Preliminary ecosystem response following invasive Norway rat eradication on Rat Island, Aleutian Islands, Alaska

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Abstract The Aleutian Islands, including many of the islands in Alaska Maritime National Wildlife Refuge, are among the most productive seabird breeding areas in North America, providing habitat for >10 million seabirds representing 26 species. Norway rats (*Rattus norvegicus*), accidentally introduced to several islands in the Aleutians, have had a negative impact on seabird populations. To reverse these effects, and recover seabird breeding habitat on Rat Island (2900ha) where burrowing seabirds have been extirpated, an eradication of Norway rats was attempted in September 2008. The project was undertaken by U.S. Fish and Wildlife Service partnered with The Nature Conservancy and Island Conservation, and was the first in Alaska to apply rodent bait aerially. No signs of rats were detected during a reconnaissance visit nine months after the operation when preliminary signs of positive responses were recorded, including notable breeding records of shorebirds and seabirds. Numerous bird carcasses, including glaucous-winged gulls and bald eagles, were found following bait application and toxicology analysis confirmed that most mortalities were direct or indirect effects of consumption of the baits. Nevertheless, with the exception of bald eagles, most bird populations surveyed increased in abundance so the impacts on non-target species are likely to be temporary. Monitoring on the island will continue for five years to further evaluate ecosystem and non-target species population recovery following rat removal.

Keywords: Invasive species, rat eradication, seabirds, *Rattus norvegicus*

INTRODUCTION

Introduced species are one of the top drivers of extinctions in island ecosystems worldwide. Island endemics are particularly vulnerable, as they often lack evolved behavioural responses to predators, or have restricted habitats or population sizes (Moors and Atkinson 1985; World Conservation Monitoring Center 1992). Increasingly, the removal of non-native predators is being used as a tool to prevent further loss of island biodiversity and restore native ecosystems to their original state. Introduced rodents are among the most detrimental mammals to island flora and fauna (Moors and Atkinson 1985) and, given their widespread colonisation and impact on native species, have been identified by land managers as key species for eradication.

The Aleutian Islands, including many of the islands in Alaska Maritime National Wildlife Refuge, are among the most productive seabird breeding areas in North America, providing habitat for 26 species of seabirds numbering more than 10 million individuals. Islands in the Aleutian Archipelago, however, have not been spared from the impacts of non-native species (Ebbert and Byrd 2002). Populations of ground nesting birds, and other native species in the Aleutians, have been depleted or, in some cases, entirely extirpated through predation by introduced species (Bailey 1993). Because of the high biodiversity values, the restoration of Aleutian Island ecosystems through the removal of invasive predators has been a long-standing management priority (Ebbert and Byrd 2002). For the past 50 years, restoration of Aleutian Island ecosystems has focused on removing introduced Arctic foxes (*Alopex lagopus*), resulting in dramatic population increases for 15-20 bird species (Gibson and Byrd 2008) and the de-listing of the endemic Aleutian cackling goose (*Branta hutchinsii leucopareia)* from the U.S. Endangered Species List. Additional species continue to be threatened by Norway rats (*Rattus norvegicus*) introduced to at least ten large islands in the archipelago.

Rat Island is thought to have been the first island in the Aleutians to be invaded by Norway rats when a Japanese ship went aground in the 1780s (Black 1983). Over the past two centuries, rats have caused extensive ecological damage by depleting breeding seabird and possibly land bird populations, and altering island plant and intertidal communities (Kurle *et al.* 2008; Croll *et al.* 2005). Arctic foxes were introduced to Rat Island by fur traders in the 1800s, but were removed in 1984 in the initial phase of native habitat restoration (Hanson *et al*. 1984) leaving Norway rats as the only remaining non-native mammal. The rats are a significant obstacle to further native habitat restoration.

The U.S. Fish and Wildlife Service, partnered with The Nature Conservancy, Alaska, and Island Conservation, to restore native biodiversity, including seabird breeding habitat, on Rat Island (2900ha) by removing introduced rats using an aerial application of cereal pellets containing 25ppm brodifacoum. Here we report generally on the aerial broadcast operations, in addition to biological surveys conducted before and after bait application to: 1) assess the potential impact to non-target species; and 2) document the recovery of native species following rat removal. We also provide preliminary results from target species monitoring to evaluate the effectiveness of the rodenticide bait in achieving rat removal.

