which people work, eat, or sleep) within the PARC station were all factors that complicated the operation. To prevent rats from accessing the food stores, all food storage areas were carefully inspected and secured prior to the operation. Food scraps from the kitchen, typically composted in an open pit, were incinerated or dumped offshore. The legal consent for the bait application did not allow for bait to be broadcast over or within 3 m

of an inhabited structure. To expose rats that had access to, or were living in, inhabited buildings, the team placed 120 bait stations in and around the buildings several weeks before the operation began. Bait was placed in stations on the first day of the bait application and this bait was refreshed every week during the operation. Bait stations were kept active for a two month period – one month after the second bait application.

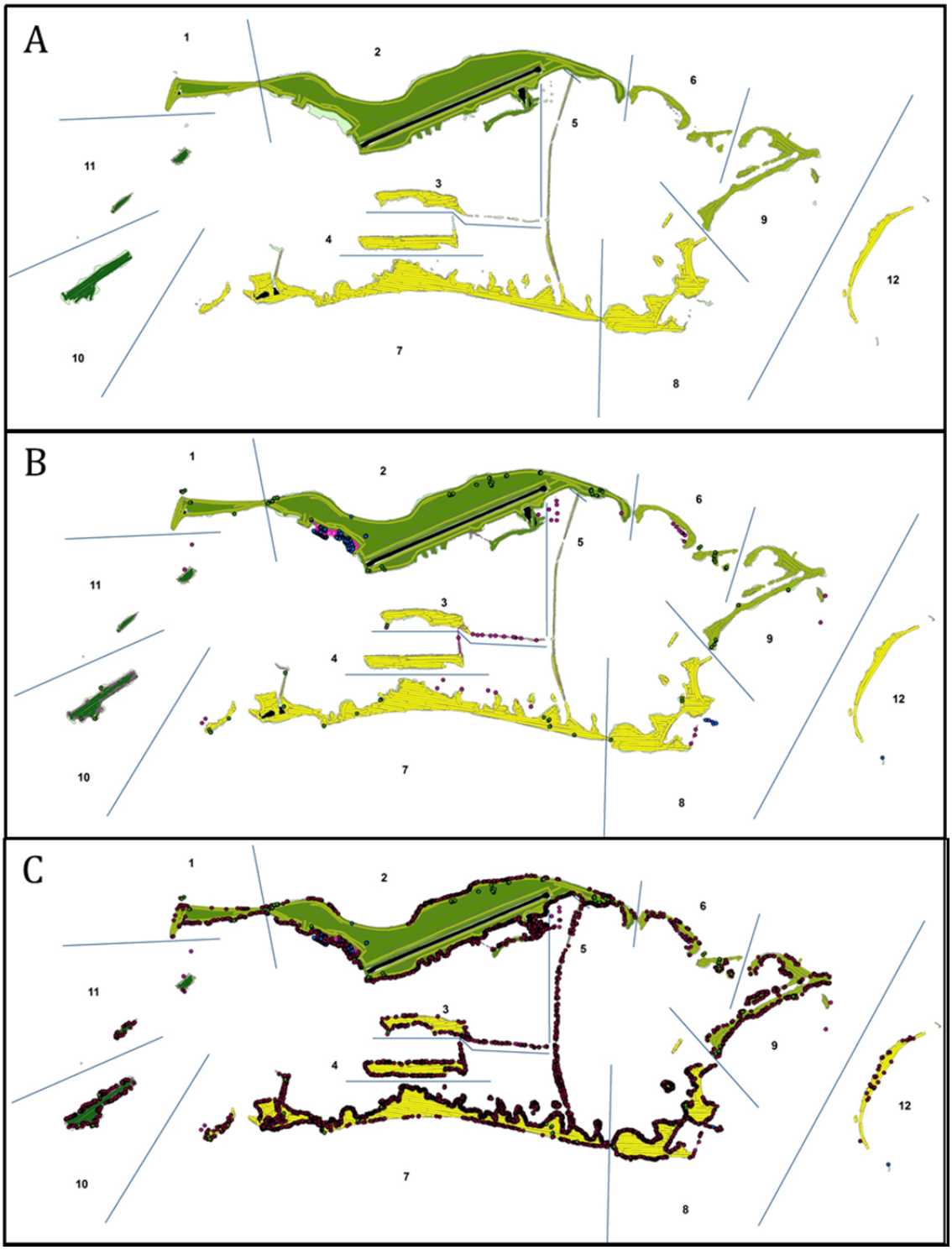

Figure 5. Maps of Palmyra Atoll depicting the second bait application during the Palmyra rat eradication project. Panel A shows bait application by aerial broadcast – areas coloured green were treated on the first day of the application, and areas coloured yellow were treated on the second day. Panel B shows hand broadcast and structure baiting locations (dots) in addition to the aerial treatment. Panel C shows the palm crowns that were treated with bola baits (dots) in addition to aerial broadcast, hand broadcast, and station baiting.

