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

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Executive summary

Introduced non-native Norway rats (*Rattus norvegicus*) have adversely impacted native ecosystems world-wide. Norway rats have become established on at least 12 large islands in the Aleutian Islands, Alaska, all within the Alaska Maritime National Wildlife Refuge. The Refuge has a long-standing objective to restore native island ecosystems by removing introduced species. In September-October 2008, the Refuge, The Nature Conservancy, and Island Conservation partnered to remove rats from 2,900-ha Rat Island by using aerially applied cereal-based bait containing brodifacoum. This is the first rat eradication program conducted in Alaska.

To evaluate the response of the native ecosystem to rat removal, pre-eradication baseline surveys were conducted at Rat Island for selected native species in June 2007 and 2008, and repeated nine months following the bait application in June 2009. Surveys conducted in 2009 also included rat detection monitoring to determine whether the eradication was successful. The results of these latter surveys are presented in a separate report.

The international standard for declaring eradication success is two years after treatment, but failure to detect any rat sign in 2009 suggests the direct effects of rat depredation on Rat Island's flora and fauna probably ceased in fall 2008. Nevertheless, bird populations would not be expected to increase immediately following eradication. Most likely increases will occur in one to three years, depending on the species, a result of improved reproductive success of species that persisted in low numbers at Rat Island despite rat presence. Additionally, non-breeding birds may be attracted from other islands, but the contribution of this component is not well understood in the Aleutians and the timing is difficult to predict.

As indicated above, no immediate increases were expected in bird populations at Rat Island in 2009, however, we did want to evaluate whether there were declines of glaucous-winged gulls (*Larus glaucescens*) or bald eagles (*Haliaeetus leucocephalus*), associated with the bait application. Indeed the bald eagle population was much lower in

2009 following the application of rodenticide, but we did not detect a decline in gull populations. Furthermore, population indices for most other species of birds were as high or higher in 2009 than before to eradication. Evidence of successful chick production for black oystercatcher (*Haematopus palliates*) probably was early evidence of response to rat removal, indicating that prior to eradication rats were severely limiting oystercatcher nesting success. Additionally, successful nesting was recorded for other bird species susceptible to rat predation, including pigeon guillemot (*Cepphus columba*), rock sandpiper (*Calidris ptilocnemis*), and common eider (*Somateria mollissima*). The successful removal of rats is expected to significantly improve breeding habitat and survival rates for many native island species. Continued monitoring is planned over the next four years to document further ecosystem response on Rat Island.

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1. Introduction

Introduced non-native species are one of the top drivers of extinctions in island communities worldwide. Due to their isolation oceanic islands contain high numbers of unique or endemic species, which are susceptible to threats by invasive species as they often lack evolved behavioral predation responses or have restricted habitats or population sizes (Moors and Atkinson 1984; World Conservation Monitoring Center 1992). Rats alone are responsible for 40 -60% of bird and reptile extinctions on islands (Atkinson 1985), and have been implicated in causing indirect and trophic-level impacts to islands ecosystems (Towns 2002, Fukami et al. 2006, Kurle et al. 2008). Increasingly, the removal of non-native predators is being used as a tool to restore native ecosystems. Introduced rodents are among the most detrimental mammals to native island species (Moors and Atkinson 1984), and given their widespread colonization and impact on native species, have been identified by land managers as key species for eradication.

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). Thus, the restoration of Aleutian Island ecosystems through the removal of invasive predators has been a long-standing management priority for Alaska Maritime National Wildlife Refuge within which most of the Aleutian Islands occur (Ebbert and Byrd 2002). For the past 50 years introduced Arctic foxes (*Alopex lagopus*) and red foxes (*Vulpes vulpes*) have been removed from many Aleutian Islands, resulting in dramatic population increases for 15-20 bird species (Gibson and Byrd 2008) and the delisting of the endemic Aleutian cackling goose (*Branta hutchinsii leucopareia*) from the U.S. Endangered Species List. Natural biodiversity, however, continues to be threatened by Norway rats (*Rattus norvegicus*) which have become established on at least 12 large islands in the Aleutian Island archipelago.