METHODS

Island description

Rat Island (51°80' N, 178°30' E) is in the Rat Islands group in the central Aleutian Islands (Fig. 1). The 2900ha (7100acres) island has steep coastal cliffs around most of the coastline backed by rolling hills and plateaus rising to a small range of mountains with a maximum elevation of 400m. Rat Island is a designated Wilderness Area and has no inhabitants or infrastructure. The Aleutian climate is marine-influenced and is characterised by generally overcast skies and frequent, often-severe, storms driven by low-pressure systems and high winds (Rodionov *et al.* 2005). Rat Island is treeless and supports a subarctic maritime tundra ecosystem. The island has a diverse bird fauna including waterfowl, birds of prey, shorebirds, seabirds, and landbirds. Burrow-nesting seabirds appear to be absent and crevice-nesting species are rare, likely due to the impact of rats.

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Eradication operation

Rats have been successfully eradicated from at least 330 islands worldwide, generally using an application of rodenticide bait to every potential rat territory on an island (Howald *et al.* 2007). The method used on Rat Island followed techniques used on large island eradications in New Zealand and elsewhere, but the details were adapted to suit the Aleutian environment (Towns and Broome 2003; Howald *et al.* 2007; Broome 2009). Cereal pellets (Brodifacoum 25W Conservation, Bell Laboratories, Madison, WI, EPA Registration # 56228-36) containing 25 ppm brodifacoum, a second generation anticoagulant, were applied twice from a specialised spreader bucket slung beneath a helicopter at a nominal sowing rate of 8.0 kg/ha (Buckelew *et al*. 2008). Bait was delivered during fall (September – October), when rats are relatively deprived of food by seasonal declines in resources and more likely to consume the pellets. Application was by flying low-altitude (*c*. 50m) parallel swaths over the entire land area and adjacent vegetated islets. A differential global positioning system was used to direct coverage across the island and ensure all individual rats were exposed to a sufficient quantity of bait. Directional deflectors were placed on the spreader buckets when applying bait to coastal and riparian areas to minimise the discharge of bait to marine and freshwater habitats. Bait was hand laid inside these aerial exclusion zones to ensure comprehensive coverage.

Biological surveys

Minimising the impacts to non-target species was a consideration in the eradication design; however, it was recognised that there might be mortality of some individual birds. Common birds were surveyed to document the recovery of native species following rat removal and to assess the impacts to non-target species in 2007 and 2008. The surveys were repeated in June 2009, nine months after the bait application. The bird population abundance indices obtained from these surveys were then compared. Additional surveys of marine mammals, vegetation, and intertidal biota are not discussed in this report (Buckelew *et al.* 2009). As much as possible, a Before-After design with replication (using the island as the inferential space) was used since logistical constraints, in most cases, precluded the use of sampling island replicates as a control. The survey methods used include point count surveys, strip transects, nearshore boat surveys, and incidental observations (Buckelew *et al.* 2007a). Values were tested using a two-sample or paired t-test ($\alpha = 0.05$)

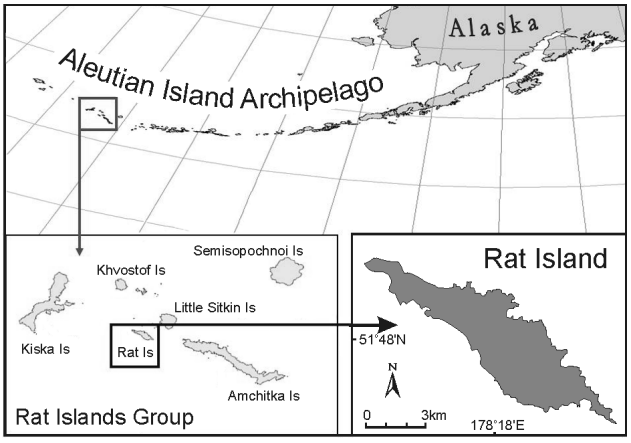

Fig. 1 The location of Rat Island in the Rat Islands group, central Aleutians Island unit of the Alaska Maritime National Wildlife Refuge.