Bait Application Effort

Table 2. A Summary of the bait application methods and application rates employed during the Palmyra Atoll rat eradication project.

BROADCAT BAIT APPLICATION			
	Bait used (kg)	**Area (ha)**	**Ground application rate (kg/ha)**
Application 1			
Aerial	19,344.0		
Hand	379.8		
Total	19,723.8	234.9	84.0 (targeted rate = 80)
Application 2			
Aerial	18,483.0		
Hand	141.0		
Total	18,624.0	234.9	79.3 (targeted rate = 75)
Detection response baiting			
Hand	723.2	10.1	71.6 (targeted rate = 80)
CANOPY BAIT APPLICATION			
	Bait used (kg)	**Palm crowns treated**	**Application rate (g/crown)**
Application 1	72.3	4,185	17.2
Application 2	71.5	4,350	16.4
Detection response baiting	5.1	351.0	14.5
BAIT STATION APPLICATION			
	Bait used (kg)	**Bait recovered (kg)**	**Application rate (g/station)**
Bait Stations	58.7	36.9	120.0
ABANDONED STRUCTURE BAIT APPLICATION			
	Bait used (kg)	**Abandoned structures**	**Application rate (g/structure)**
Application 1	3.3	22	149.7
Application 2	6.9	35	197.4
BAIT TOTALS			
Total initial bait (kg)	43,020.0		
Total bait used (kg)	38,560.6		
Total bait remaining (kg)	4398.3*		

*The 61.1 kg difference between the sum of the total bait used and the total bait remaining, and the total initial bait is most likely attributed to estimation and rounding

CONFIRMATION OF ERADICATION SUCCESS

During the operation, a monitoring team led by the US Department of Agriculture assessed the near-term efficacy of the eradication by following 25 radio-collared rats; all recovered rats were dead (Pitt et al. 2012). Eight weeks after the second bait application, a small team returned to Palmyra to establish rat detection stations throughout the atoll; with 2,560 detection station-nights, the team found no sign of rats. One year after the eradication, a monitoring team returned to Palmyra to re-establish and resample the rat detection stations; rats were not detected.

There is a general perception that the required waiting period for confirming the success of rat eradication projects is two years. The "two-year" convention is based on rat reproductive biology in temperate or subarctic/subantarctic environments where the time for populations of rats to produce a new generation is approximately one year; the relevant metric is the number of new generations rather than the number of years (Broome 2011). In wet tropical environments where rat reproduction can be aseasonal, black rat generation time is approximately 0.3 years (Strecker et al. 1962), which allows for more than three generations within a one year period. By this measure, a failure to detect rats one year after the end of the baiting period (21 June 2011) provided the confidence needed to confirm the success of the Palmyra rat eradication at one year after operation while complying with best practices established by the conservation community.

The results from this detection effort provide sufficient confidence to say that rats have been successfully eradicated from Palmyra. A future incursion; however, remains a serious risk that requires persistent attentiveness and mitigation.

2012 confirmation monitoring effort

Indicator blocks

One year after the rat eradication, a three-person team returned to Palmyra to establish rat detection stations (n = 284) throughout the atoll (Figure 6). Palmyra's land area is fragmented into numerous islands, each of which could harbor a residual population of rats. To maximize the probability of detecting rats, we designed the rat detection effort so that the detection station network included all of the islands. While it can be advantageous to utilize more than one type of detection device while determining whether or not rats are present on islands, we only used indicator blocks (Figure 7). Prior to the eradication, live traps and tracking-tunnels were paired with indicator blocks during rat detection efforts. While the traps and tracking-tunnels were able to detect rats, the probability of detecting rats with these two methods was significantly lower than the probability of detecting rats with indicator blocks (Table 3). By only using indicator blocks, we deployed more detection stations, achieved greater coverage with the detection station network, and refreshed the stations more frequently than we could have if we had incorporated live traps and tracking tunnels into the detection station network. Other detection devices, such as kill-traps (snap-traps), glue boards, and tracking-tiles were considered and found to be ill-suited for Palmyra's land crab-rich environment.