Rat Island, located in the central Aleutian Islands, 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 1780's (Black 1983). Over the past two centuries, rats have caused serious ecological

damage to the islands natural ecosystem by depleting some breeding seabirds and probably landbird populations, and altering plant and intertidal communities (Kurle et al. 2008, Major et al. 2006, Croll et al. 2005). Evidence from Aleut archaeological sites suggest that seabirds were likely more common on Rat Island prior to rat introductions (Funk et al. 2009). Particularly burrow-nesting seabirds such as tufted puffins, ancient murrelets, and whiskered, crested and least auklets (Funk et al. 2009), likely were extirpated by rat and introduced foxes, which we introduced in the late 1800's and removed in 1984 (Hanson and Goos 1984).

To complete the process of restoring Rat Island, the US Fish and Wildlife Service The Nature Conservancy, Alaska ,and Island Conservation partnered in September-October 2008 to remove introduced rats by aerially broadcasting cereal grain pellets containing 25-ppm brodifacoum (Brodifacoum 25-W Conservation, Bell Laboratories, Madison, WI) following standard techniques for rodenticide delivery on large islands.

To document the recovery of native species following rat removal and to assess the potential impact to non-target species from the rodenticide, biological surveys were conducted before and after eradication. These surveys, which focused on common birds, marine mammals, and intertidal biota, were conducted in 2007 and 2008 before the eradication and in 2009, nine months after the rodenticide application. Additional surveys are planned in 2010 and 2013 to assess population changes on the island. Here we report the results of surveys in 2009 and make preliminary comparisons to pre-eradication surveys.

2. Methods

2.1 ISLAND DESCRIPTION

Rat Island (51° 80' North, 178° 30' East) is located in the Rat Islands group of the Aleutian Islands (Fig. 1). The 2,900 ha (7,100 acres) island has steep coastal cliffs along the majority of the coastline backed by rolling hill and plateaus rising to a small range of

mountains with a peak elevation of 400 m. There are more than 30 offshore rock stacks and several islets. The largest, which is approximately 4 ha (10 acres) in size, is located less than 1 km off the southeast end of the island (Ayugadak Point). Rat Island is a designated Wilderness Area and has no inhabitants or facilities.

The Aleutian climate is marine-influenced and is characterized by generally overcast skies and frequent, often-severe, storm events driven by low-pressure systems and high winds (Rodionov et al. 2005). Rat Island is treeless and supports a subarctic maritime tundra ecosystem. Inland plant communities are characterized by low-lying dwarf shrubs (*Empetrum nigrum*), mosses, lichens and an assortment of forbs. The influx of marine-derived nutrients support densely vegetated grassland communities along the island's coast which is dominated by rye grass (*Leymus mollis* and *Calamagrostris* spp.) and interspersed with large umbels (*Angelica lucida* and *Heracleum lanatum*). The island is inhabited by a diversity of birds, including waterfowl, birds of prey, shorebirds, seabirds,

