Progress in Restoration of the Aleutian Islands:

Trial Rat Eradication,

Bay of Islands, Adak Island, Alaska 2006

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EXECUTIVE SUMMARY

A trial rat eradication was carried out on five islands (3.0 ha to 15.6 ha in area) in the Bay of Islands, Adak Island, Alaska to test methods of rat removal and to structure future operational and logistical plans for rat eradication in the Aleutian Islands Unit of the Alaska Maritime National Wildlife Refuge (AMNWR). The main objectives of the trial were to:

1. Study rat attraction and susceptibility to the proposed bait (*Brodifacoum 25 Conservation*).
2. Validate the bait application rate.
3. Mimic an aerial application of bait using hand broadcast.
4. Measure baiting efficacy on the rat population.
5. Study the movement of the rodenticide brodifacoum into the ecosystem.
6. Evaluate potential risks to non-target species.

The study demonstrated that an aerial-based rat eradication could provide successful conservation results for islands in the Aleutian archipelago. Rats are attracted to Brodifacoum 25 Conservation bait and prefer it to the natural foods presented in palatability feeding trials. Bait application rates must take into account the higher density of rats in coastal compared to upland areas; over twice the application rate of bait was needed for upland sites (8kg/ha) than for coastal sites (17kg/ha) to ensure all rats had access to bait consistently for four days. Following bait application, radio telemetry, live-trapping, and wax chew blocks all showed no sign of rats following eradication (rats no longer detectable 6, 13, and 20 days following eradication, respectively). However, rat sign was detected on wax chew blocks on one island 19 days post-bait application. This was likely a reinvasion event from a nearby rat-inhabited island that is within rat swimming distance (50 m) from the treated island. During large eradication projects, care must be taken to ensure there are no sources for reinvasion within rat swimming distance (~1 km) of target islands. An artificial seabird nest study showed that potential rat predation decreased from as many as 94% of nests depredated to zero nests depredated following trial eradication. No marine mammals, shorebirds, or seabirds showed effects of poison. The majority (88%) of rat carcasses recovered after the bait application were found underground or in burrows, reducing the probability of secondary poisoning to avian predators or scavengers. Some granivores, namely song sparrows, are at risk of primary bait exposure. However, while some song sparrow mortality was experienced, they persisted on all treated islands following the trial eradication. Release from rat predation may allow these species to quickly recover to pre-eradication levels. It is unlikely bait will enter the marine food chain through fish consumption; fish presented placebo bait rejected it as a food source. Lastly, bait withstood the moist Aleutian climate for longer than required for bait to be effective at complete rat eradication. In concert, these studies suggest that with special consideration for non-target species and acute attention to the possibility for reinvasion, rat

eradications in the Aleutian Islands can be successful using an aerial application of Brodifacoum 25 Conservation bait.

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INTRODUCTION

A trial rat eradication was undertaken on five islands in the Bay of Islands, Adak Island, Alaska in order to assess the feasibility of eradicating Norway rats (*Rattus norvegicus*, hereafter rat) from islands in the Aleutian Island environment using an aerial application of Brodifacoum 25 Conservation. Specific aims of the project include:

1. Study rat attraction and susceptibility to the proposed bait (*Brodifacoum 25 Conservation*).
2. Validate the bait application rate.
3. Mimic an aerial application of bait using hand broadcast.
4. Measure baiting efficacy on the rat population.
5. Study the movement of the rodenticide brodifacoum into the ecosystem.
6. Evaluate potential risks to non-target species.

Trial eradication site selection

Adak Island was selected to perform the trial because: 1) it is representative of the climate and ecosystems of the Aleutian Island archipelago, 2) it has an abundance of small offshore islets suitable for the trial and 3) infrastructure on Adak provides logistical feasibility, with regular flight service from Anchorage and boat access in protected waters from the town of Adak itself. A survey of two potential trial locations, Boot Bay and the Bay of Islands[1] (Fig. 1), was conducted from the USFWS research vessel *M/V Tiglax*. These locations were chosen because of the availability of island replicates ranging from ~2-20 ha in size, and the close proximity of both locations to Adak town for logistical support. During the 5-day survey of the two locations, measures of rat density were obtained to help in site selection, which ultimately was the Bay of Islands.

[1] Camel Cove was visited during the rat surveys; however it was considered inappropriate for the trial due to exposure to prevailing weather and terrain poorly suited for establishing a camp.

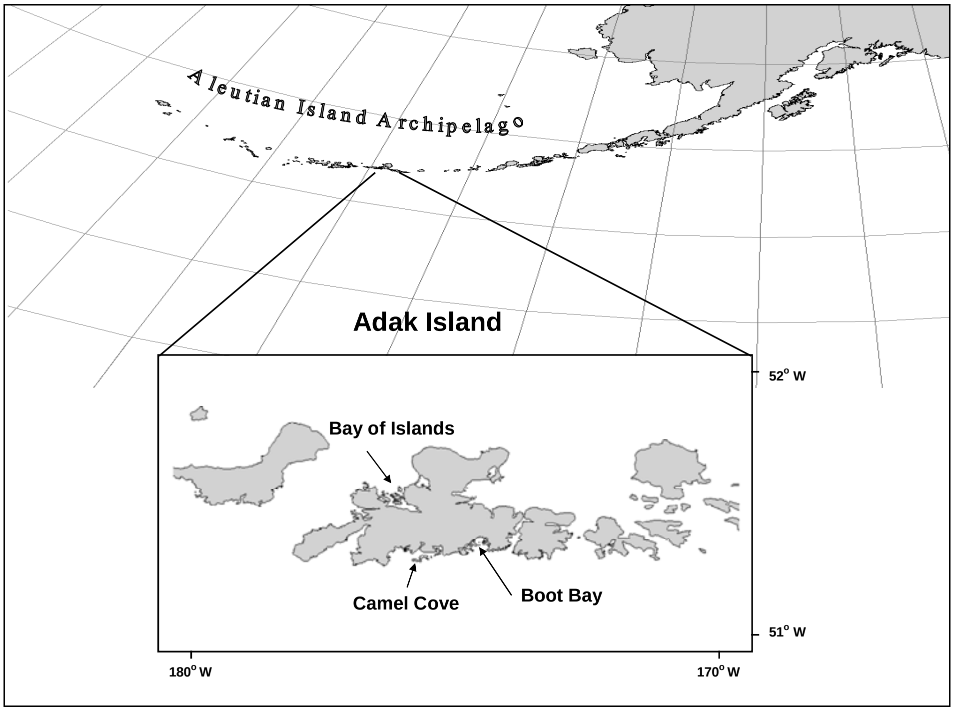

Figure 1. Potential study areas, Adak Island, Alaska Maritime National Wildlife Refuge, Alaska.

Survey methods

Six islands in Boot Bay and four islands in the Bay of Islands, Adak Island, Alaska, were surveyed to index rat densities. Trap stations were used as the measure of rat densities. Trap stations consist of three different indication methods: a live trap, wax chew block, and tracking tunnel, each spaced 1-2m apart. Trap stations (n = 25) were spaced at 15-20 m intervals, depending on topography. Trap stations were monitored for two nights on six islands in Boot Bay on August 23-24, 2006, and on the four islands in the Bay of Islands (Cormorant, Viejo, Sea Parrot, and Hawaii) on August 25-26, 2006. Rat use of trap stations was scored and results compared between the two bays to determine the location where the trial would occur. A priori criteria for selecting the trial location were increased detectability of rat presence in order to maximize the confidence in determining the result of the trial eradication. A single factor ANOVA was used to compare data between the different sites, and independent contrasts were performed using a Tukey post-hoc test. Statistical tests conformed to parameters of normality and homogeneity of variance.

Survey results

Success was greater for trap stations on islands in the Bay of Islands than in Boot Bay ($F_{.05,2,42} = 3.53$, $p = 0.038$). Based on the difference in rat activity between the two locations, the Bay of Islands was selected as the location to conduct the trial rat eradication.

Rat detection for all methods was greater on islands in the Bay of Islands than Boot Bay except for tracking tunnels (Table 1). Of the detection methods used, chew blocks had more positive results than live traps and tracking tunnels ($F_{.05,2,42} = 5.99$, $p = 0.005$).

Table 1. Percent success of trap stations by indicator type (chew blocks, live traps, and tracking tunnels) for two trap sessions in the Bay of Islands and Boot Bay.

Location	#	Chew block	Live trap	Tracking tunnel
Bay of Islands	185	22 %	14 %	< 1 %
Boot Bay	212	2 %	5 %	< 1 %

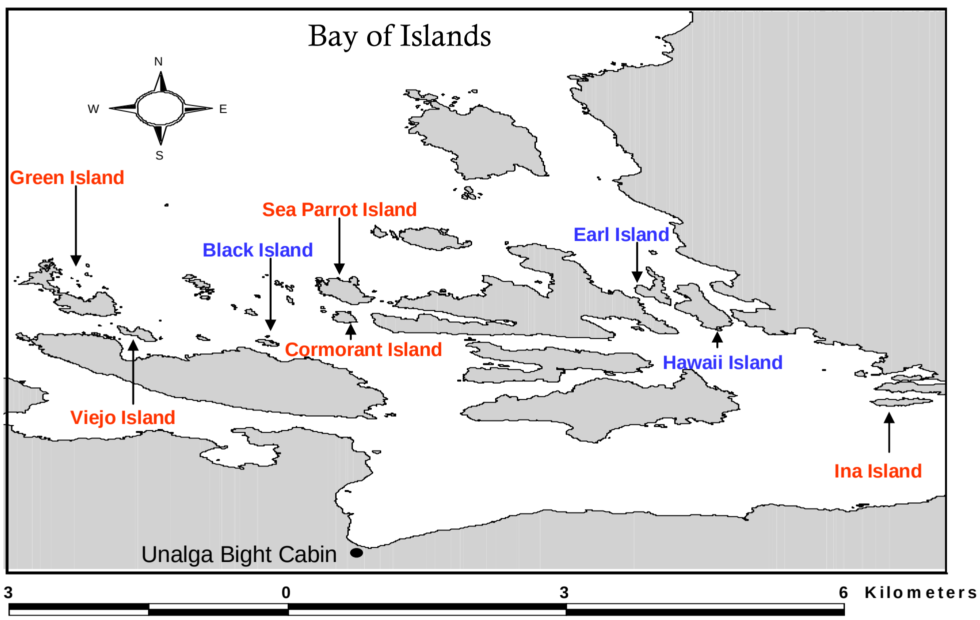

Figure 2. Focal islands in the Bay of Islands, Adak Island, Alaska, 2006. Blue islands are control (untreated) islands; red islands were treated.

Study area

Within the Bay of Islands, we chose the islands of Green (15.6 ha), Sea Parrot (5.6 ha), Cormorant (3.3 ha), Ina (3.2 ha), and Viejo (4.0 ha) to conduct the trial eradication (Fig. 2). The Bay of Islands is a large, sheltered bay forming a portion of the northwestern coastline of Adak Island (Fig. 2). The bay contains approximately 20 islands ranging in size from <1 ha to 150 ha. Islands within the bay lie between 10-500 m offshore from mainland Adak, and are characterized by dense tussocks along the coast and dwarf shrub vegetation covering the interior. The islands exhibit jagged and rocky, volcanic topography, and have high, steep cliffs along the northern portions of most islands due to erosion from prevailing weather.

Pre- bait application studies

The objectives of the pre-bait application phase of the trial were to:

1. Assess attractiveness of the bait to rats compared to available natural foods.
2. Calibrate an effective broadcast application rate (kg/ha) ensuring bait availability for a minimum of four days.

Choice preference trials

Prior to applying active bait to study islands, the attractiveness of the bait to rats was tested in both a laboratory and a field setting.

Methods

Bait palatability was examined using paired feeding preference trials against natural food sources common in the Aleutian archipelago. The trials compared fresh samples of the conservation bait Brodifacoum 25 Conservation (Bell Laboratories, Madison, WI; active ingredient: brodifacoum) against three alternative food sources: 1) Ramik Green (Hacco Inc, Randolph, WI; active ingredient: diphacinone), a competing conservation bait; 2) abundant food sources known to be common in rat diet; and 3) Brodifacoum 25 Conservation bait that had been exposed to ambient environmental conditions ("weathered") for 10 days.

Feeding preference trials consisted of multiple choice trials in which replicates of identical paired food choices were tested on individual rats. The paired choice tests were as follows:

1. Fresh Brodifacoum 25 Conservation bait vs. fresh alternate bait matrix (Ramik Green)
2. Fresh Brodifacoum 25 Conservation bait vs. weathered Brodifacoum Conservation 25 bait
3. Fresh Brodifacoum 25 Conservation bait vs. natural food source

Natural food sources included:

1. Coastal beach pea leaf material and seeds – *Lathyrus* spp.
2. Coastal vegetation material – *Honckenya peploides*
3. Fresh intertidal mussel (shucked from shell) – *Mytilus edulus*
4. Live intertidal amphipods

Food preference was determined in a field laboratory-based setting. Rats [mean weights: females = 173 ± 56 g (n = 17); males = 183 ± 57 g (n = 12); juveniles = 94 ± 4 g (n = 4)] were live trapped from areas adjacent to the treatment islands in Bay of Islands. Rats were housed in individual cages and maintained in a sheltered location to prevent direct exposure to wind and rain. Each rat was provided dry bedding for warmth, and water was provided ad libitum. Rats were fasted for 24 hours prior to testing. For each choice category, replicates of each food source were run using different individual rats. Two food choices were placed side by side on a small tray in each cage with random placement of food orientation (left or right). Food choice was determined when a rat completely consumed one or the other prey item. Observations continued to determine whether rats consumed only one food or eventually consumed the alternate food as well. Observations were made from a distance of 3-5 m to minimize disturbance. For each test the start time and time elapsed between presentation and food selection were recorded. Results of the feeding trials were compared using a Pearson chi-square analysis to determine the preferred food choice.