Table 3. A comparison of trap-based and indicator block-based detection of rats at Palmyra Atoll, from 2005 to 2010 (2-tailed, paired t-test, $\alpha = 0.05$).

Rat detection events at Palmyra Atoll	Stations (n)	Paired detection devices	Detection-nights	Rat detection (%)	df	t-value	p-value
2005 eradication trials (Buckelew et al. 2005)	82	Live trap	533.5	29.4 (SD 11.5)	2,988	13.82	< 0.001
		Indicator block	638	74.5 (SD 24.2)			
2010 pre-eradication rat detection (Alifano et al. 2010)	90	Live trap	539.5	30.9 (SD 46.2)	644	-4.55	< 0.001
		Indicator block	510.5	42.7 (SD 49.2)			
	20	Tracking tunnel	72	13.3 (SD 34.2)	74	4.21	< 0.001
		Indicator block	59.5	39.3 (SD 48.8)			

Each detection station consisted of a corrugated plastic indicator block filled with a peanut butter-flavored attractant (Figure 7). After inserting the attractant into the channels of the corrugated plastic detection blocks, the blocks were dried for several hours (typically overnight) before they were deployed. Excess blocks were sealed in plastic bags and stored in freezer for future use. The indicator blocks were nailed to the trunks of trees one to two meters above the ground. When possible, indicator blocks were nailed to coconut palms (*Cocos nucifera*); the crowns of coconut palms are preferred habitat for rats (Howald et al. 2004, Wegmann et al. 2007). Once established, the detection stations were checked and serviced every three days over the twelve-day monitoring period. The incisor marks that rats leave in the plastic shell of the indicator block are readily distinguished from marks left by crabs or other invertebrates (Figure 7).

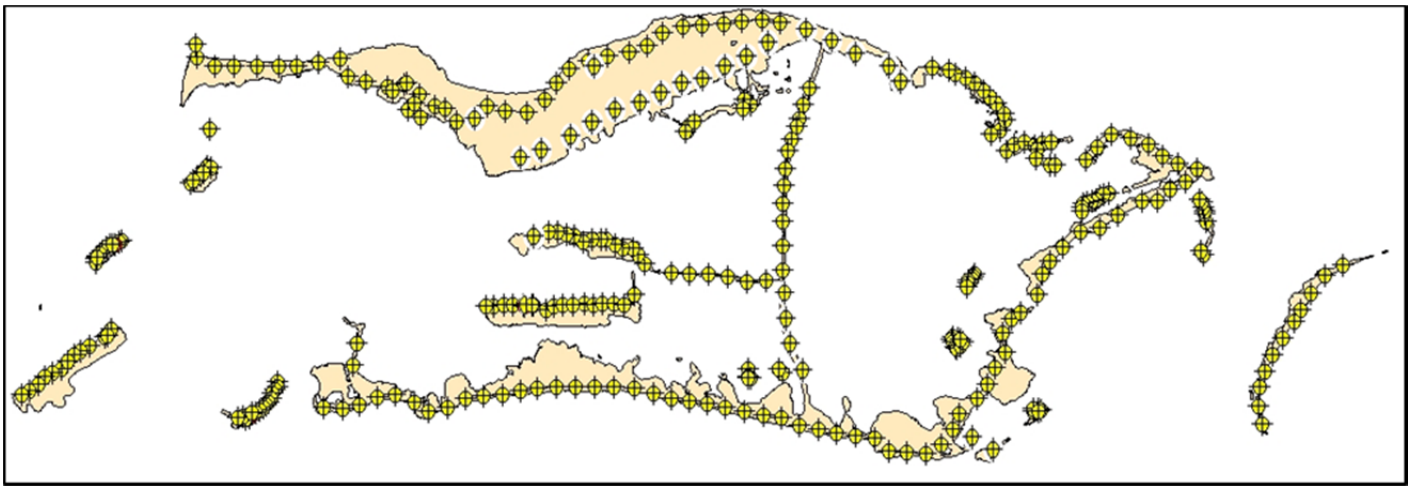

Figure. 6. Rat detection stations placed throughout Palmyra Atoll from 1 -15 July, 2012. Each station contained an indicator block. Each station was checked and serviced every three days over a twelve-day monitoring period.