Eradication confirmation monitoring

Following common practice, final determination of the eradication outcome will not be determined until two years after bait application, allowing time for any surviving rats to repopulate to detectable levels. Preliminary rat detection monitoring from May-June 2009 used transects of trap stations and chew devices. Thirty-one transect lines were placed along the coast and in riparian habitats. A transect line consisted of ten trap stations and ten peanut butter-flavoured wax chew blocks spaced 25-50m apart. Trap stations consisted of a Victor snap trap (baited with peanut butter) and a chew block placed 1-2m apart. Every other trap station was housed inside an unarmed Protecta bait station (Bell Laboratories, Madison, WI) for protection against adverse weather. Transects were checked for activity and rebaited every 3-4 days for 18-22 days. The total number of trap nights was calculated as one trap set for one night; traps sprung without capture were assigned a value of 0.5 trap night. Results from these surveys were compared with similar surveys conducted before bait application in August 2007 when eight trap station transects were placed in coastal and upland habitats (Buckelew *et al.* 2007a).

Rats in the Aleutians are more frequently detected in late summer (August-September) when densities are highest following the completion of peak breeding (Dunlevy and Scharf 2006); however, logistical constraints prevented monitoring during this period. Therefore eleven transects, totalling 335 chew devices, were placed on beaches before leaving the island in late June for prolonged detection through late summer. During 2010 all chew devices will be inspected for incisor marks and reset.

To evaluate the persistence of bait during winter, 3m radius circular plots (28.3m^2) were sampled for pellets nine months after bait application. Randomly located plots were sampled staking one end of a 3m string to the plot centre, and the observer counting pellets while walking in a circle at the distal end of the string. The mean number of pellets encountered in plots (n = 466) was used to extrapolate the amount of bait (in kg/ha) remaining in different habitats.

Mortality of non-target species

During May-June and August 2009, formal and informal carcass surveys were conducted for birds that might have died from exposure to rodenticide. Formal surveys involved searching for carcasses on 67 beaches (or beach segments) either once or multiple (3-5) times. Informal surveys were opportunistic encounters of carcasses made while transiting the island. All carcasses encountered were collected and stored at ambient temperature until later transferred to a freezer (1-8 days after collection). Testable tissues or carcasses were analysed for brodifacoum residues. Carcasses too old to have any testable organ tissue were removed from the island to reduce secondary exposure by avian scavengers.

We did not study natural "background" mortality at Rat Island prior to the bait application. Therefore, standardised beach carcasses surveys (Coastal Observation and Seabird Survey Team, (COASST)) data available from islands east (Adak Island, 350km distance) and west (Buldir Island, 175km distance) of Rat Island were used as a control to provide reasonable approximation of the diversity of birds expected by natural mortality.

RESULTS

Biological surveys

Mean detections per point count were similar in 2009 to prior years for Lapland longspurs (*Calcarius lapponicus*) and gray-crowned rosy finches (*Leucosticte tephrocotis*), but the counts for winter wrens (*Troglodytes troglodytes*)

Table 1 A comparison of abundance of bird species (mean ± s.d.) detected using standardised surveys conducted before and nine-months after (2009) the application of cereal baits containing brodifacoum (25ppm) on Rat Island.

Species	Pre	Post	t	P
Gray-crowned rosy finch[1]	1.3 ± 0.8	0.8 ± 0.8	1.993	ns
Gray-crowned rosy finch[2]	0.0 ± 0.2	0.0 ± 0.1	0.327	ns
Lapland longspur[1]	2.1 ± 0.6	2.6 ± 1.1	-1.963	ns
Lapland longspur[2]	4.5 ± 3.0	5.1 ± 1.9	1.444	ns
Winter wren[1]	2.6 ± 0.7	3.3 ± 1.0	-2.469	0.026
Winter wren[2]	0.1 ± 0.4	0.3 ± 0.7	2.197	0.030
Rock ptarmigan[3]	1.2 ± 1.4	3.6 ± 1.6	-7.186	<0.001
Glaucous-winged gull[4]	615	1027	-	-
Black oystercatcher[1]	0.2 ± 0.2	0.1 ± 0.2	-2.076	ns
Rock sandpiper[1]	0.5 ± 0.9	0.6 ± 1.1	0.825	ns