Results

Brodifacoum 25 Conservation was chosen significantly more often than natural food choices ($\chi^2_{2.05,1} = 304.0$, $p < 0.001$) (Table 2). However, Ramik Green was preferred over fresh Brodifacoum 25 Conservation during the trials ($\chi^2_{2.05,1} = 8.0$, $p = 0.05$).   Weathered Brodifacoum 25 Conservation bait was the first food choice selected in 60% of the trials against fresh Brodifacoum 25 Conservation. In all of the feeding trials when fresh Brodifacoum 25 Conservation was not the first food choice, 71% of the rats switched to fresh Brodifacoum 25 Conservation within 30 minutes of presentation.

Discussion

Brodifacoum 25 Conservation bait appears to be acceptable and palatable to rats, in both fresh and weathered condition. These results suggest that conservation bait will be readily consumed even when natural food sources are present. Although the competing conservation bait, Ramik Green, was initially selected more frequently than Brodifacoum 25 Conservation bait, diphacinone, the active ingredient in Ramik Green may not be effective in complete eradication in the Aleutian environment.   Diphacinone efficacy has not been proven internationally for eradication purposes (it has no track record in eradications; Howald et al. in press), it is a multi feed anticoagulant requiring rats to feed on the bait for up to one week before succumbing to symptoms of exposure, and the results from previous trials in the Bay of Islands were equivocal (AMNWR). On this basis, Brodifacoum 25 Conservation was selected for the trial eradication.

Table 2. Results from paired food preference trials indicating percent first choice for all rats. Second row results indicate the percent selection if trial rats switch food choice consumption from the first choice.

Fresh Brodifacoum 25 Conservation Versus:	% Brodifacoum 25 Conservation	% Competing Food
Honckenya (n = 5)	100	0
Second choice	-	-
Lathyrus (n = 5)	100	0
Second choice	-	-
Mussel (n = 5)	80	20
Second choice	100	0
Weathered bait (n = 5)	40	60
Second choice	100	0
Ramik Green (n = 5)	40	60
Second choice	100	0
Amphipod (n = 3)	100	0
Second choice	-	-

Validation of application rate

The amount of bait applied to islands, measured in kg/ha, must be sufficient to provide every individual rat present on an island access to bait for a sufficient time to ensure that it encounters and consumes a lethal dose of rodenticide. Rat eradications can fail from insufficient bait application (Howald et al. 2004). Conversely, while high application rates will ensure enough bait for all rats on the island, excessive bait on the ground for long periods will leave non-target species with an unnecessarily high risk of primary exposure. A bait application rate that is sufficient to deliver bait to all rats for a minimum of four days, but not substantially longer, should limit the risk of primary exposure to non-target species while maximizing the chances of successful eradication.

Methods

An appropriate application rate was calculated on a control island using a non-toxic, placebo bait replica of Brodifacoum 25 Conservation bait. Placebo bait was broadcast by hand at a rate of 24 kg/ha – deliberately in excess of a reasonable consumption rate given the local conditions – to Earl Island (~5 ha). Bait was systematically applied at 10 m (Fig. 3) to obtain the target density (24 kg/ha).

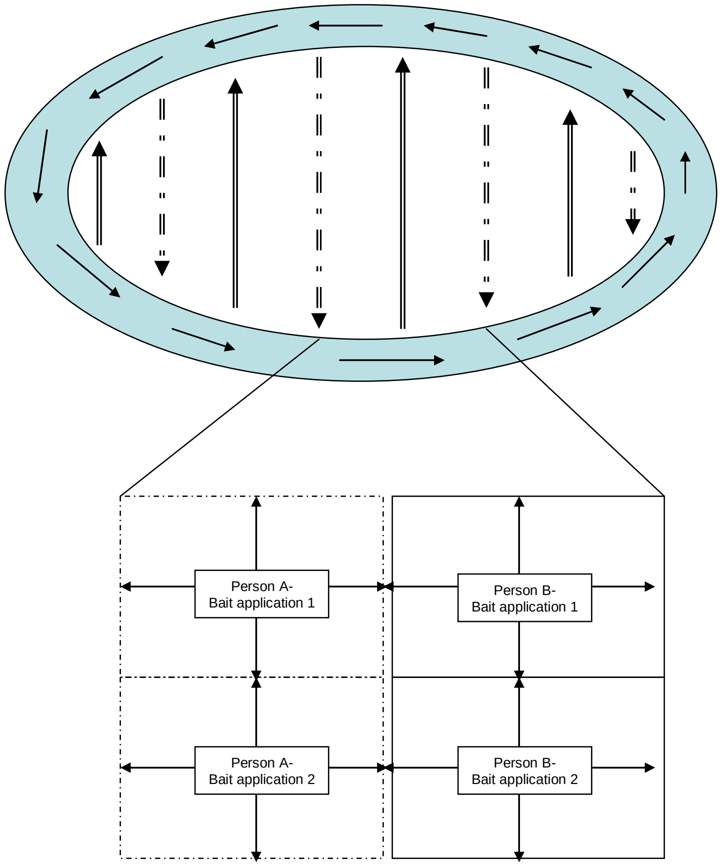

Figure 3. Hand broadcast methods during the placebo and active bait application. The oval depicts the study island where bait was applied longitudinally in alternate directions by an application team. Arrows around perimeter are direction of travel for bait application along coastline. Members of the application team (Person A and Person B) were spaced 10 m apart, bait was applied in all four directions from each applicator at each application point.

After application, bait uptake was monitored for four days within 30, 25 m^2 plots. Bait pellets within these plots were placed by hand and marked with a wire stake flag (Fig. 4). During each visit, each bait pellet that disappeared overnight was tallied and its flag removed. The number of pellets consumed from each plot was converted to kg/ha by multiplying the number of missing pellets by mean weight of dry pellets, then dividing that product by the area of the plot (in ha or acres). The upper 99.9% confidence limit of bait consumption was used as the effective target application rate for the active bait application. Bait uptake was measured in both coastal and upland habitats because of the disparity of rat activity indices, suggesting a preference for the coastal fringe habitat on Aleutian Islands (Witmer 2005; A. Sowls, pers. comm.). A two-tailed, two sample t-test (α = 0.05) was used to compare bait consumption between coastal and upland habitats. Statistical tests conformed to parameters of normal distribution and homogeneity of variance. A significant difference in bait consumption between habitat types would suggest that bait application should be stratified across island habitat types to maximize bait availability without unnecessarily overexposing non-target species.

Figure 4. Bait uptake plots monitored for bait persistence in the Bay of Islands, Adak Island, Alaska.

Results of bait application calibration

Results from the bait uptake plots indicated that bait consumption differed significantly between coastal and upland habitats over four days ($t_{.05,28} = 2.197$, $p = 0.007$) (Fig. 5). Bait consumption was greatest in coastal plots where rats were known to concentrate their activities.

Discussion

Application of active bait should be stratified across habitat types to target areas of higher rat density and reduce exposure to non-target species in low rat density habitats. Using the upper 99.9% confidence limit of bait consumption over the entire island, an island wide bait application rate of 12.1 kg/ha was estimated to be effective in providing bait to all rat territories for a minimum of four days. Stratifying application across upland and coastal sites resulted in an application rate of 8 kg/ha in upland sites and 17 kg/ha in coastal areas (Table 3).

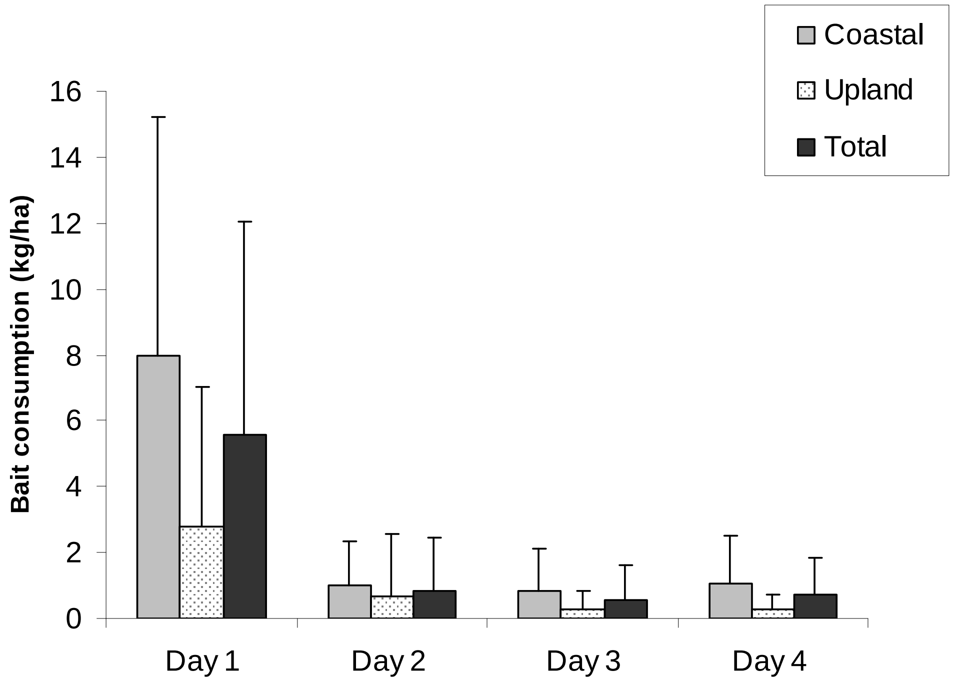

Figure 5. Consumption of placebo PI25 bait measured over four days in 25 m^2 plots (n = 30). Consumption was differentiated between coastal and upland habitat types. Bay of Islands, Adak Island, Alaska, 2006.

Table 3. Mean bait consumption, variance, and upper limit (α = 0.001) measured over four days in 25 m^2 plots (n = 30). Consumption was differentiated between coastal and upland habitat types to determine an effective, stratified application rate.

	Coastal	Upland	**Cumulative average**
Mean consumption (kg/ha)	10.9 ± 7.4 (n = 16)	4.0 ± 4.5 (n = 14)	**7.7 ± 7.2 (n = 30)**
99.9 % confidence limit (kg/ha)	6.1	4.5	**4.3**
Calibrated application rate	17.0 kg/ha	8.5 kg/ha	**12.1 kg/ha**

TRIAL ERADICATION

Trial bait formulation

A grain-based bait containing the rodenticide brodifacoum (currently named Brodifacoum 25 Conservation) was formulated by Bell Laboratories, Inc. to withstand the moist weather conditions of the Aleutian archipelago. The newly formulated bait is a 1/2” diameter, blue colored, highly compressed grain pellet (mean weight: 2.4 g) and is designed to be broadcast from a hopper suspended under a helicopter. Prior to the trial eradication the concentration of brodifacoum in the bait was validated by High Performance Liquid Chromatography (HPLC) analysis in an approved laboratory.

Bait application

Beginning September 17, 2006, bait was applied at the target application rate of 12.1 kg/ha as calculated above, and stratified by habitat type (coastal: 17 kg/ha and upland: 8 kg/ha). Bait was applied by hand to mimic an aerial application, and was applied to a total emergent land area of 31.65 ha. Bait was first applied at a uniform rate across the entire island, followed by a second application along the coastal fringe habitat to achieve the desired bait stratified application. Bait was applied to the following study islands (Table 4):

Table 4. Schedule of active bait application to treatment islands.

Island name	Island size (*ha*)	Date of Application
Viejo*	4.0	9/17/2006
Ina	3.2	9/18/2006
Sea Parrot	5.6	9/19/2006
Cormorant	3.3	9/19/2006
Green	15.6	9 /21/2006 & 9/22/2006

*-the island called “Viejo” was the one called “Camouflage” by Dunlevy et. al

Bait was systematically applied to islands using two bait application teams of 2-6 persons each, one for coastal habitat and another for upland habitat. The boundary between coastal and upland habitat was marked using wire stake flags before bait was applied to the islands. The habitat boundary was determined either by the distance from shore (~25 m), or on high coastal bluffs, the differentiation between coastal rye grass and upland, dwarf shrub vegetation.

For the upland application, individuals walked in parallel transects 10 m apart with an additional team member directing movement and spacing of the bait applicators. Bait was systematically applied at 10 m intervals, in all four directions (i.e. front, back, lateral right, lateral left) to achieve the appropriate density (8 kg/ha) (Fig. 3). Each member applied bait until the coastal/upland habitat boundary was reached.