A three-day monitoring period was allowed for each indicator block. After the three-day period, the condition of each block was noted, and the blocks were replaced. To estimate the scale of the detection effort, blocks that had been relieved of the attractant by invertebrates (ants, crabs, cockroaches) were allotted half of the possible detection-nights (1.5 nights); blocks that retained at least half of the original amount of attractant were allotted all three detection-nights.

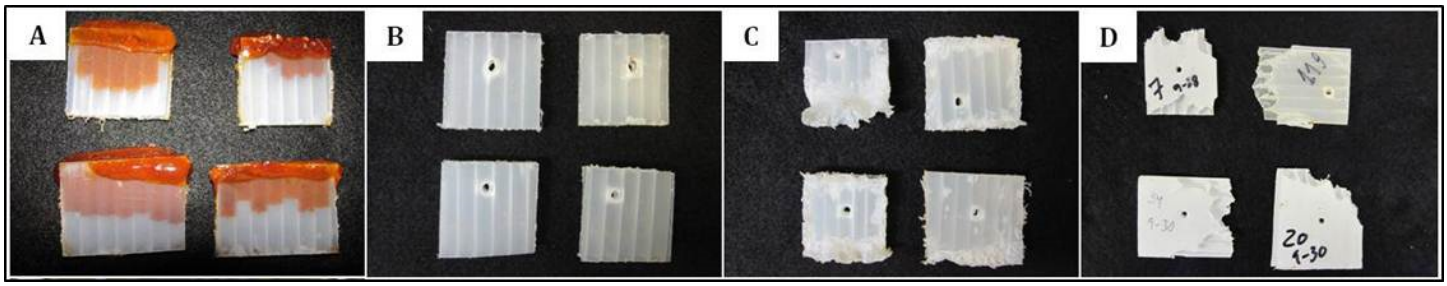

Figure. 7. Rat indicator blocks used to detect rat presence on Palmyra: A) rat indicator block filled with peanut butter candy attractant, B) deployed indicator blocks with the attractant removed by ants, C) deployed indicator blocks with the attractant removed by land crabs, D) deployed indicator blocks with the attracting removed by rats from a pre-eradication rat detection effort (Alifano et al. 2010).

With 284 indicator blocks deployed throughout the atoll, and 2,496 station-nights, rats were not detected (Table 4).

Table 4. Results from pre-eradication (Alifano et al. 2010) and post-eradication rat detection efforts where corrugated-plastic indicator blocks were deployed throughout Palmyra Atoll.

Island	Pre Eradication - September 2010			Post Eradication – July 2012		
	Stations (n)	Block Nights	Blocks chewed by rats (%)	Stations (n)	Block Nights	Block chewed by rats (%)
Ainsley	2	8	38	1	12	0
Barren	10	37.5	29	11	102	0
Bird Island				5	42	0
Bunker	3	8.5	31	2	15	0
Castor				2	12	0
Cooper				59	516	0
Dudley	5	8.5	0	7	72	0
Eastern	12	53.5	66	19	169.5	0
East-West Causeway				5	36	0
Fern				8	69	0
Home	5	39.5	85	10	91.5	0
Leslie	4	22.5	84	9	64.5	0
Little Eastern				6	52.5	0
Lost				17	135	0
North Fighter Strip	9	34	46	17	163.5	0
North-South Causeway	11	68.5	56	2	16.5	0
Paradise Peninsula				7	72	0
Pollux				14	118.5	0
Portsmouth	3	14.5	34	13	118.5	0
Quail	5	39	38	46	396	0
Sand	9	37	62	16	154.5	0
South Island Complex	15	82	62	8	67.5	0
South Fighter Strip	4	9.5	42	1	12	0
Whippoorwill	8	38.5	44	11	102	0
TOTAL	105	501		284	2,496	
MEAN			51			0

Opportunistic rat detection

While traversing the islands, the rat detection team scoured the forest and beaches for sign of rats: rats scurrying out of our way, coconuts and other fruit chewed by rats, fresh husking stations, scat, and rat tracks on sand and in mud. In addition to the indicator block network, all personnel at Palmyra (5-35 people were on the atoll at any given time since the eradication commenced) were aware of the rat eradication project and were vigilant for sign of rats.