[1]Species detected using line transects (pre (2007-08), n = 32 with 5 repetitions, and post (2009), n= 16 with 5 repetitions).
[2]Species detected using point count surveys (pre (2007-08), n = 74; post(2009), n = 57).
[3]Species detected using swath transects (pre (2007-08), n= 56; post(2009), n = 52).
[4]Species detected using nearshore boat surveys (pre (2008), n =1; post (2009), n=1).

were slightly higher in 2009 than previously (Table 1). Similarly, counts on fixed beach transects showed no differences between 2009 and earlier years for longspurs and rosy finches, but were higher for winter wrens (Table 1). Rock ptarmigan (*Lagopus muta*) counts were higher in 2009 than in earlier years (Table 1).

Black oystercatchers (*Haematopus palliates*) and rock sandpipers (*Calidris ptilocnemis*) were detected in equal numbers to previous years (Table 1). While transiting the island, incidental observations were made of rock sandpiper and black oystercatcher nests. Seven black oystercatcher nests and six rock sandpiper nests were encountered.

Given differences in sampling methods, statistical comparisons of glaucous-winged gull (*Larus glaucescens*) estimates were not possible (Table 1). However, detection rates for all common bird species monitored in this survey, including glaucous-winged gulls, were as high or higher than prior to rat eradication.

Eradication confirmation monitoring

In August 2007, before eradication, there was a 38% trap success (TN = 362) and rat chews were detected on 39% of the blocks. Rat activity was highest in coastal compared to stream or inland habitats. Trap success was 59% in coastal areas (TN = 212) and chews were detected on 64% of the blocks. In June 2009, after bait application, no rats or rat sign were detected on trap station transects after 9068 trap nights. Similarly, no signs of rat activity were detected in 1550 nights of chew block detection effort.

All bait pellets in coastal habitats were either directly consumed or degraded during the winter (Table 2). Very few, highly-degraded pellets remained in upland and lake habitats, with an average of < 1 pellet per 100m^2. Pellets were laterally compressed and in an advanced state of decay, having lost their shape and integrity, after prolonged exposure to weather and snow.

Mortality of non-target species

A total of 422 bird carcasses were found during formal and informal surveys in May-June and August 2009 (Table 3). Of these, it is likely that some of the carcasses encountered during August were first discovered but not removed in June. Ninety one of the carcasses were submitted for analysis, and the results will later be made available for publication. The majority of carcasses collected were in moderate to advanced stages of decomposition.

Most carcasses were of glaucous-winged gulls, but a few carcasses of other species, normally encountered on beached bird surveys in the Aleutian Islands, were also found and are unlikely to be casualties of the operation (Table 4). A small proportion of the gull carcasses were scavenged, presumably by avian predators, and only the skeletons remained. Most of the bald eagle carcasses were around the coastal periphery of the island, either along the beach berm or near coastal streams. Eagle carcasses on the interior of the island were found close to lakes or streams, with the exception of a few that were in upland areas. No lethargic birds or birds exhibiting abnormal behaviour suggestive of exposure to rodenticide were observed during our surveys.

DISCUSSION

Biological surveys

Surveys conducted after eradication showed no evidence of a significant difference in detection rates for Lapland longspur or gray-crowned rosy finches, although high variability and low sample sizes made detecting any pattern difficult. There was evidence of a significant increase in the counts for winter wrens following the eradication of rats. The number of ptarmigan detected on line transects were 105% higher after eradication than before, indicating that there were no adverse effects of the eradication on ptarmigan abundance.

Table 2 Number of pellets detected (per plot and per ha) during May-June 2009 and the nominal number of pellets applied per habitat type during September-October 2008 on Rat Island.