The coastal bait application team consisted of 2-4 persons applying bait in pairs. Beginning ~5-7 m above the mean high tide watermark, coastal applicators were spaced 10 m apart. Bait was systematically applied at the appropriate density in all four directions at 10 m intervals. Bait was first applied to the coastal fringe at the upland application rate (8 kg/ha) and then at 9 kg/ha to achieve the desired stratified application.

Prior to broadcasting bait on islands 40 pellets (~100 g) were collected from each 10 kg bucket, to confirm the bait formulation. Samples were pooled and homogenized for HPLC analysis in an approved laboratory.

The total mass (kg) of bait applied to each treatment island (based on the target bait application rate) was extrapolated from measured island area sizes. Island area was measured using geographically-referenced satellite imagery. The outermost perimeter of islands was delineated above the mean high tide water line. The net nominal application rate for all islands was found to be 12.56 kg/ha, 0.46 kg/ha over the target application rate. This net application rate was calculated as the total weight of bait applied per island (kg) divided by the surface area (ha).

Field efficacy of Brodifacoum 25 Conservation on rats

The rat populations on treatment islands were actively monitored throughout the trial eradication to evaluate the efficacy of the eradication. Monitoring methods included: 1) live trapping, 2) radio telemetry, and 3) wax chew blocks. Tracking tunnels were not used because of the poor detection rate measured prior to the trial eradication. We used a Before-After / Control-Impact (BACI) study design where indicators were run before and after the bait application and compared to an untreated location as a reference for what the likelihood of rat detection would be. The live traps and chew blocks were grouped at stations established on transect lines as described below.

Radio telemetry

Methods

A subset of rats from each treatment island were fitted with radio collars prior to the application of bait on islands and monitored until rats were found dead as a measure of eradication efficacy. Five to 20 days before bait broadcast, 54 rats (weighing >115 g) were chosen randomly from live traps, anesthetized with isoflourane and fitted with a radio collar programmed to a unique frequency (165-166 mHz; Advanced Telemetry Systems, Isanti, MN). The sex, age class, reproductive condition, and weight of each collared rat were recorded.

Directional Yagi antennas (AF Antronics, Urbana, IL, 164-168 mHz) and digital receivers (Wildlife Track, Caldwell, ID, model WTI-1000) were used to track collared individuals daily (whenever possible) prior to baiting to confirm that rats were alive and mobile. During each tracking session the location of each rat was determined and marked with a Global Positioning System (Garmin, 76 model series). The activity of each rat (moving beneath vegetation, active or inactive in burrow, no radio contact) was recorded at each session.

Inactive rats (no movement for >3 days) or those with no contact (collar failure) prior to bait application were excluded from final analyses.

Rats were tracked until the fate of each collared rat was determined following the bait application. The condition of the rat carcass, location of recovery (in burrow, beneath vegetation, or exposed above ground), and the time since application were recorded. Two radio-collared rats per island (total = 10) were collected and frozen for submission to an approved laboratory for brodifacoum residue analysis. All remaining collared rats were necropsied for symptoms of anticoagulant poisoning.

Results

Following the bait application, all radio-collared rats (n = 44) were recovered dead; all showing symptoms of anticoagulant poisoning. Ten radio-collars failed before the bait application (no signal) and were eliminated from final analysis.

Individual radio-collared rats were located an average of 4.4 (± 0.7) times before bait application. Following the bait application, all rats with functioning radio collars were recovered dead within six days of bait dispersal (Table 5). Eighty-eight percent of the radio collared rats were recovered from burrows below ground while the remaining 12% were recovered in an open, exposed location.

A total of 10 radio collared rats were collected and frozen to be submitted for brodifacoum residue analysis. Radio collared rat carcasses not submitted for brodifacoum residue analysis (n = 34) all displayed symptoms of rodenticide exposure except for two, which, based on their decomposed condition most likely either succumbed quickly to poisoning after the application or from unknown causes prior to the bait application. Of the radio-collared rats necropsied, 28 (73.5%) showed symptoms of external bleeding, 23 (67.76%) showed internal hemorrhaging, and 18 (41.2%) contained bait pellet remnants in the gut.

Discussion

The recovery patterns of radio collared rats parallel observations in similar studies (Buckelew et al. 2005; Howald et al. 2004; Howald et al. 1999) (Table 6). The results suggest that all radio collared rats were active before bait application and consumed enough bait following exposure to induce a lethal toxic effect. The large proportion of rats that died beneath the ground reduces the probability of secondary poisoning by avian scavengers, such as ravens and eagles.

Table 5. Number of collared rats, islands, tracking days and day of recovery post bait application, Bay of Islands, Adak, Alaska, September 2006.

Island	# Collared rats	Mean # times tracked $\pm$ *sd*	Day recovery (post-application) $\pm$ *sd*
Cormorant	5	4.9 $\pm$ 2.9	4.5 $\pm$ 0.6
Green	4	3.8 $\pm$ 1.8	6.8 $\pm$ 1.5
Ina	12	4.0 $\pm$ 0.9	4.9 $\pm$ 0.7
Sea Parrot	12	4.1 $\pm$ 1.5	5.4 $\pm$ 1.1
Viejo	11	5.4 $\pm$ 2.4	5.0 $\pm$ 0.0

Table 6. Recovery location of dead, radio collared rats (n = 44) on treated islands. Recovery locations were designated as: exposed (on top of vegetation or rock with no surface coverage); beneath vegetation (entire carcass obscured by vegetation coverage); and in burrow (located in burrow beneath the vegetation or soil surface line), Bay of Islands, Adak, Alaska, September 2006.

		# recovered	
Island	**Exposed**	**Beneath vegetation**	**In burrow**
Cormorant	0	1	4
Green	0	3	1
Ina	1	2	9
Sea Parrot	4	3	5
Viejo	0	3	8
Total	***5 (12%)***	***12 (28%)***	***27 (60%)***

Live trapping

Methods

Two, three-night live trap sessions were conducted on each island prior to and beginning approximately 10 days after bait application. Each trap session was monitored for three nights with two nights between sessions. A trap session consisted of transect lines (n = 3-8 per island) beginning from random start points. Each transect contained 10 trap stations 10-15 m apart. A trap station consisted of a live trap and chew block spaced 1-2 m apart. Rats captured during each trap session were marked using a numbered ear tag, and the weight, sex, age class, and reproductive condition were recorded before release. Tag number and trap location were recorded for all recaptured rats.

Rat live-capture rates before and after bait application on two untreated, control, islands (Earl and Hawaii) were used as a reference to post application trap rates on the treatment islands. The rate of capture on island transect lines before application were compared to capture rates after application using a paired samples t-test ($\alpha = 0.05$). Differences in capture rates between treatment and control islands were measured using a two-tailed, two sample t-test ($\alpha = 0.05$). Statistical tests conformed to parameters of normality and homogeneity of variance.

Results

Trap success ranged from 3% to 37% across all study islands (both control and treatment) prior to the bait application. No difference in trap success was detected between treatment and control islands prior to application ($t_{.05,45} = 0.20$, $p = 0.85$). The age distribution was similar on most islands; all islands except Sea Parrot had a high juvenile to adult ratio (Table 7).

Post-application, trap success on treatment islands was significantly different than on control islands ($t_{.05,45} = 9.18$, $p = 0.00$). No rats were captured on treatment islands after treatment, except on Viejo Island where one male rat was found dead in a trap 13 days after application (Table 8). However, necropsy results showed heavy internal bleeding and the gut contained only bait pellets. There was no difference in the trap success on Earl Island before and after application, while on Hawaii Island, trap success was greater after application.

Discussion

Results from the live trap session indicate that the bait application provided a lethal dose of rodenticide to all rats on treated islands. Therefore the methods used were successful in removing rats from the treated islands.

Table 7. The proportion of rats by age class is displayed for rats captured in live traps on treatment islands (before bait application). In parenthesis the total of rats trapped are shown. Bay of Islands, Adak Island, Alaska, 2006.

ISLET	Rats trapped	% juvenile	% adult
Cormorant	11	64%	36%
Green	6	67%	33%
Viejo	29	66%	34%
Ina	23	48%	52%
Sea Parrot	30	43%	57%

Table 8. The percent trap success prior to and following the application of bait on treatment and control islands (used as a reference). Bay of Islands, Adak Island, Alaska, 2006. Asterisks indicate island which were not treated with bait and used as a reference for rat activity for treated islands.

ISLET	RATS TRAPPED		PERCENT CHANGE	TRAP SUCCESS		PERCENT CHANGE
	Pre-treatment	Post-treatment		Pre-treatment	Post-treatment	
Cormorant	11	0	-100%	12%	0%	-100%
Green	6	0	-100%	3%	0%	-100%
Viejo	29	1	-97%	37%	0%	-100%
Ina	23	0	-100%	25%	0%	-100%
Sea Parrot	30	0	-100%	24%	0%	-100%
Hawaii*	6	28	+367%	13%	41%	+215%
Earl*	7	9	+29%	16%	11%	-31%

Chew blocks

Methods

As a third measure of efficacy, peanut flavored wax blocks were placed at the same stations as live traps. Chew blocks were checked daily during trap sessions and inspected for rat incisor marks. Each chewed block was replaced with a fresh block or marks were removed.

Chew blocks were deployed before and after the bait application on both treated islands and two untreated islands as a reference for rat activity. Pre- and post-application detection rates were compared prior to and following bait application using a paired samples t-test for each treated island (α = 0.05). Additionally, detection rates were compared between treated and untreated islands using a two-tailed, two sample t-test (α = 0.05). Chew block data were log-transformed to conform to the parameters of normality and homogeneity of variance for statistical tests.

Results

Detection rates ranged from ~2-60% on all study islands (both control and treatment) prior to the bait application. Chew block activity on treatment and control islands were not different before application ($t_{.05,45}$ =

.13, p = 0.90). Following application a significant difference in activity was measured between treatment and control islands ($t_{.05,45} = 8.05$, $p = 0.00$), which suggests that the bait was successful in killing rats.

On control islands, there was no difference in activity before and after the bait application. Activity was significantly different following bait application on all treatment islands (Table 9). No rats were detected with chew blocks on treatment islands for at least 18 days post application (Table 9). However, after 19 days, two blocks on the east side of Sea Parrot Island showed signs of rat activity.

Discussion

For the rat chew detected on Sea Parrot Island post-application, the origin of the rats are unknown, possibilities include:

1. Rats reinvaded the island;
2. Young weanling rats (given the size of incisor marks) survived the bait application;
3. The eradication failed.

We believe that rats reinvaded the island. Eradication failure was unlikely in this case because: 1) no rats were detected post-application on any of the other four treated islands, 2) all radio collared rats died from rodenticide exposure, and 3) brodifacoum is transferred from lactating females to young, making weanling survival unlikely. Further, Sea Parrot Island is separated from Dora Island (populated by rats) by a narrow channel interspersed with rocks 2 to 10 m apart. Rats were observed swimming between other islands within the Bay of Islands, and it appears they could easily have crossed from Dora to Sea Parrot Island.

Table 9. Percentage of chew blocks showing signs of rat activity prior to and following bait application on treated and control islands (used as a reference). Bay of Islands, Adak Island, Alaska, 2006. Asterisks indicate islands that were not treated with bait and were used as a reference of rat activity for treated island .

ISLET	# BLOCKS CHEWED		% BLOCKS CHEWED		PERCENT CHANGE
	Pre-treatment	Post-treatment	Pre-treatment	Post-treatment	
Cormorant	68	0	38%	0%	-100%
Green	9	0	2%	0%	-100%
Viejo	111	0	61%	0%	-100%
Ina	93	0	52%	0%	-100%
Sea Parrot	97	4	40%	3%	-93%
Hawaii*	39	46	19%	61%	+221%
Earl*	31	8	31%	10%	-68%

Bait uptake

Methods

The consumption of bait on each treated island was measured using 100 m^2 fixed area plots similar to the 25 m^2 plots described above. Consumption was measured to validate the application rate, and to provide additional measures of bait availability in all rat territories for a four day period on islands with different rat densities and demographic composition.

Five to 10 uptake plots were randomly established the day of bait broadcast. All bait pellets within uptake plots were placed by hand and flagged. The density of pellets with the plots matched the nominal application rate appropriate to its placement, coastal or inland. Bait uptake in each plot as measured at 4, 7, 14, and 21 days post-application. Flags were removed as the pellets were removed.

The mean number of pellets consumed per monitoring interval were calculated and converted to percentage of bait pellets consumed for each island. The 99.9% confidence interval was calculated and the upper limit used to estimate the maximum likelihood of bait consumption after four days.

Results

All plots had bait remaining after four days post-treatment. As expected, bait consumption was higher in coastal areas where rat activity was greatest than upland areas for all treatment islands (Table 11). In coastal plots the maximum bait consumption measured across all the islands was 85% at 21 days post bait application.

Discussion

The results of the bait consumption study suggest that the density of bait applied to islands was sufficient to ensure availability to all rats for a minimum of four days. The data also reinforce the importance of applying bait at the upper range of estimated consumption to ensure that sufficient bait is available in all rat territories.