Opportunistic searches for sign of rats also found none. The rat detection team logged 99.5 person-hours of searching for sign of rats (this excludes transit time to and from the detection station transects) and traversed a total of 152 km while checking the indicator blocks. The search effort covered an area equivalent to 152 ha, or 65% of Palmyra's emergent land area, assuming that a 10 m wide swath was visible to the observer. Natural indicators of rat presence that were assessed during this search effort were green coconuts chewed by rats, coconut palm inflorescences chewed by rats, and *Pandanus* diaspores chewed by rats. No sign of rats was found with the natural indicators (Table 5).

Table 5. Natural indicators observed during opportunistic search for sign of rats at Palmyra in July, 2012. The pre-eradication measures are from an assessment of rat impacts on the recruitment of species of trees at Palmyra (Wegmann 2009).

Natural indicator	Pre-eradication measure	Post-eradication observations (n)
Green coconuts chewed by rats	1.04/m^2 (n = 275, SD 1.35m^2)	0
Pandanus diaspores chewed by rats	0.4/m^2 (n = 30, SD 0.93m^2)	0
Coconut palms with inflorescences chewed by rats	81% (n = 21, SD 40%)	0

The two UC Santa Cruz personnel engaged in monitoring the response of plant, bird, and invertebrate communities to the removal or rats spent 75 person-hours crisscrossing most of Palmyra's islands; rats were not observed. Ana Guerra, a researcher with Stanford University, accompanied by TNC and USFWS personnel, logged 38 person-hours of opportunistic night-time observation for rats on 12 of Palmyra's 25 islands; rats were not observed

ECOSYSTEM RESPONSE TO THE RAT ERADICATION

The University of California Santa Cruz Coastal Conservation Action Lab (UCSC-CCAL) is monitoring the response of Palmyra's terrestrial ecosystem by comparing measures of seabird, shorebird, and plant populations taken before and after rat removal. In the summer of 2012 they found dramatic increases, including:

- Over 130% increase in native tree seedlings (Palmyra has ten locally rare native tree species), and the first record of *Pisonia* seedlings (no seedlings were observed in 2007 prior to rat removal)
- A 367% increase in arthropods (such as insects, spiders, and crabs)
- No change in Bristle-thighed Curlews found at Palmyra (special care was taken to ensure this imperilled species was not negatively impacted by the rat removal project)

Another round of ecosystem response monitoring is scheduled for 2016, while USFWS, TNC scientists and members of the Palmyra Atoll Research Consortium will directly and indirectly measure response factors for many years to come.

BIOSECURITY

A biosecurity plan was developed specifically for Palmyra to prevent the reintroduction of rodents after the eradication. An additional biosecurity plan was created for the expedition to prevent the R/V AQUILA from transporting rodents and other invasive species to and between the project sites. A biosecurity manager (Nick Torr) was appointed to ensure that all equipment and supplies from the Palmyra project that continued on the vessel for use in the two subsequent projects was cleaned and inspected prior to the departure from Palmyra. To minimize the probability that one or more of Palmyra's 30,000 rats would board the R/V AQUILA before bait the bait application began, and then disembark after bait was no longer readily available, the R/V AQUILA was only tied to the wharf for loading and unloading of supplies.

A subset of the bait stations that were utilized during the operation were kept in place as permanent biosecurity stations. The stations are activated during and for two weeks after a plane lands on the runway or a ship anchors in the lagoon.

CONSISTENCY WITH THE OPERATIONAL PLAN AND LESSONS LEARNED

The following narratives portray aspects of the operation that represent modifications to the Operational Plan. Many of the modifications represent important lessons that may apply to subsequent rat eradication projects.

Helicopter and bait storage

Neither the helicopters nor the bait pods were stored in the shop area, as prescribed in the Operational Plan. The helicopter vender (Pathfinder Aviation) was happy to keep both machines on pads near the edge of the wharf – this made it easy to maintain a consistent landing and zone kept the machines away from the everyday trafficking of vehicles and supplies. To ease the logistics of staging bait, we did not store bait pods in the shop. Cracked lids on pods (cracks were possibly from stacking the pods 4 high in the ship's hold) led to the spoiling of ~ 450 kg of bait when heavy rain pooled water on the lids of pods that were staged in the loading zone. This could have been avoided if we had stored the pods inside the shop.

Timing in between bait applications

The window between the first and second bait application ranged from 6 to 10 days, depending on the baiting block. The team chose to deviate from the 10 to 14 day window specified in the Operational Plan to take advantage of forecasted good weather.