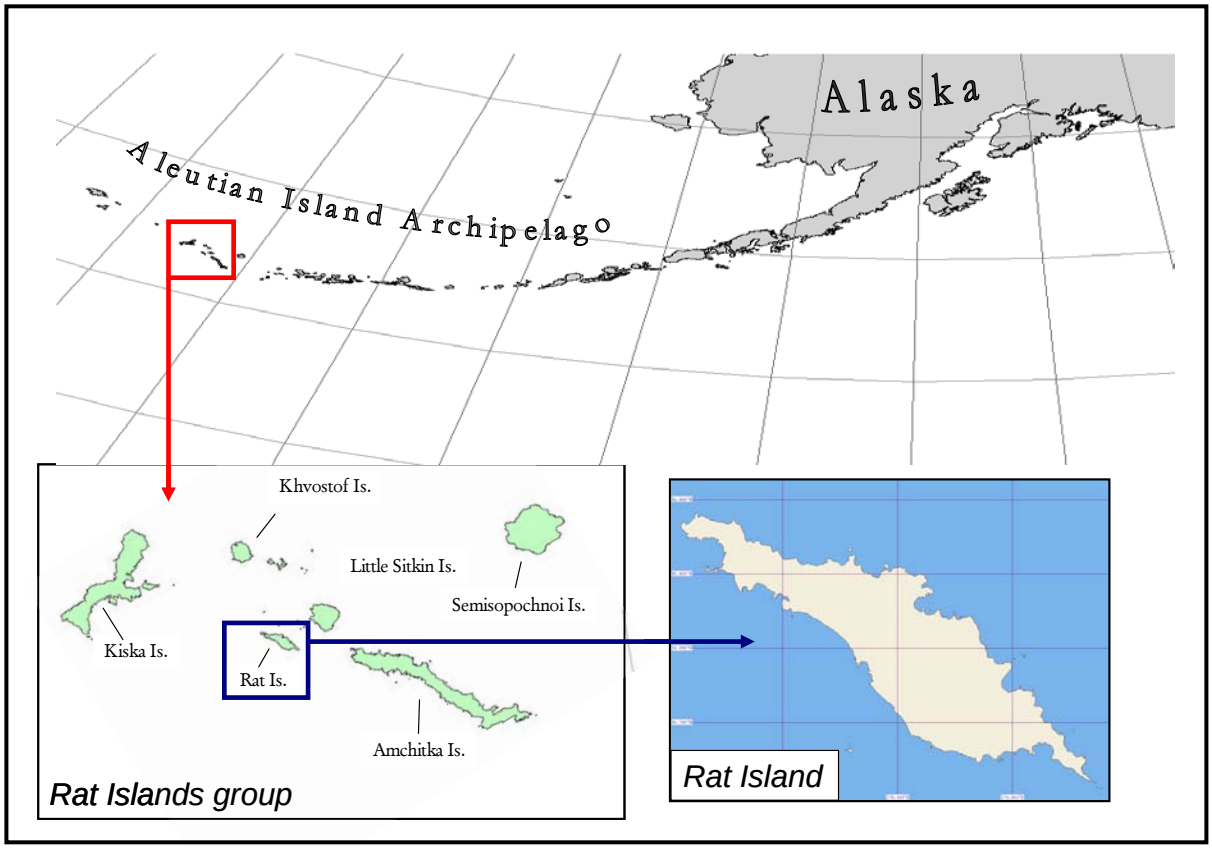

Figure 1. The location of Rat Island in the Rat Islands group, central Aleutian Island archipelago of Alaska is shown.

and landbirds (Dragoo and Deines 1983, Buckelew et al. 2007, Curl and Buckelew 2008). There appears to be an absence of burrow-nesting seabirds on Rat Island, and crevice-nesting species are rare, likely due to the impact of rats.

2.2 PARTICIPANTS

In 2009 the team of seven people arrived at Rat Island via the USFWS M/V *Tiglax* and set up the field camp on May 26, 2009 (Fig. 2). Surveys continued until June 18. These dates were similar to pre-eradication surveys when the island was visited in late May-mid June in 2007 and 2008 (Buckelew et al. 2007, Curl and Buckelew 2008). .

Figure 2. Field camp located in Gunner's Cove, Rat Island.

2.3 SURVEY DESIGN AND TIMING

Biological surveys were conducted in early spring (May-June) for most native island species to coincide with early seasonal breeding activity when birds tended to be occupying territories. The 2009 surveys were conducted approximately nine months after rat eradication occurred. Therefore the results reported here occurred less than one full breeding season after rat eradication, and therefore measures early pre-eradication effect.

Logistical constraints precluded the use of sampling other islands as controls, excluding a full Before-After Control-Impact design. In addition, while repeated measures across multiple years for the time periods prior to and after the eradication would have been ideal (i.e. Before-After Series with Replication), logistical and funding constraints precluded this design. Thus, selected sample plots were randomly distributed annually to produce abundance indices for each of three periods:

- two time periods before the eradication 2007 and 2008;
- two time period after the post eradication 2009 (this study)and 2010;
- and one period 5 years post eradication 2013

2.4 BIRDS

2.4.1 Passerines

To measure response of landbirds, particularly passerines, to the bait application three types of surveys were primarily used: i) point counts over the island interior; ii) beach surveys along coastlines ; and iii) passive acoustic surveys in both habitat strata. Calling winter wrens also were recorded during near shore boat surveys.

2.4.1.1 Point counts

A total of 55 random points were selected from a sampling universe of points at least 200 m apart over the island's interior (Appendix 1). These points were centers for "point counts" to document population indices for various species. One observer spent five minutes at each point recording all species seen or heard in two distance categories; within 50 m of the point and beyond 50 m (Fig. 3).

If a bird was flushed by the observer it was recorded by its take-off position. Weather conditions (wind direction and speed, percent cloud cover, and precipitation) were recorded at each point.