Table 10. Percent of bait consumed in 100 m^2 uptake plots on treated islands. Consumption rates are shown for coastal and upland plots. Bay of Islands, Adak Island, Alaska, 2006.

	PERCENT OF BAIT CONSUMMED			
ISLET	Coastal plots		Upland plots	
	Mean	Upper 99.9% confidence interval	Mean	Upper 99.9% confidence interval
Cormorant	20.1%	50.4%	2.0%	6.2%
Green	12.4%	36.6%	0.0%	0.0%
Ina	33.3%	65.1%	0.0%	0.0%
Sea Parrot	34.2%	98.2%	0.0%	0.0%
Viejo	22.3%	36.3%	1.6%	3.9%

RAT IMPACT STUDIES

Seabird nest predation by rats

Methods

Seabirds, based on their life history traits, are particularly vulnerable to local extinction from the introduction of invasive species to islands. Burrow and crevice nesting seabirds with small body size and high nest fidelity are susceptible to predation by rats occupying the same habitat (Jones et al. 2005). To demonstrate the predatory effects that rats may pose to breeding seabirds, a manipulative nest predation study was conducted on treatment islands prior to and following the bait broadcast. Rat predation on artificial nests mimicking those of the family Alcidae was quantified to experimentally document the negative impacts of rats.

Prior to the bait application artificial Ancient Murrelet (*Synthliboramphus antiquus*) nests were created on Sea Parrot and Viejo Islands during two spatially and temporally independent nest predation study sessions. Artificial nests were created to mimic natural murrelet nesting habitat under rocks, in crevices, and in burrows handmade in the vegetation. Eighteen nests were created at each study session and left for two nights. Two eggs, a chicken egg to attract predation by scent and a model plasticine egg to detect rat activity from incisor marks, were deployed into each nest. The plasticine eggs were hand shaped (using latex gloves to reduce human scent) to mimic the size and shape of murrelet eggs. Rat predation on artificial nests was identified by incisor marks in the clay, or the disappearance of a plasticine or chicken egg from the nest.

The study was repeated 15-17 days after the bait application in the same locations as the pre-bait application location. A Pearson chi-square statistical analysis was used to compare the rates of nest predation by rats prior to and following bait application.

Results

Nest loss to rat predation ranged from 11-94% (Table 11). Following the bait application, there was complete absence of rat predation on artificial nests for both study sites ($\chi^2 = 57.6$, df = 1, $p < 0.001$; $\chi^2 = 23.2$, df = 1.0, $p < 0.001$, for Sea Parrot and Viejo, respectively).

Discussion

The high rates of rat predation demonstrate that invasive rat impacts to nesting seabirds can be severe. The removal of rats from island ecosystems with extant seabird colonies has potential to provide measurable increases in seabird breeding success on these colonies.

Table 11. The percentage of artificial seabird nest predation by in1vasive rats on Sea Parrot and Viejo Islands prior to and following the application of bait, Bay of Islands, Adak Island Alaska, 2006.

ISLET	STUDY SITE	% NEST PREDATED		% CHANGE
		Pre-treatment	Post-treatment	
Sea Parrot	1	94%	0%	-100%
Sea Parrot	2	79%	0%	-100%
Viejo	1	11%	0%	-100%
Viejo	2	89%	0%	-100%

ECOTOXICOLOGICAL IMPACTS: EVALUATION OF PRIMARY AND SECONDARY EXPOSURE TO NON-TARGET SPECIES

Minimizing the movement of the rodenticide into the environment and its associated impact on non-target species was a consideration in the trial eradication design. However, it was recognized prior to the eradication that there would be some movement of the rodenticide into the environment. Thus, we evaluated the impact to non-target groups and taxa including:

- Threatened or rare species (endemics, and species listed under the Endangered Species Act – the northern sea otter *Enhydra lutris kenyoni* and Steller sea lion *Eumetopias jubatus*)
- Shorebirds (in general)
- Seabirds (in general)
- Land birds (song sparrows *Melospiza melodia*, winter wrens *Troglodytes troglodytes*, and in general)

In addition we monitored exposure pathways by:

- Collecting environmental samples for measuring brodifacoum residues
- Monitoring environmental fate of bait over time

Threatened or rare species

No species present in the study area considered at risk of exposure to the rodenticide were solely endemic to the trial islands, and all species found on the trial islands are abundant throughout the Aleutian chain.

The Steller sea lion is listed under the U.S. Endangered Species Act as endangered in the Aleutians. No pathway of exposure to sea lions was expected during the trial since seal lions are piscivorous and during the application bait was broadcast only to emergent land areas. Further, Steller sea lions were not observed hauled out on the islands in the Bay of Islands.

Special concern was expressed that a potential pathway of exposure may exist for northern sea otters since these animals occur in the Bay of Islands and may have used treatment islands as haul-out locations. We surveyed the shoreline habitat for sea otter activity or any evidence of carcasses as an indicator of exposure risk (see Island Conservation report to the USFWS on monitoring potential northern sea otter risk, 2007).

Shorebirds

Shorebirds are common to the Aleutians Islands but are present in relatively low numbers inside the Bay of Islands. The primary resident species in the Aleutians are Black Oystercatcher (*Haematopus bachmani*) and Rock Sandpiper (*Calidris ptilocnemis*). The species most commonly encountered during the trial was the Black Oystercatcher, which was determined to be at low risk of brodifacoum exposure since it predominantly occurs on offshore rocks >50m from the treatment islets. Therefore, potential impacts to shorebirds could be measured indirectly through carcass search effort along accessible coastline areas of treatment islands.

Seabirds

The Aleutian archipelago provides habitat for 26 species of breeding seabirds (Gibons and Byrd in press). Prior to the trial, seabirds were predicted to be under minimal to no risk for rodenticide exposure since they exist in low numbers in the Bay of Islands and forage exclusively in marine environments. Glaucous-winged Gulls (*Larus glaucescens*) were the most common seabird species encountered on treated islands, but they were observed perched only on rocks offshore from treated islands. Potential impacts to seabirds were indirectly measured through carcass search efforts along accessible coastline areas of treatment islands.

Land birds

The Bay of Islands supports a small assemblage of resident and migratory land birds. The most abundant resident bird species in this area is the song sparrow. Winter wrens and gray-crowned rosy finches (*Leucosticte tephrocotis*), resident species, occur at low densities on a subset of the larger islands in the bay. Lapland longspurs (*Calcarius lapponicus*) are a migratory species occasionally seen on the treatment islands. Additionally common ravens (*Corvus corax*) and bald eagles (*Haliaeetus leucocephalus*) are found widely distributed throughout the bay.

Song sparrows were considered at risk to rodenticide exposure since they are granivorous and occupy the coastal habitat of treatment islands. The presence and abundance of song sparrow and other land birds was monitored on the trial islands prior to and following the bait application to determine both individual- and population-scale impacts from rodenticide exposure. Three different methods were used to determine both individual- and population-level impacts to birds, including:

1. point count surveys,
2. radio telemetry of resident song sparrows, and
3. acoustic recording.

Methods – point count surveys

Land bird point count surveys were conducted on treated and untreated islands prior to and following the bait broadcast to index the impact from rodenticide exposure. Untreated islands were sampled identically to treated islands to serve as a reference for bird activity, particularly since bird densities are known to vary around periods of post-breeding dispersal and seasonal migrations (Emison et al. 1971). Two surveys of standardized point counts surveys (n = 76; PRBO Conservation Science, http://www.prbo.org) were performed on each island prior to and following the bait broadcast on trial islands. Surveys consisted of counts for each species of the number of birds seen or heard in a 50 m radius over a five minute time period by a single observer. On each island, the numbers of individuals + 1 seen in plots were compared for each species prior to and following bait application with paired sample t-tests (α = 0.05). Comparisons of the five treated islands with untreated islands were made using a two-tailed, two sample t-test (α = 0.05). Statistical tests conformed to parameters of normal distribution and homogeneity of variance.

Results –point count surveys

Prior to the bait application, the average number of song sparrows encountered per point count ranged between 1.0-2.0 birds and averaged 1.30 ± 0.68. Following the bait application the mean number of sparrows declined significantly between survey points on each treatment island. There was a non-significant change between survey points for sparrows on all control islands except Black Island (Figs. 6 and 7). Post application sparrow numbers were not significantly different between treated and reference islands after the bait application.

Discussion –point count surveys

Results of the point count surveys suggest that, in part, the decline measured was related to birds migrating off or traveling between islands or was an artifact of inadequate sampling. Clearly, some sparrows were exposed and some succumbed to brodifacoum (see “Carcass searching” and “Radio telemetry” below); however, sparrows were extant and regularly observed on the treated islands post application.

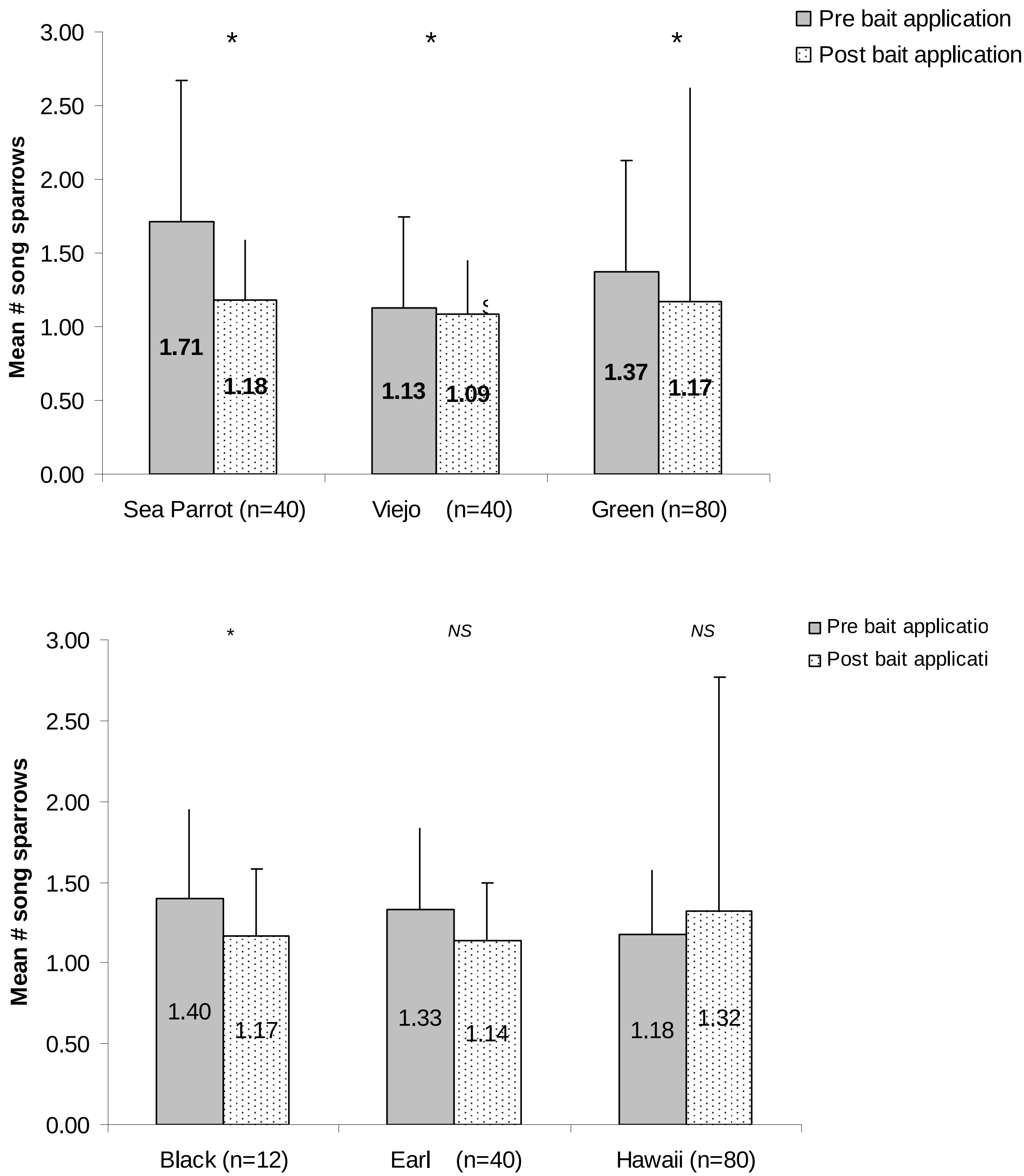

Figure 6. The mean number of song sparrows encountered during point count surveys prior to and following the application of bait. Asterisks indicate significant differences between paired survey points sampled pre and post application. The upper figure shows islands treated with bait and the lower figure shows untreated, control islands. Bay of Islands, Adak Island, Alaska, 2006.