Habitat	No of plots	No. pellets/ha applied (2008)	No. pellets/ha remaining (2009)	Mean pellets/plot	Kg/ha remaining	% diff
Coastal	88	*8180*	2	0.006 ± 0.054	0.005 ± 0.042	*99.9*
Upland	296	*4090*	43	0.122 ± 4.361	0.095 ± 0.409	*98.9*
Lake	82	*8180*	195	0.549 ± 1.982	0.427 ± 1.543	*97.6*
Total	466	*4090*	62	0.176 ± 0.978	0.137 ± 0.738	*98.5*

Table 3 The bird species and maximum number of individuals found dead on Rat Island during summer 2009 following the application of cereal bait containing brodifacoum (25ppm). Birds were encountered either opportunistically or during beach carcass surveys. Bald eagles and glaucous-winged gulls are listed in parentheses by age class (adult: subadult: unknown) (P= present, encountered but not enumerated).

Species	May/ June	Early Aug	Late Aug
Predominantly terrestrial species			
Bald eagle	43 (14:29:0)	2 (0:1:1)	1
Common raven	2		
Emperor goose	1		
Gray-crowned rosy finch	2	1	
Green winged teal	1		
Rock ptarmigan		1	1
Lapland longspur	2		
Peregrine falcon	1		
Snow bunting	2		
Predominantly marine species			
Common eider	2		
Glaucous-winged gull	222 (58:188:0)	57 (10:59:1)	41
Black-legged kittiwake		3	
Unidentified shearwater		1	
Harlequin duck	2	2	
Green-winged teal		1	
Northern fulmar	2	6	1
Parakeet auklet	1		
Pelagic cormorant or unk	2	1	1
Pigeon guillemot	2		
Tufted puffin	3		
Unidentified puffin		1	1
Thick-billed murre		1	1
Common murre		1	
Unidentified murre		1	
Unidentified auklet	1		P
Least auklet		2	
Whiskered auklet	1	1	

Table 4 A) The total numbers of bird carcasses found during COASST beach surveys conducted on Adak, Rat, and Buldir Islands during summer 2006-09. B) The total number of bird carcasses by species found during beach surveys conducted during summer 2009 (data source: COASST, accessed on December 2, 2009, http://depts.washington.edu/coasst/patterns.html). Total beach area surveyed on transects on Adak I. = 2.3 km, Buldir I. = 4.7 km, and Rat I. = 37 km. Numbers in ( ) refer to number of carcasses found per km of beach surveyed.

	Adak I. no seabird colony; rat-infested	Rat I. no seabird colony; rat- free	Buldir I. seabird colony; rat-free
A) Total bird carcasses found			
2006	0	na	32
2007	0	na	61
2008	Na	na	83
2009	0	235	57
B) Carcasses by species found during 2009 surveys			
Ancient murrelet	0	0	2 (0.43)
Black-legged kittiwake	0	0	7 (1.49)
Common eider	0	2 (0.05)	0
Common raven	0	2 (0.05)	0
Emperor goose	0	1 (0.03)	0
Glaucous-winged gull	0	214 (5.78)	13 (2.77)
Green- winged teal	0	1 (0.03)	0
Harlequin duck	0	2 (0.05)	0
Horned puffin	0	0	2 (0.42)
Laysan albatross	0	0	1 (0.21)
Northern fulmar	0	2 (0.05)	0
Parasitic jaeger	0	0	1 (0.21)
Parakeet auklet	0	1 (0.03)	1 (0.21)
Pelagic cormorant	0	2 (0.05)	5 (1.06)
Peregrine falcon	0	1 (0.03)	0
Short-tailed shearwater	0	0	1 (0.21)
Thick-billed murre	0	0	16 (3.40)
Tufted puffin	0	3 (0.08)	2 (0.43)
Unknown	0	1 (0.03)	6 (1.28)
Whiskered auklet	0	1 (0.03)	0
Total	0	235 (6.35)	57 (12.13)

It is not known how productive Rat Island was for nesting shorebirds prior to rat introduction, but the coastal and upland areas were not highly productive breeding habitat in 2007-2009. Nevertheless, while breeding was recorded previously, ours is the first record of chicks hatching for black oystercatchers and rock sandpipers. No specific surveys for burrowing nesting seabirds on rock stacks had been conducted in previous years; therefore, it is not clear whether four pigeon guillemots nests discovered on rock stacks were a response to rat removal. The location of at least one of the guillemot nests in the entrance of a burrow believed to have belonged to a rat (identified by small pile of chewed invertebrate shells located beneath a low rock overhang; a potential rat feeding station) is suggestive of recolonisation.