Surveys were performed only when winds were less than 15 knots, visibility was greater than 250 m, and there was little or no precipitation. As much as possible, point counts were conducted in

Figure 3. Winter wren observed on umbel during point count surveys.

the morning hours (0700-1100), although comparisons made among different time periods in 2007 indicated no difference in the number of birds detected between the morning vs. afternoon counts under comparable weather conditions (Buckelew et al. 2008).

Abundance indices were calculated as the mean number and standard deviation of birds observed per point by species. Results before and after the eradication were compared using a two sample t- test (α = 0.05). Additionally, the frequency of occurrence of bird detections observed during point counts by species was compared before and after eradication using a Pearson chi-square test with Yates' correction factor.

2.4.1.2 Beach transects

Five repetitions of beach transect surveys were conducted on 16 fixed beach transects located on the north and south sides of the island (Fig. 4; Appendix 2). The same beaches were sampled across all three years of this study (2007 to 2009) and were selected based on their relative length and suitability as bird habitat (e.g. areas of vegetation and beach wrack or debris characteristic of coastal bird habitat; Fig. 4). An observer slowly walked along each beach transect, counting all passerine birds seen or heard between the water's edge and 50m inland from the storm tide line. For each species, aural detections were recorded separately from visual detections, and when identified, fledgling winter wrens were tallied separately from adults.

Figure 4. Fixed beach transect surveyed for birds on Rat Island.

The time and GPS location were recorded for the start and end of each transect. The length

of each transect was measured following the contour of the beach between waypoints from a geo-referenced map in ArcGIS.

Surveys were performed only during favorable weather periods, when wind was less than 15 knots, visibility was greater than 250 m, and there was little or no precipitation. As much as possible, transects were conducted in the morning hours (0700-1100), although, results from 2007 surveys indicated no difference in the number of birds detected between the morning vs. afternoon under comparable weather conditions (Buckelew et al. 2008).

The abundance index for common passerine species (winter wrens, Lapland longspurs, and gray-crowned rosy finches) was calculated as the mean and standard deviation of observations made on replicate beach transect surveys. Results were compared to an average of bird abundance measured for two years prior to eradication using a paired t-test ($\alpha = 0.05$). The grand mean (e.g. mean of averaged observations per beach transect) and standard deviation by species were also calculated.

2.4.1.3 Acoustic recording

The relative abundance of species of interest, song sparrow, Lapland longspur, and winter wren, were indexed by recording bird vocalizations using Autonomous Recording Units (ARU's; Fig. 5) developed by the Bioacoustics Research Program (BRP) (Cornell University's Lab of Ornithology). Using a repeated measures design, the units were placed at locations randomly chosen for surveys conducted in 2007 and 2008, and moved to the next designated location after each recording interval (Appendix 3). Six units were deployed at 21 locations between May 31and June 14. Units were

Figure 5. An autonomous recording unit (ARU) and battery pack at a recording location on Rat Island.

deployed for three to four days at each location and sound files were recorded each morning for four hours just after sunrise, from 0700 – 1100.

Automated acoustic surveys measure two response variables of interest: occupancy (presence/absence) and activity rates (calls/hour) of target species at each survey point. Measurements of occupancy and activity at each sample point were calculated from recordings of ambient acoustic activity at each site. The vocalizations of target species were counted using X-BAT (Bioacoustics Lab, Lab of Ornithology, Cornell University), an acoustic analysis program that includes an automated detection method. Specifically, calls were detected using spectrogram cross-correlation, a method that calculates the correlation between the spectral qualities of a template sound (the calls of target species) and sounds on the audio files recorded in the field. When developing new templates and correlation thresholds, X-Bat results are checked in at least five audio files and refined to reduce error rates to a minimum. Due to the use of new, more accurate templates in 2009, data from 2007 and 2008 need to be re-analyzed prior to a comparison between years. This analysis will be completed in 2010.

As in any classification process, two types of errors are possible – *Missed Detections* (when target calls are missed) and *False Alarms* (when the calls of another species are classified as target sounds). Modification of the detection process to minimize one error can lead to increased rates of the other error type. To optimize our classification technique, we refined our templates and defined correlation thresholds so that *Missed Detection* and *False Alarms* were below 20% on five randomly selected audio files from the field. Besides the calls of other species, the greatest factor influencing error rates is wind. Recordings with >33% wind noise (where recordings are clipped) were omitted from the analyses for the focal species. Because of variation and complexity of song sparrow calls, we used multiple templates to generate alternate estimates occupancy and activity.