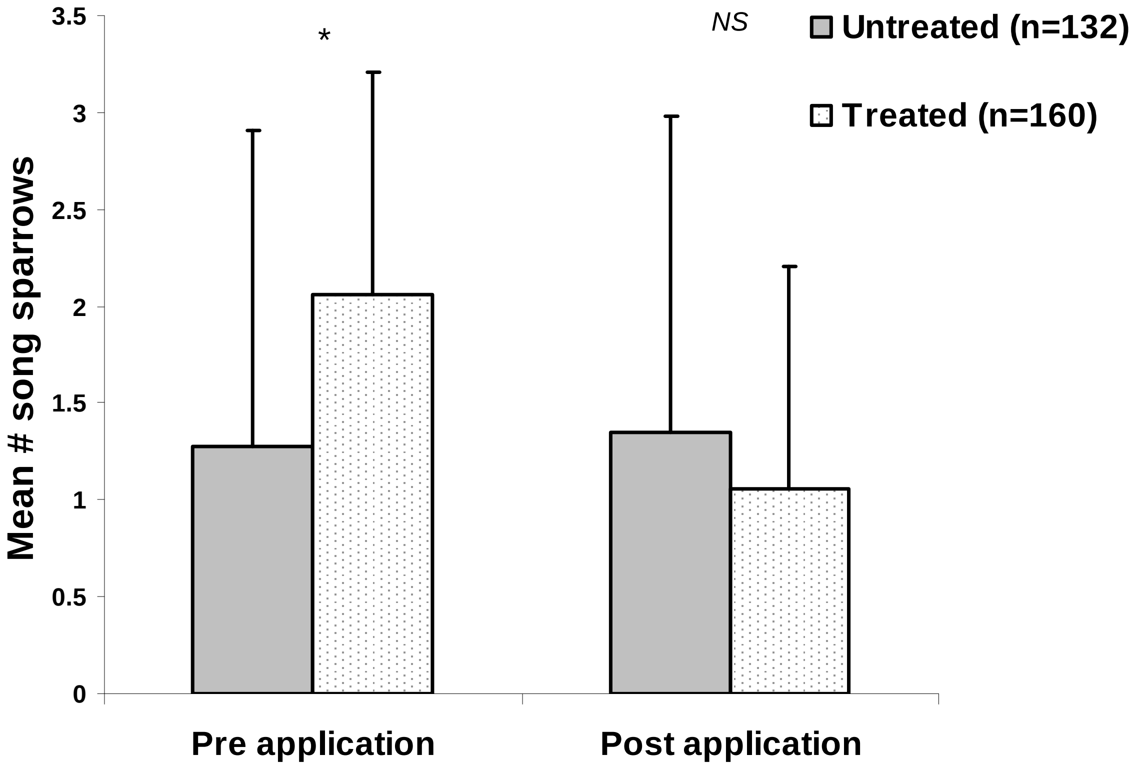

Figure 7. The average number of song sparrows encountered during point count surveys between treated and untreated island groups prior to and following the application of bait, Bay of Islands, Adak Island, Alaska, 2006.

Methods – radio telemetry

Playback vocalizations of song sparrows were used to attract adult birds for capture in mist nests (Avinet, 30 mm mesh, 4-shelf). Five mist nets were located 50 m apart in coastal habitat and monitored for activity at 20-minute intervals. Radio telemetry tags (ATS 167.020-.995 mHz , weight = .75 and .90 g – <3.0% body mass for wrens and sparrows, respectively) were deployed on recently molted adult song sparrows captured prior to the bait broadcast on treatment islands and used to determine the fate of individual birds as a measure of impact of rodenticide application on the island. The transmitter was adhered with superglue to a piece of cheese cloth (8 x 15 mm) and attached directly to the bird's back with a small swab of Skin Bond. Immature or molting birds were banded using a unique three color combination (including USFWS aluminum band, 2231-40101-(142)) and released at their respective capture location. Song sparrows on three treatment islands (Green, Sea Parrot, and Viejo; n = 18, 5, and 5, respectively) were fitted with radio tags beginning 5-20 days prior to the application of bait. The radio tags were monitored daily through the trial period to determine possible direct or indirect impact pathways in relation to rodenticide exposure. Some transmitters (n = 13) either fell off or failed; these were excluded from the analyses.

Directional Yagi antennas (AF Antronics, 164-168 mHz) and digital receivers (Wildlife Track, model WTI-1000) were used to track individuals prior to baiting to confirm movement of the radio signal indicating that the bird was active. Radio tagged birds were radio tracked for a maximum of 21 days post bait application or until fate of the bird (whether dead or radio transmitter recovered) was determined.

For birds recovered dead, the carcass was collected, and individually labeled, bagged and frozen. The birds were submitted for brodifacoum residue analysis. Each individual sparrow had its feathers, legs, and wings removed. The remaining portion of the whole body was then homogenized in a SPEX liquid nitrogen freezer mill. Homogenized sample was placed in a bag, vacuum sealed and frozen (-30 C) until analysis. The analytical procedure for brodifacoum residue used validated methods and was measured by reversed-phase ion-pair HPLC (T.M. Primus, unpublished Method 160A, 2008).

Results – radio telemetry

Following the bait application six (66%) of the marked sparrows were collected dead on treated islands (Table 12). In addition, 16 untagged song sparrows were found dead in carcass searches following treatment. At three weeks post broadcast, when the field camp was removed, four (44%) of the marked sparrows were active and still demonstrating normal, healthy behavior.

All 22 sparrows found dead were analyzed for brodifacoum residues and confirmed to have been exposed to brodifacoum at a mean detection of 0.82 mg/kg (maximum detected 1.33 mg/kg). One Gray-crowned Rosy Finch found dead in a live rat trap on Green Island had no detectable levels (<MLOD) of brodifacoum exposure.

Discussion – radio telemetry

For study birds with transmitters remaining attached, mortality was likely a result of rodenticide exposure as many observations of sparrows picking at bait pellets were made and individual birds collected showed symptoms of anticoagulant exposure. The telemetry results and the point count data taken together suggest that there was an impact to individual sparrows, likely from primary exposure to the rodenticide. However, the impacts did not cause complete extirpation of sparrows on the islands during the monitoring period, and it is likely that sparrow populations will quickly recover from any increased mortality.

We recognize that the sample size was small and problematic due to birds losing transmitters and radio battery failure. It is likely that the high rate of transmitter detachment resulted from a combination of adult post-breeding molt and the persistent wet conditions in the Aleutian environment.

While sparrows were not extirpated from the individual treatment islands, results of the telemetry and point count surveys demonstrate that the use of brodifacoum for rat eradication requires consideration of at-risk land birds and may require mitigation, either through the limiting of potential exposure to individuals or translocation of birds. The longer term consequences of the impact in future eradications should be considered in terms of population dynamics and viability.

Table 12. The individual fate of radio tagged song sparrows on treated islands. Displayed are the number of radio tags with percentages of the total number of transmitters for each island in parentheses: 1) recovered detached from sparrow, 2) on active and healthy sparrows (21-25 days post application), 3) recovered on a dead carcass, 4) with no contact (battery failure), or 5) fate unknown (active signal but location of the tag inaccessible).

Island	*n* transmitters	# detached	# active	# dead	# no contact	# fate unknown
Green	18	8 (44.4)	3 (16.7)	2 (11.1)	4 (22.2)	1 (5.6)
Sea Parrot	5	3 (60.0)	1 (20.0)	0 (0.0)	1 (20.0)	0 (0.0)
Viejo	5	1 (40.0)	0 (2.0)	4 (80.0)	0 (0.0)	0 (0.0)

Methods – acoustic recording

The relative abundance of land birds on treated and untreated islands, with particular emphasis on song sparrows, was compared using recordings of bird vocalizations prior to and following the bait broadcast. Automated recording units (Bioacoustics Lab, Lab of Ornithology, Cornell University) were deployed on three treated and three untreated islands in the Bay of Islands (Fig. 8). Units were programmed to record dawn bird chorus (recording from 0730 to 1130) at randomly selected locations on treated and untreated islands prior to the bait application. To maintain spatial differentiation, recording units were moved to a random location on each island after every fourth recording interval. Beginning one week after the bait broadcast recording units were reset at identical locations (chosen randomly from pre-bait application locations) and moved to the successive, randomly chosen recording location after every fourth recording interval.

Comparisons of bird call rates (number of calls per hour) prior to and following the bait application werecompared between treated and untreated islands to infer impacts from rodenticide exposure using statistical analyses. Acoustic recordings will be post-processed using Raven (1.02) and call rate analysis made using Exbat (1.0), an automated call recognition program software (Bioacoustics Lab, Lab of Ornithology, Cornell University).

Figure 8. Automated recording unit used to acoustically record land bird calls before and after trial eradication in the Bay of Islands, Adak Island, Alaska.

Results –acoustic recording

The results of the acoustical recordings are prepared in a separate report (see Appendix 1), and these findings discussed.

Carcass searching

Methods

To assess the impact of the eradication on individuals of non-target species, formal and informal carcass searches were conducted beginning two days post bait broadcast on each treatment island. Any carcasses (birds, rodents, etc.) encountered during the search were collected and the date and location of mortality (whether above or below ground) were noted. The carcasses of birds were individually bagged, labeled, and frozen, and will be submitted for brodifacoum residue analysis in a laboratory. Rat carcasses encountered were necropsied to confirm rodenticide exposure and then buried > 40 cm beneath the soil surface.

Formal searches were conducted at regularly scheduled intervals of 2, 4, 7, 10, 14 and 21 days post application. Individuals walked the entire coastlines of treated islands and swaths covering the island interiors actively searching for carcasses. Carcasses were also collected during informal searches, conducted opportunistically during other monitoring work.

Results

A total of 221 person hours were spent searching for carcasses across all treated islands (Table 13). No marine mammals were encountered on the shoreline of islands during the surveys. Additionally no shorebirds, seabirds, or other non-target species, with the exception of song sparrows (see above), were observed in a dead or unhealthy condition on the islands.

Discussion

Based on the time spent on each treatment islands following the bait application and the lack of recovery of any non-target species other than song sparrows, marine mammals, shorebirds, and seabirds appeared to experience no direct threat from the application of rodenticide to the island environments.

Table 13. The number of person hours spent conducting carcass searches (both formal and informal) on treated islands and the number of carcasses recovered by species type (*All land bird carcasses encountered were song sparrow).

		Carcasses			
Island	**Person hours**	**Marine mammal**	**Shorebird**	**Seabird**	**Land bird***
Cormorant	30.7	-	-	-	2
Green	65.9	-	-	-	3
Ina	40.5	-	-	-	1
Sea Parrot	38.9	-	-	-	3
Viejo	45.2	-	-	-	6
Total	**221.1**	**0**	**0**	**0**	**15**

ENVIRONMENTAL MONITORING

To assess the movement of brodifacoum into the terrestrial and marine ecosystem we collected environmental samples for brodifacoum residue analysis. The residue data will be used for modeling the risks to non target species, and to measure rates of environmental degradation. Environmental samples were collected post application on all treatment islands and on an adjacent, untreated island (Dora Island, 152 ha) as a reference. Samples were individually bagged and frozen, and were analyzed in an approved laboratory for brodifacoum.

Methods – terrestrial

We collected soil (top 2 cm), predominant vegetation, and freshwater for brodifacoum residues. Soil and vegetation collected were individually bagged into Ziploc bags, labeled and frozen on day of collection. Water samples were collected into chemically-cleaned, glass laboratory jars, sealed, and maintained at ambient environmental temperatures in the field and in the refrigerator on return to the mainland.

Methods – marine

Intertidal sampling

To assess the movement of brodifacoum from the marine environment we collected samples of intertidal mussels (*Mytilus edulis*) 2, 6, 10, and 21 days post broadcast. Mussels are the most abundant and widely distributed bivalve species in the Bay of Islands. Samples were individually wrapped in aluminum foil and placed into Ziploc plastic bags, labeled, and frozen on day of collection. A minimum of 5 mussels were available for each sample day. Mussels were prepared by opening the shell and removing all soft tissue until approximately 10 grams of tissue was available or all mussels were used. Tissue was then homogenized in a SPEX liquid nitrogen freezer mill. Homogenized sample was placed in a bag, vacuum sealed and frozen (-30° C) until analysis. The analytical procedure for brodifacoum residue used validated methods and was measured by reversed-phase ion-pair HPLC (T.M. Primus, unpublished Method 159A, 2008).

Marine sampling

No marine water was collected during the trial as the precision of bait application by hand broadcast eliminated the risk of bait pellets drifting into the ocean. However, during an aerial broadcast application, there is a likelihood of bait drift into the ocean, most notably along steep cliffs and precipices. To evaluate the potential rodenticide exposure to marine fishes, we carried out a study to evaluate fish response to non-toxic placebo bait. Placebo bait pellets were broadcast by hand into the ocean at a comparable application rate to terrestrial application. Snorkelers noted the number and species of fish present in the area and their specific response to the bait pellets (e.g. ignore, swim away, inspection, mouthing, chewing, and rejecting or swallowing bait pellets). Broadcast presentation was repeated three times in each of eight locations (320 observation minutes) throughout the Bay of Islands.