Baiting strategy

The order in which the 12 baiting blocks were treated was altered for the second application so that baiting overages from unavoidable overlap on narrow land masses could be monitored and then absorbed by the largest block – Cooper Island. This strategy allowed the operation to remain within the limits of the legal consent; however, the team accepted some risk of failure by shortening the period between bait applications when rat breeding was known to be occurring.

Measurement of the treatment area

Prior to implementation, Palmyra's emergent land area was reassessed with updated satellite imagery. We measured 235 ha of emergent land in contrast to the previously reported 250 ha; the new, more accurate value was used during the implementation and for reporting purposes.

Record of radio communications

The Operational Plan stated that a record would be kept of all operations-related radio traffic during the eradication in case the team needed to refer to the record to understand a problem or respond to an incident. With 40 personnel and up to 6 different teams working at the same time, radio communications were frequent and often overlapping (on different channels). A record of radio communications was not kept.

Treatment of Sooty Tern nesting sites

Sooty Terns were nesting at the Range Marker site and at the North Fighter Strip site during the implementation. We decided that treatment of these areas by hand, as prescribed in the Operational Plan, would incur an unacceptable risk to the success of the project and would result in the inadvertent take of many eggs. Aerial bait application occurred over both colonies and concurrent and subsequent monitoring found no evidence of egg loss due to falling pellets and minimal disturbance to the colony.

Aerial broadcast over seabird colonies
The broadcast application was complicated by more than 110,000 nesting sooty terns and thousands of red-footed, brown, and masked boobies sharing the airspace. The helicopter pilots remarked that bird densities were greater than anything they had previously experienced. As a result, operational plans were augmented to enhance the safety of aircrew by instructing them on bird behavior, modifying application timing to coincide with lower bird activity, enhancing emergency response capabilities, and slowing flight speed to improve bird avoidance. Project leadership also revised and instituted a precautionary protocol for dealing with suspected bird strikes.

Aerial broadcast over narrow islands (when applying bait into the water is not permitted)
An operational change was also made to authorize the pilots to use their discretion for gauging potential accidental bait drift into the marine environment as well as ensure their safety. The GIS treatment blocks used to direct and document aerial baiting were based on 2010 satellite imagery that could not differentiate between the actual shoreline and dense vegetation overhanging thewater, resulting in the potential to add to accidental bait drift. Pilots were directed to use their best judgment rather than strictly flying by the map when applying bait to coastal areas in order to minimize the amount of bait drift into the marine environment, maximize the evenness of bait spread across the islands, as well as provide an additional safety margin when flying around birds.

Broadcast baiting the commensal area
The camp area was treated by hand-broadcast as described in the Operational Plan; however, the team intentionally avoided applying bait to roads and foot paths so as to minimize the risk of personnel stepping on moist bait pellets and dragging bait stuck to the bottom of shoes into “clean” areas, e.g., the kitchen, the command center, and sleeping quarters. Bait that was accidentally applied to roads and foot paths was quickly collected and reapplied to nearby forested areas.

Baiting the abandoned structures
The Operational Plan stated that the planar areas of all abandoned structures would be measured so that bait could be broadcast into the structures according to the target application rates: 80 kg/ha for the first application and 75 kg/ha for the second. Measuring the structures was deemed an inefficient use of personnel time and the amount of bait applied to each structure was estimated on-site.

Baiting narrow strips of land
The Operational Plan stated that narrow islets and strips of land would be treated by hand to minimize the risk of placing bait in the water. The accuracy of the narrow-swath bucket was better than expected, so we used this tool rather than hand broadcasting to bait most islets and strips of land between 5 – 10 m wide.

Post operations external review
A post-operation audit by an entity outside of the project partnership (FWS, TNC, IC) was not scheduled, even though the Operational Plan called for this. However, IC, EcoOceania, RSPB, and NZ Department of Conservation, conducted a review and debrief of the project sequencing process.

OTHER WORK

Targeted and independent monitoring of the bait application and possible environmental effects from this action was undertaken by the USDA, with FWS and IC assistance, throughout the operation and continued through August. Samples of wildlife (geckos, land and marine crabs, fish, cockroaches, ants), soils, water, and carcasses collected are under-going follow-up analysis by the USDA to provide additional scientific understanding of the movement and fate of the toxicant in the ecosystem to inform future eradication operations.

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