Mean call detections were calculated at daily and hourly scales for analysis. Call rates were standardized by hour. An individual sample consisted of all the data collected at a

single location. Calling rates for each location were calculated using the total of usable recordings from each site which varied due to high wind conditions.

2.4.1.4 Near shore skiff surveys

The entire shoreline and near shore waters of Rat Island were surveyed in designated segments (section 2.4.5.1) by small boat on June 3 and June 5. In addition to recording numbers of eagles and peregrine falcons (section 2.4.5.1), male winter wrens aurally detected along the coastline were recorded. The boat moved slowly (less than 10 knots) and as close to shore as possible so birds could easily be heard singing. When the boat could not move close to shore the boat motor was occasionally shut off to listen to for calling birds.

2.4.1.5 Strip transects (on the islet off Ayugadak Point)

The islet was visited on May 28 and June 11. During each visit surveys were conducted on each of two strip transects (Williams 2008) to document abundances of passerine birds (Appendix 4). One transect was conducted along the west beach where the number of individuals observed between the bluff edge and water edge were recorded by species. The second transect was conducted on an upland along the greatest north-south distance on the plateau. All individuals visible in the upland areas were counted by species. The mean and standard deviation of birds detected per transect were recorded and compared to identical transects walked in 2008.

2.4.2 Gamebirds

Rock ptarmigan were surveyed with transect territory mapping and by acoustic surveys.

2.4.2.1 Line transects

Figure 6. A rock ptarmigan flushed from the tundra on Rat Island.

Surveys for rock ptarmigan abundance were conducted by counting birds flushed while walking 750-m long line transects (Fig. 6). In 2009, a total 29 transects were surveyed:18 along the coast and 11 inland (Appendix 5). Survey locations were randomly select by habitat strata (coastal and inland). Twenty of these were repeated transects also surveyed in 2007 and 2008 before the eradication. The remaining nine transects were new transects added in 2009. Coastal transects were located along the top of the coastal berm parallel to and within 200 m of the coast and inland transects were perpendicular and farther from to the coastline. Surveys were conducted by one observer walking a transect and recording all birds observed regardless of distance from observer. When possible, distinctions between male and female ptarmigan were made as an abundance index of occupied territories.

For each transect a GPS waypoint was taken for both the start and end points, to facilitate repeat surveys in future years. Surveys were conducted during favorable weather conditions. When possible, transects were completed in the morning hours, when male ptarmigan are believed to more readily flush (S. Ebbert, pers. comm.).

The mean number of ptarmigan detected per transect before and after eradication and partitioned by habitat strata was compared using a two sample t-test ($\alpha = 0.05$). Mean abundance was compared on fixed transects before and after eradication using a paired t-test ($\alpha = 0.05$).

2.4.2.2 Acoustic recording

Autonomous recording units were used to measure occupancy and activity rates of rock ptarmigan using identical methods and survey points as described for passerine birds (section 2.4.1.3).

2.4.3 Birds of prey

Birds of prey were surveyed along the entire Rat Island coastline by foot and by boat.

2.4.3.1 Coastline survey on foot

The entire coastal periphery of Rat Island was visually surveyed for nesting birds of prey over a two-day period, June 9 and June 12, where the island was divided into two segments (East and West). An observer followed the coastal contour of the island walking the tops of cliffs or berms, where accessible, and visually scanned for nests or displays of territorial or nesting behavior. Observed visited known nest sites from surveys in previous years and carefully checked for attendance in 2009. Sections of the shoreline that could not be accessed on foot were visually scanned using binoculars. Coastal areas that were obscured from observation while on top of the island (e.g. cliff faces and sea stacks) were surveyed during the circumnavigation by boat (section 2.4.3.2). A GPS waypoint was taken at each nest location or for an area where adult birds displayed territorial behavior. When possible, the number of eggs, chicks and adults for each suspected or encountered nest was recorded.

2.4.3.2 Near shore skiff surveys

During near shore skiff surveys all birds of prey encountered were tallied and recorded according to methods in section 2.4.5.1. The locations and contents (when possible) of any nests encountered were marked with a GPS and recorded. Nest locations observed during skiff survey were merged in ArcGIS with those observed by foot to detect for potential overlap or double-counting of nests.