Results

Terrestrial

Only the fresh water samples were analyzed. No brodifacoum was detected in any of the samples from any of the islands treated (Table 14) or the control samples (Dora Island n=5; Green Island n=1 collected day before application; Sea Parrot n=5, collected immediately before bait application)

Table 14. Brodifacoum residues in fresh water samples (n in brackets) collected over time on Green and Sea Parrot Islands, Bay of Islands, Adak, Alaska 2006

Island	Day/Week Post Bait Application Samples Collected			
	2	6	10	3 weeks
Sea Parrot Island	<MLOD (5)	<MLOD (5)	<MLOD (5)	<MLOD (5)
Green Island	<MLOD (5)	<MLOD (5)	<MLOD (5)	<MLOD (5)

Marine

Intertidal Sampling

No brodifacoum was detected in any of the mussel samples (n=26 samples analyzed).

Marine Sampling

We observed 17 kelp greenling and black rockfish in our observation areas. One rockfish mouthed and quickly rejected the presented bait pellet (Table 15). No other fish showed any response to bait pellets falling through the water column or on the ocean floor.

Discussion

The results suggest that there is low risk of fish consuming bait pellets in the Bay of Islands should they enter the marine environment. While these same results may not be achievable for different islands in the Aleutians, observations of fish behavior to the bait pellets were comparable to observations made with nearshore fish in California (Howald et al. 2005) and Hawaii (USFWS 2005). Other efforts could consider the use of equipment allowing for greater time intervals of observation, such as SCUBA, or repeated count surveys to evaluate fish response to bait inadvertently entering the marine environment.

Table 15. Response of coastal fish to the presence of inert bait pellets in the water column, Bay of Islands, Adak Island, Alaska, 2006.

Number of sites	Observation minutes	Bait response		
		# consume/reject	# swim away	# no response
8	320	1	2	14

ENVIRONMENTAL FATE OF BAIT

To understand the process of brodifacoum degradation in the Aleutian environment, a persistence study was conducted and the condition of bait and levels of degradation monitored at short and longer term temporal scales. The rate and characteristics of bait applied during the trial were monitored over time to understand how bait withstands ambient environmental conditions. Additionally, bait was collected at set intervals to be analyzed in an approved laboratory for levels of brodifacoum degradation.

Methods – short term bait persistence

The environmental fate of bait in the Aleutian environment was monitored by actively following unconsumed bait for 41 days post application. Bait pellets were placed under five wire-mesh cages at Unalga Bight but exposed to ambient weather conditions. Cages were placed in each of the two predominant habitat types on the island, coastal and upland, characterized by thick tussock vegetation and dwarf shrub, lichen vegetation, respectively. The integrity of bait was qualitatively described at three-day intervals for the duration of the monitoring period. The color of the bait, consistency, mold and mold color were noted at each visit. A sub-sample of bait pellets were collected from each cage at days 2, 4, 6, 10, 21, 35, and 41 days post application (upon camp departure), and individually bagged, labeled, and frozen. An 8 to 14 gram portion of each bait sample was homogenized with a Spex liquid nitrogen mill. Each sample was analyzed in duplicate The analytical procedure for brodifacoum residue used validated methods and was measured by reversed-phase ion-pair HPLC (T.M. Primus, unpublished Method 145A, 2006). Minimum Level of Detection (MLOD) was reported to be 0.073-0.076 ppm.

Methods – long term bait persistence

The over winter persistence of bait and degradation of brodifacoum was monitored in the Aleutian environment. Specifically, the integrity of bait and rate of degradation was followed through the winter and early spring seasons on Adak Island. Bait cages were deployed in mid-August in a military exclusion zone, following approval by qualified UXO escorts and establishment of a proper access corridor. Bait cages were set in coastal and upland habitats following methods described above. The integrity of bait was qualitatively described at monthly intervals prior to and following snow cover. The color of the bait, consistency, mold and mold color was noted at each visit, in addition to photo documentation and archived. A sub-sample of bait pellets was be collected at the same interval, and individually bagged, labeled, and frozen. An 8 to 14 gram portion of each bait sample was homogenized with a Spex liquid nitrogen mill. Each sample was analyzed in duplicate. The analytical procedure for brodifacoum residue used validated methods and was measured by reversed-phase ion-pair HPLC (T.M. Primus, unpublished Method 145A, 2006). Minimum Level of Detection (MLOD) was reported to be 0.073-0.076 ppm.

Results and discussion

During the short term bait persistence trials, the bait (Brodifacoum 25 Conservation) maintained its integrity in the moist, wet conditions of the Aleutian environment. The characteristics of the bait are such that it readily absorbs moisture and becomes soft when saturated, however, the bait maintained its shape and size through 21 days post application (Table 16). Beginning on Day 9 post application bait pellets began to mold in some plots, and by Day 21 all bait pellets were covered in a layer of thick mold. The molds and microbes are involved in the degradation of the rodenticide to its base components of water and CO_2. On Day 21 post-application bait began to lose its integrity as pellets were starting to crumble and disintegrate. Residues of samples analyzed at Day 2 and Day 21 post placement were reported to be 21.6 (n=5) and 17.0 (n=5) ppm, respectively.

Table 16. Mean number of days (± *sd*) of bait pellet degradation following deployment to ambient environmental conditions.

	Swollen	**Mold**	**Crumble**
Mean day post application	5.2 ± 1.1	12.2 ± 3.5	21 ± 0.0

During the long term bait persistence trials, bait pellets were monitored in the caged enclosures in coastal and upland habitats at 87, 116, 147, 184, 210, and 252 days post placement. In the coastal habitat bait pellets were entirely degraded at Day 87 post placement (Figure 9). At Days 116 through 210 bait enclosures in the upland habitat were entirely concealed by snow. On Day 252 remaining bait pellets in the upland enclosures were colleted and analyzed for brodifacoum residues. Analysis confirmed that if bait pellets are not consumed or degrade over the winter (due to freezing) the few remaining pellets could contain brodifacoum residues. Samples analyzed at Day 252 post placement were reported to be 20.4 ppm (n=2).

Coastal bait cage enclosure # 1 (11/16/06)

Coastal bait cage enclosure # 5 (11/16/06)

Figure 9. Cages containing bait for long term persistence analysis in coastal areas show bait entirely degraded at 87 days post placement.

Over the entire spectrum of bait degradation monitoring, the apparent decrease in concentration of brodfiacoum residues by Day 2 likely reflects the increasing water absorption and subsequent weight of the pellet. However, the apparent further decline and subsequent increase in brodifacoum concentration between Day 21 and 252 is counter to what was reported on Anacapa Island where brodifacoum residues in residual bait pellets declined by >90% over a 6 month period (Howald et al., in prep.). Each bait sample in this analysis was normalized for moisture content and weighed. The weight of the pellets had declined to 1.4 grams at Day 252, or almost 50% of starting weight, suggesting that the inert ingredients degrade relatively quickly while the brodifacoum in the sample degrades more slowly in upland habitats.

CONCLUSIONS

This trial eradication suggests that rat eradication is possible in the Aleutian Islands environment using Brodifacoum Conservation 25 bait. Bait application rate should be stratified according to rat habitat preference; more bait is needed in coastal areas than upland areas. Brodifacoum Conservation 25 was shown to stand up to the wet, harsh environment of the Aleutians, for the time required for lethal exposure. Although some non-target species were impacted, it is likely that for species such as song sparrows, release from rat predation pressure will allow populations to quickly recover to pre-eradication levels. No endangered or threatened species were observed to be affected by trial eradication activities. Resident fish did not eat any bait during this trial, suggesting spillover into the marine food web is unlikely. With careful consideration of non-target species, and provided there is no source of rats within swimming distance of targeted islands, aerial application of Brodifacoum Conservation 25 is an effective conservation tool to eradicate rats from the Aleutian Islands.

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Appendix 1. Results of the acoustical monitoring of land birds.

Acoustic recording of song sparrows (Melospiza melodia) in the Aleutians: Assessing the impacts of rodenticide on island bird species

Jennifer A. Curl

Abstract

A trial eradication of the Norwegian rat (*Rattus norvegicus*) was conducted from August to October 2006 using a pelletized rodenticide. Song sparrow populations were surveyed on both treated and reference islands using both point count and acoustic monitoring techniques to test the impacts of the active ingredient, brodifacoum. The results of this study are three fold: 1) there is a significant difference in the mean abundances of birds during point counts conducted before and after the dispersal of the rodenticide on three treated and one reference island (for treated islands, Green Island $t_{39,0.05}$ =2.35, P = 0.029, for Viejo Island $t_{19,0.05}$= 3.49, P = 0.007, and for Sea Parrot $t_{19, 0.05}$ = 2.60, P = 0.028; and for the reference island, Black Island, $t_{5, 0.05}$= 7.00, P = 0.002); 2) there is not a significant difference between treated and reference islands in the mean difference before and after rodenticide application for both point counts and mean call rates (calculated from acoustic recording sessions); and 3) the use of acoustic recording was statistically a more powerful method than point count surveys at detecting differences in bird abundances before and after brodifacoum application. The overall implication of these findings is that the application of rodenticide during a trial eradication may not have significant population effects on residential song sparrows, which is a species of concern for rat eradication efforts in the Aleutians. The use of acoustic recording is proposed as a conservation tool to improve methods of assessing the non-target impacts on bird species in relation to island eradications.

Introduction

Many native species on oceanic islands lack evolved defenses to predation by introduced species, especially invasive mammals (Brown 1997, Howald et al. 2005). Rats have been introduced to more than 80% of islands globally and have had a particularly detrimental impact on island bird populations (Atkinson 1985). Invasive rats are implicated as one of the main causes of historical bird extinctions, and as one of the main threats to currently endangered bird species (Atkinson 1985, IUCN Red List of Threatened Species, 2006). Rats are especially harmful to land birds and seabirds that nest in rat territories, directly on the ground or in low lying vegetation at lower elevations and along island coastlines (Jones et. al. 2006, Towns et al. 2006).

Islands are especially important for migratory species that travel thousands of miles across open ocean, as they provide small, isolated and essential land masses for resting and breeding (Howald et. al. 2005). The Alaskan Maritime National Wildlife Refuge (AMNWR), which encompasses the 1800 km expanse of the Aleutian Island chain, is habitat for 26 species and more than 10 million migratory seabirds (Byrd et. al. 2005). In addition to seabirds, the Aleutian Islands support numerous species of shorebirds, waterfowl, birds of prey, passerines, marine mammals and invertebrates.

The Norwegian rat (*Rattus norvegicus*) first invaded the Western Aleutians from a shipwrecked fishing vessel in the 1780's. Several other islands in the refuge now have invasive rat populations, mostly due to ship traffic between several islands occupied by U.S. and Japanese naval fleets during World War II (Ebbert and Byrd, 2002). Negative impacts caused by invasive rats in the Aleutians have been well documented, especially those on seabirds (Witmer et.al. 2006, Ebbert and Byrd, 2002, Major 2004). Seabirds reported to be negatively effected by rats include storm petrels, Cassin's and least auklets, and tufted puffins (Ebbert and Byrd, 2002, Major 2004). Resident passerines that nest on the ground such as song sparrows and winter wrens have also been reported as negatively impacted by rats (Kenyon 1961).

In response to extinctions and declining populations of native and endemic bird species, rat eradications have now occurred on islands all over the world, and have become effective and relatively economical tools in the preservation and restoration of island ecosystems (Donlan et al. 2003). However, rodent eradications usually involve the dispersal of a lethal toxin into island environments, resulting in the exposure of non-targeted species to the toxin directly or indirectly through predation or scavenging on target species (Howald et.al. 2005, Donlan 2002). With the primary goal of implementing an eradication program to remove rats from multiple islands across the Aleutians, a trial of eradication methods was conducted on several small islands in the Bay of Islands, off the coast of Adak, Alaska in the fall of 2006 to test eradication methods and identify possible non-target impacts on native island species (Buckelew et. al 2007).

Melospiza melodia (or song sparrow) is an abundant land bird species occupying islands throughout the Aleutian archipelago. Song sparrows have an insectivorous and granivorous diet (Sibley 2001), and are therefore at significant risk of rodenticide exposure through direct consumption (Buckelew et. al. 2007). As such, song sparrows were the focus of three different types of surveys conducted during the trial to assess the magnitude of impacts to non-target bird species: radio-tagging and tracking of individuals, observational point counts, and acoustic recording surveys. The tagging/tracking results are discussed elsewhere (Buckelew et. al. 2007). This paper reports and compares the results of the point counts and acoustic surveys, both of which attempted to create indices of *M. mespiza* populations on sampled islands before and after bait application, to detect if there was any significant and negative change.

Though point counts were conducted in the field, the focus of this study was the use of autonomous acoustic recording units (hereafter ARU's) developed by the Cornell Lab of Ornithology Bioacoustics Research Program. Point counts rely on a relatively short sampling period (5 minutes, conducted twice at each point before and after the bait application), a fairly high input of observer time and effort, and the ability of observers to accurately detect the presence of birds. Because of this, it was hypothesized that the use of ARU's, which have a longer sample time (4 hours every day for 8-16 days), and eliminate the need for observers outside of unit transportation and maintenance, could provide a more robust index of abundance while simultaneously requiring less time and effort in the field.