Eradication confirmation monitoring

Nine months after bait application, no rats were observed or detected and no bait remained on the coast. A few baits did, however, persist into the spring following their application in inland habitats. This observation of varying decomposition rates according to habitat is consistent with degradation trials conducted in the Bay of Islands on Adak Island, where pellets placed in inland habitats persisted longer than those in low altitude coastal habitats (Buckelew *et al.* 2007b). Pellets remaining on Rat Island were in the final stage of decomposition, and likely persisted due to the overwinter freezing conditions. After a summer of relatively warm temperatures and heavy rains it is likely that the few remaining pellets will dissolve entirely.

Mortality of non-target species

Mortality of individuals of some non-target species is often an unavoidable consequence of successful eradications. Some winter die-off of birds is not unusual in the Aleutian Islands, but the numbers of glaucous-winged gull and bald eagle carcasses observed during our surveys were substantially higher than expected. The numbers of other bird carcasses encountered, particularly for seabird species, were consistent with coastal observations on Buldir Island, the closest seabird colony for which data exist. Buldir Island is rat-free and contains large seabird breeding colonies (unlike Rat Island); therefore, it is not

an ideal reference site. Nevertheless, the list of carcass species from Buldir provides a reasonable approximation of the diversity of birds that could be expected naturally on Rat Island, suggesting that many of the species found were unlikely to have been a result of the eradication campaign.

Gull and eagle carcasses tested positive for brodifacoum suggesting that most of these mortalities were due to primary and/or secondary exposure to rat baits. At the time of writing the toxicology results were unavailable for publication, and will be made available in a later report. The highly degraded state of most carcasses encountered suggests that the birds died many months before they were collected, probably soon after the baits were spread. Considering their advanced state of decay, most carcasses recovered during repeated visits to Rat Island during August 2009 were from beaches not surveyed during May-June or were carcasses encountered but not previously collected. Thus it is likely that some carcasses were double-counted during August, thus may have been an overestimate of mortality.

Secondary poisoning of bald eagles is presumed to have been from scavenging sick or dead gulls and rats. Gull feathers and rat remains (fur and bones) were found in several eagle boluses (Buckelew *et al.* 2009). This pathway of secondary brodifacoum exposure was not previously identified as a significant risk to eagles. Typically, eagles are absent from Rat Island during fall when they congregate around streams on nearby islands to feed on spawning salmon (Gibson and Byrd 2007). Eagles are most abundant on Rat Island during summer. We only recorded six eagles during the baiting operation suggesting that most eagles had already departed. Nevertheless, eagles apparently arrived on Rat Island later in the season (fall or early winter) and scavenged or preyed on gulls exposed to brodifacoum.

CONCLUSIONS

Eradication of invasive species has direct benefits to species impacted by non-native predators and indirect benefits to native ecosystems. However, there may be short term impacts on native species from the rodenticide, as observed on Rat Island. Eagles and gulls suffered unintended and unexpectedly high mortality which has resulted in a decline in the eagle population. The recovery of a native ecosystem on Rat Island is almost certain to provide prey resources sufficient for eagles to completely recover to former, or possibly higher, breeding densities. Methods to estimate gull populations on Rat Island were not consistent with those used after bait application, so we were unable to detect small changes with confidence. Available counts, however, did not suggest a population-level decline for gulls.

The removal of Norway rats and Arctic foxes (completed in 1984) should enable the recovery of communities on Rat Island similar to those present before the introduction of these non-native predators. Our data indicate that following rat removal recovery is beginning for species such as winter wrens. Additionally, we documented successful nesting by pigeon guillemots, rock sandpipers, and black oystercatchers. If Rat Island is now rat-free, 2009 was the last season in which species on the island were affected by rats. Continued monitoring in future years will further document ecosystem changes on Rat Island. We anticipate that there will be increased densities of land birds that were previously preyed on by rats, recolonisation of the island by burrow-nesting seabirds, and changes in the vegetative and intertidal communities.

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