The null hypothesis of this study has three parts: 1) there is no difference between mean song sparrow abundances during point counts before and after bait application on treatment and reference islands, 2) there is no difference between the change in mean song sparrow abundance during point counts on treated vs. reference islands, and 3) there is no difference in mean call rates recorded during the acoustic surveys between treatment and reference islands. The results of the point counts and acoustic surveys are compared and the effectiveness of using ARU's in eradication-orientated studies is discussed.

Methods

Study Area

The trial eradication took place in the Bay of Islands, off Adak Island, Alaska (see figures 5 and 6). Bait application occurred from September 17 to September 22, 2006 on five treatment islands. 3 of these islands were used as reference islands, Viejo, Sea Parrot and Green islands. Three islands that did not undergo bait application were chosen as reference islands; Ina, Earl, and Black islands. Bait application consisted of the hand broadcast of Bell Labs Brodifacoum 25 Conservation bait, and further details of bait application and all other eradication methods used can be found in Buckelew et. al (2007).

Point Counts

Point counts were conducted on three rodenticide-treated and three reference islands. Depending on island size, between 3 and 20 counts were conducted on each island, twice both before and after the application of bait to trial islands. Before bait application, point counts were conducted from the 1st to the 13th of September, point counts after bait application were conducted from the 4th to the 7th of October. Counts were conducted by a single observer, around the perimeter of the island (within 100 meters of the coast line, to sample in the same territories the ARU's were deployed in, see next section), for five minutes. Point counts were at least 50 meters apart to ensure that multiple counts were not conducted in the same song sparrow territory. Both audio and visual observations of song sparrows were recorded by the observer. Behavior for each bird, if sighted, was also noted. Location was recorded for each point count and marked with flagging for repeated counts at the same point. A paired two-tailed t-test was used to detect differences in the mean number of song sparrows observed per count on each island before and after the bait application. A paired two-tailed t-test and power analysis was conducted to determine if there was a larger change in the means of sparrows observed per count on treated rather than reference islands. All statistical tests were done in Systat 10.

Acoustic Surveys

Six ARU's were placed on three treated and three reference islands each. The units were deployed both before and after the ground broadcast of Bell Labs Brodifacoum 25 Conservation bait. The ARU's were programmed to record between 7:30 and 11:30 am each morning, targeting the dawn chorus of song sparrows (Buckelew et. al. 2007). Each unit stayed on a single island for the entire duration of the project. Units were placed in 2-4 locations both before and after bait dispersal, and left at each location for four nights/mornings. Locations were chosen as random points within 100 meters of the shoreline, according to species accounts (Gabrielson and Lincoln, 1951, and Byrd et. al. 1974) that describe song sparrows in the Aleutians as foraging and nesting almost exclusively along rocky beaches and the vegetation immediately above them.

The call recordings were recorded as .bin files, converted to .aiff files using DataBeast 1.0, and then analyzed using Xbat 2.0 software, an extensible sound analysis application developed by the Cornell University Lab of Ornithology Bioacoustics Research Program. The detection function in Xbat was used to select a specific piece of recorded information (for example, a song sparrow call or song) and then use it to scan the entire four hour recording, marking and counting other pieces of the recording that were similar to the original selection. Xbat has a sensitivity threshold built into the detection function that permits control of how similar the calls needed to be to be recognized and counted. A sensitivity of 0.20 (out of a scale of 1.00), was determined to be appropriate by testing different sensitivities and finding the minimum level of similarity that would eliminate all calls of other passerine bird species (winter wrens, lapland longspurs, and gray crowned rosy finches), or other sound interferences (seabirds, wind, rain, etc.) from recognition during the detection scan.

To double check the chosen sensitivity, a single recording (one day worth, or four hours) was chosen that had numerous calls of other passerine species (particularly the songs of winter wrens, which have a fairly similar frequency range to song sparrows). After the chosen file was scanned, a visual check of the entire length of the file was conducted to verify that every selection detected was in fact a song sparrow call or song. A manual check was completed for one full recording from each unit/island.

Once all files were run through the detection function in Xbat, a call rate was calculated for each location (which consisted of 2-4 mornings, based on having to omit some recordings because of inclement weather resulting in a corrupted file, or a unit not functioning for part of a sample period). Two mean call rates were calculated for each unit/island; one for the period before bait application and one for the period after bait application. A mean difference (post-application mean – pre-application mean) was calculated for each island. Mean differences between treated and reference islands were tested statistically to determine if the mean difference in call rates was greater on treated islands than reference, using a paired, two-tailed t-test and a power analysis.

Results

Point Counts

For point counts, the mean number of song sparrows observed per count for treated islands ranged from 1.37 - 1.71 before and 1.09 - 1.18 after the bait application. For reference islands, the mean number of song sparrows observed per count was 1.32 – 1.40 before and 1.14-1.32 after the application. A significant difference was found on all treated islands (for Green Island $t_{39, 0.05}$=2.35, P = 0.029, for Viejo Island $t_{19, 0.05 =}$ 3.49, P = 0.007, and for Sea Parrot $t_{19, 0.05}$ = 2.60, P = 0.028), and one reference island (Black Island, $t_{5, 0.05}$ = 7.00, P = 0.002) in the mean numbers of song sparrows per point count observed before and after bait dispersal (Figure 1).

A paired two-tailed t-test was conducted between the mean difference in the mean number of birds observed per point count in samples before and after bait application on both treated and reference islands and found no significant difference in the means ($t_{2, 0.05}$= 4.307, P = 0.6442) (Figure 2). A power analysis detected a power of 0.06.

Acoustic Surveys

Mean call rates for treated islands ranged from 2.9 to 7.3 calls per hour before and 0.29 to 0.89 calls per hour after the bait application. For reference islands mean call rates ranged from 2.65 to 12.94 calls before and 0.17 to 7.63 calls after the bait application. Figure 3 shows the before and after mean call rates for each island. Figure 4 shows the mean difference of the before and after bait application mean call rates for treated and reference islands. The paired, two-tailed t-test revealed no significant difference in the means of treated and reference islands ($t_{2,\ 0.05}=1.47$, $P = 0.28$), so the null hypothesis cannot be rejected. A power analysis detected a power of 0.1245.

Discussion

The primary purpose of this study was to determine if there were significant negative effects on song sparrows during the 2006 Bay of Islands trial rat eradication. Significantly more birds observed per point count on treated islands before the bait broadcast than after the application would seem to indicate that the application had a negative effect on song sparrow populations. However, there was also one reference island that had significantly less birds after the broadcast on treatment islands. In addition, there was no significant difference between the mean difference (before to after bait application) in the number of birds observed on treated islands in comparison to reference islands, which indicates that a larger pattern of decrease may have occurred on all islands. Similarly, the mean differences in song sparrow call rates between treated and reference islands were not significantly different, which indicates that call rates were decreasing across all islands sampled, not just treated. Therefore, the first part of the null hypothesis is rejected, and the second and third parts of the null hypothesis cannot be rejected.

In a species account by Nice (1943), the call rates of song sparrows throughout their breeding cycle were quantified, and he asserted that sedentary or non-migratory song sparrows have highly variable call rates which vary seasonally from 2 to 140 calls per hour depending upon the time in the breeding season. Therefore, song sparrow call rates can vary dramatically in relatively short periods of time (Arcese 2002). Because of this highly variable call rate, it is likely that song sparrows were displaying normal seasonal behavior in calling at a higher rate before the rodenticide application. The reduced number of birds observed and calls recorded could be attributed to seasonality and not solely to the impacts of the trial eradication.

This study does not suggest that the application of brodifacoum did not have any effect on song sparrows during the trial eradication. Data from transmitters placed on individual song sparrows suggest that some song sparrow mortality did occur as a result of the trial eradication (Buckelew et. al. 2007). Although not statistically significant (Fig. 3 and Fig 4), there is a large change in the number birds observed and the call frequency on treated islands in comparison to reference islands. A greater change on treated islands could indicate that although slight, there may have been a negative impact on song sparrows on treated islands that was not observed on reference islands. Another potential factor influencing the results was that the trial was conducted on small islands off the coast of the larger island of Adak, and it is possible that some migration between small islands and the mainland occurred. This would make the impact of the rodenticide hard to detect due to new individuals occupying territories of lethally affected sparrows.

However, the non-significant results may suggest that the risk to song sparrows on a population level is minimal, and the trial eradication did not have a significant negative effect on the populations on the treated islands sampled in comparison to reference islands. Although migration of individuals from Adak is a possibility, there were song sparrows visually observed and calling on all treated islands immediately following the trial, as well as consistently during the sampling period after the application, even if at lower numbers and rates than before the application (Fig 1 and Fig 2). While it is impossible to determine that no new individual song sparrows migrated from Adak, it is also impossible to infer that individuals did move from the larger source population as a direct impact of brodifacoum application, as no individuals were tagged or banded from the mainland.

Further, while it is important to reduce effects on any non-target species during an eradication, species (or subspecies) of greatest concern are those that are endemic and that could potentially be affected to the point of local or global extinction. Song sparrows are found throughout the entire Aleutian Island chain, and there are no subspecies endemic to only one island in the Aleutians (Gabrielson and Lincoln, 1951). Thus if there was a significant effect on individuals on an eradication island, sparrows from other islands in the Aleutians could potentially migrate naturally or undergo facilitated translocation without incurring permanent population declines or losses. Further monitoring of song sparrows on islands in the Aleutians considered for eradication may be necessary, but should focus on islands that are extremely remote and isolated from other source populations of sparrows where individual mortality is a large concern (i.e. islands where they exist at extremely low densities).

The secondary goal of this study was to test the ability of ARU's developed by the Bioacoustics Research Program at the Cornell Lab of Ornithology as an eradication tool to monitor non-target rodenticide impacts to bird species. Logistical challenges resulted in some recording sessions lost to weather conditions, unit malfunctions, and the switching of treatment or control islands in the early stages of the trial. Call rates were only compared from data from the same island before and after bait application, so some samples collected at the beginning had to be thrown out, if the units were moved to another island because of a change in the trial strategy. These challenges may have contributed to the low power calculated by the power analysis. However, it should be noted that the power of detecting a difference in bird abundance was higher for the recording units than for the point counts, indicating that the units did provide a statistically stronger measure of the difference in bird presence on the islands before and after the trial eradication efforts than the point counts.

For future studies that may consider the use of acoustic recording, the units are efficient at providing a measurement of the difference between call rates before and after an action or disturbance, but could be problematic if used to try and determine an actual density, as calls are not necessarily representative of how many individuals may be recorded. Often the same individual may repeat songs/calls multiple times. To account for this, units were moved multiple times to record in different territories, and did not stay in one place for more than four recording sessions, so a mean call rate could be determined, although the number of individuals was not.

Eradications are expensive and time intensive projects (Donlan et al. 2003), and tools that help to decrease the cost or increase time efficiency can be extremely valuable. A study in New Zealand during the Kapiti Island rat eradication involved a similar call rate study, but instead of automatic recording units, a field team manually recorded calls heard for a total of 256 person-hours (Empson and Miskelly, 1999). Putting acoustic recording devices in the field requires less time, effort, and personnel investment than other observer-reliant bird census techniques, and they are a valuable tool for biological monitoring in any eradication project that is faced with the concern of non-target impacts to bird species. Donlan et al. (2003) stresses the need for collaboration in improving upon the tools used in invasive species eradications. In future projects, acoustic recording may need to undergo further testing and trial in the field, but could prove to be an extremely important and innovative tool in facilitating fewer non-target impacts to native island birds and in furthering the effectiveness of eradication efforts globally.

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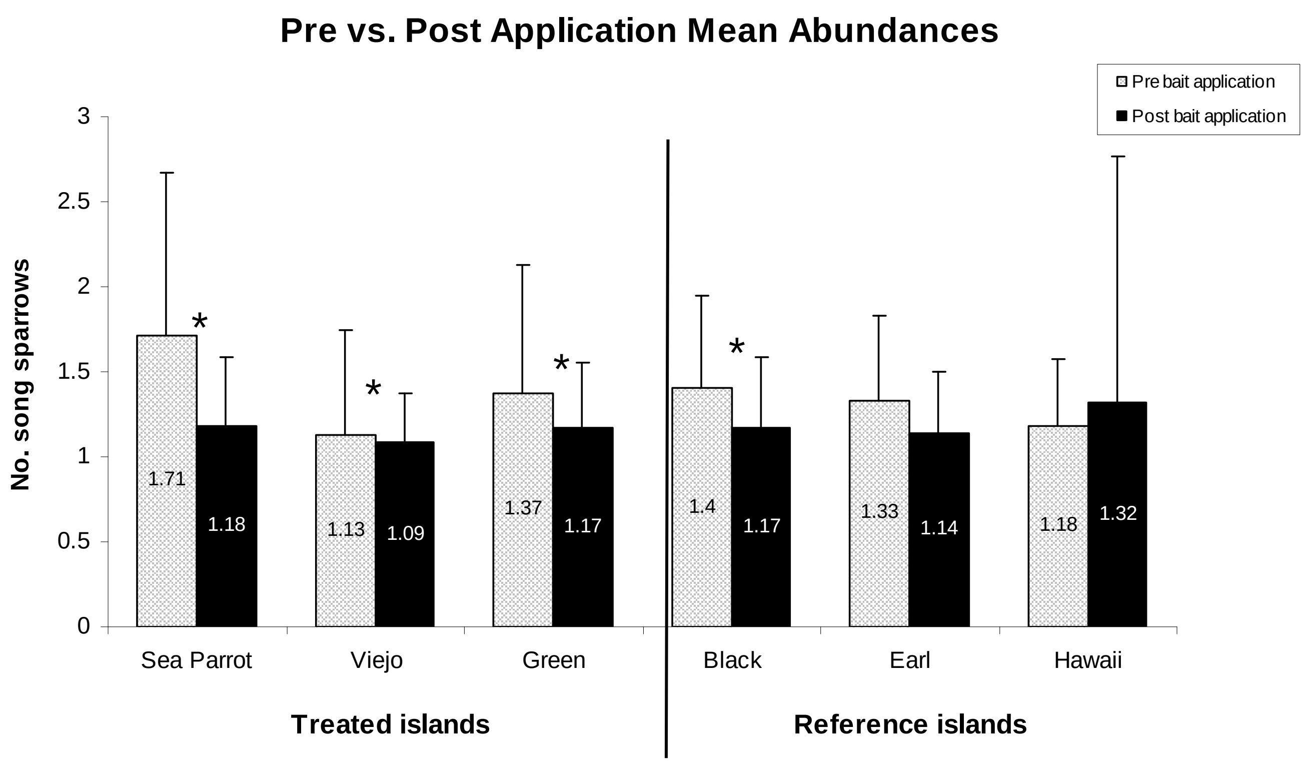

Figure 1. The mean abundance of song sparrows, per point count, found on each island, before and after the application of rodenticide (* indicates a significant result).

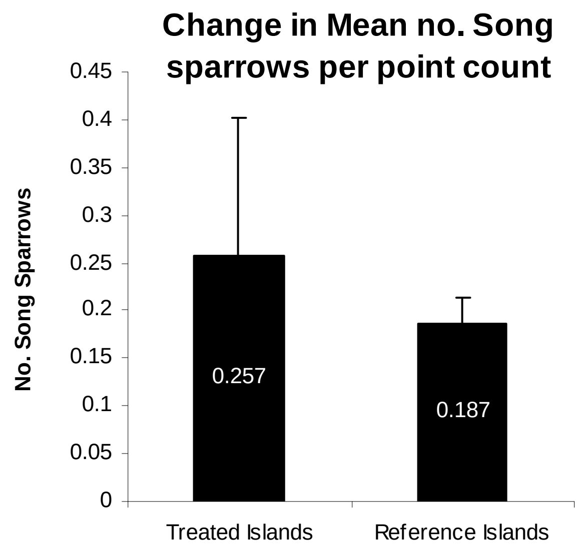

Figure 2. The mean differences in the abundance of song sparrows (per point count) between samples before and after bait application. The mean differences were tested to see if mean changes on treated islands were greater than those on reference islands. No statistically significant difference was found.

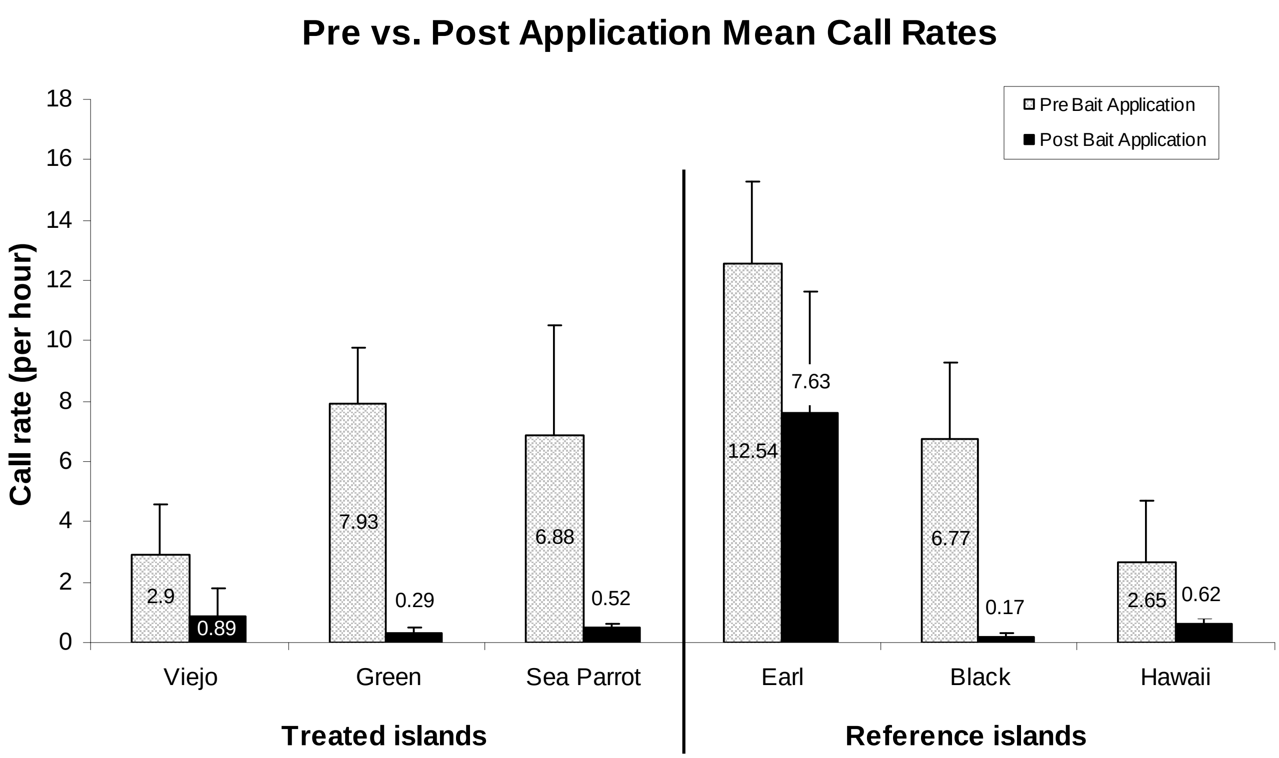

Figure 3. The mean call rates on all islands sampled, before and after rodenticide application. T-tests were not conducted due to experimental design.

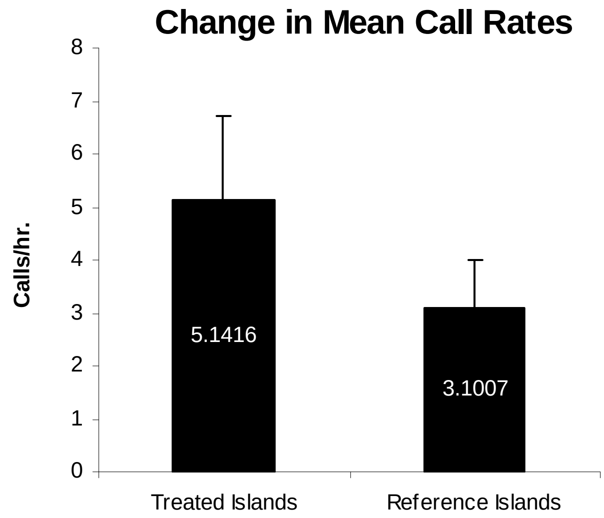

Figure 4. The mean changes in call rates of song sparrows between samples before and after bait application. The mean differences were tested to determine if mean changes on treated islands were greater than on reference islands. No statistically significant difference was found.

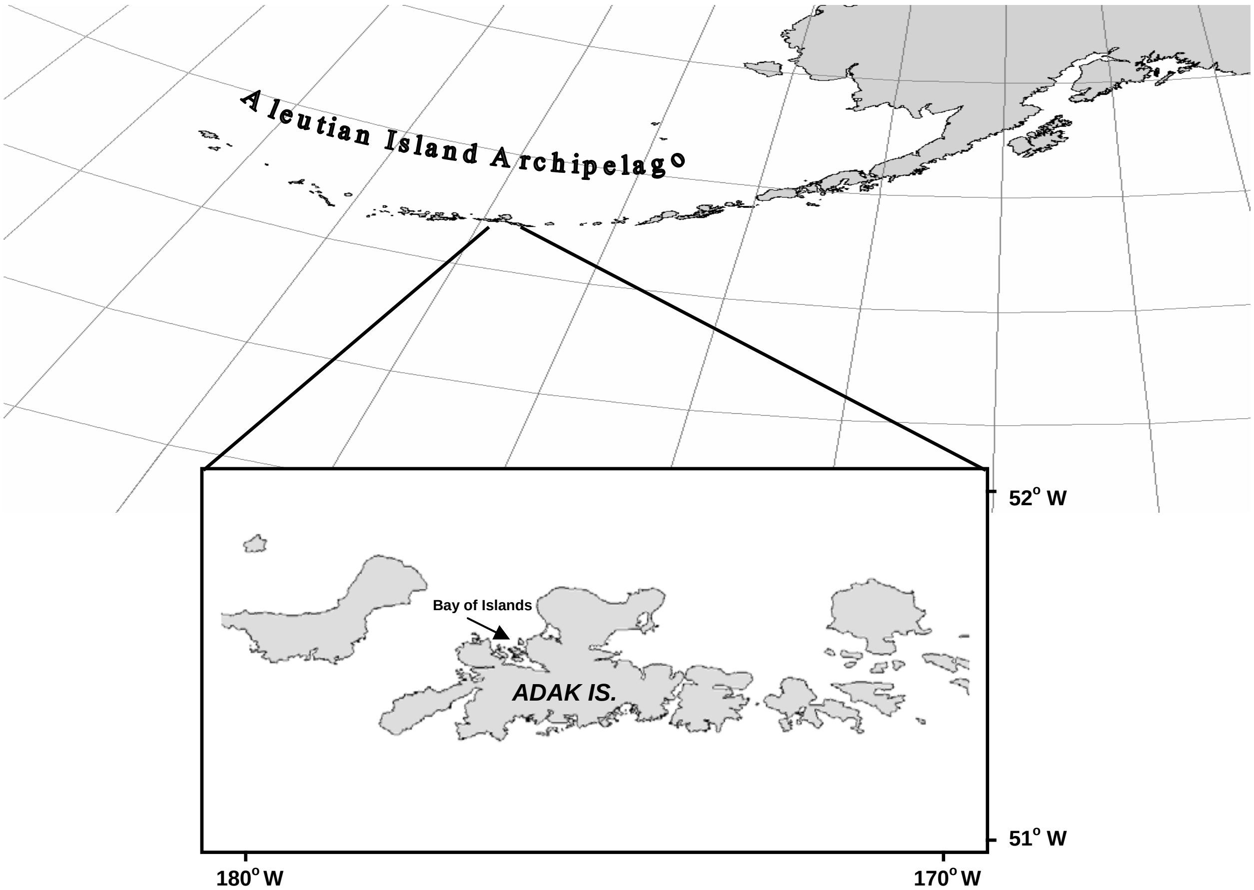

Figure 5. Adak Island, Alaska in the Aleutian archipelago (Map by S. Buckelew).

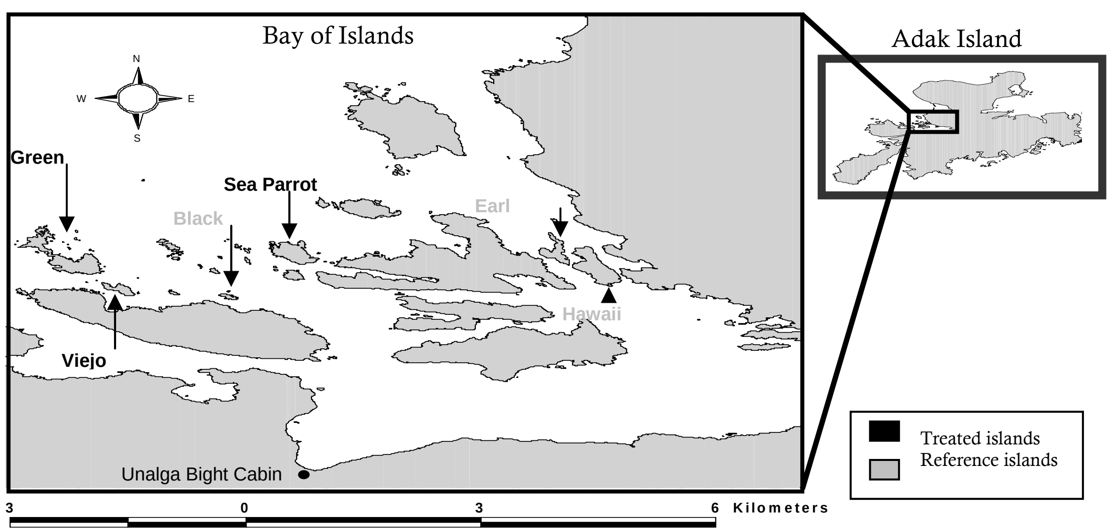

Figure 6. Treated and Reference Islands in the Bay of Islands of Adak Island, Alaska (Map by C. Hanson)