2.4.4 Waterfowl

Data were gathered on waterfowl by conducting lake surveys, beach surveys, and near shore boat surveys.

2.4.4.1 Lake surveys

Figure 7. A cluster of lakes surveyed for waterfowl on Rat Island.

The majority of lakes in nine main clusters of freshwater bodies identified on the island (Fig. 7; Appendix 6) were surveyed for waterfowl. Because the freshwater lakes and ponds are perennially fed by snow runoff, there is inter-annual variation in amount of water and therefore the size of the lakes. For consistency, surveys were only conducted at lakes previously surveyed in 2007 and 2008. In total 60 lakes (of approximately 96 on the island) were surveyed by walking the lake perimeter and visually scanning the water and shoreline for any nests, chicks, or adult birds. The number individuals encountered by species and a GPS point for each lake surveyed were recorded.

2.4.4.2 Beach transects

During beach transect surveys (section 2.4.1.2) any waterfowl species encountered were tallied. The average abundance by species was compared to before the eradication using a paired t-test ($\alpha = 0.05$).

2.4.4.3 Near shore skiff surveys

During near shore boat surveys (section 2.4.5.1) the numbers of seabirds, marine mammals, and waterfowl species seen or heard were tallied and recorded.

2.4.5 Seabirds

Abundance indices for seabirds were derived from near shore boat surveys and by observation of nesting birds made in the interior or along the islands' coast during all surveys for other species.

2.4.5.1 Near shore skiff surveys

Figure 8. Observers conducting a near shore survey from a skiff along the coast of Rat Island.

Surveys for species occupying the coastline and near shore waters, particularly ledge and crevice-nesting seabirds that may not have been encountered during other surveys, were conducted by small boat during an island circumnavigation on June 3 and June 5 (Fig. 8). The island circumnavigation was broken into six designated segments that spanned the periphery of near shore waters around the island (Appendix 7). The numbers of seabirds encountered were recorded by species. Surveys were conducted from a skiff travelling as close to the shoreline as swell and algae beds would allow. Approximate ranges from shore were 50 m along the north shore and 150 m along much of the south shore. The skiff maintained a steady velocity forward (approximately 3 knots) with occasional stops made to listen for calling winter wrens (section 2.4.1.4). Two observers positioned on the port and starboard side of the skiff counted birds seen on the water and shoreline. A third observer was responsible for recording data.

2.4.5.2 Nest surveys

2.4.5.2.1 Ledge-nesting seabirds

During near shore skiff surveys counts of all ledge-nesting seabirds (e.g. cormorants) observed on cliffs or offshore rocks were made. No replicate counts were made. Counts included individual birds or nests as far as 200 m offshore of Rat Island.

2.4.5.2.2 Surface-nesting seabirds

The locations of surface-nesting seabirds (e.g. glaucous-winged gull) nesting areas were recorded and attendant birds were counted during all surveys for other species. At the one

nesting colony found, the survey team walked through the area approximately 5 meters apart documenting nests and their status (i.e., nest bowls which were considered active if they had fresh nest material and the number of eggs or chicks in each nest). The GPS location of all nest bowls and active nests were recorded (Appendix 8).

2.4.5.2.3 Burrow-nesting seabirds

Figure 9. Photo of burrow-nesting seabird plot established on Rat Island.

To document the potential recolonization of burrow-nesting seabirds (such as storm-petrels, ancient murrelets, Cassin's auklets, whiskered auklets, and tufted puffins) following rat removal we established three permanent study plots (Appendix 9) in the type of habitat used by these species on nearby islands. Two plots were established on gentle sea facing slopes (Fig. 9) with soft, peety soils covered by tall plants mostly a mix of *Calamagrostis, Poa*, and coastal forbs. A third plot was established in an area with a prominent coastal berm sloping to the coast with vegetation predominantly composed of coastal forbs interspersed with *Leymus* grass.

Each plot was 100m^2, with dimensions of 10 x 10m or 5 x 20 m. Plot corners were permanently marked with rebar, and a GPS location taken at one of the corners (Appendix 9). Burrows located in each plot were tallied, and for each burrow the diameter, presumed state of activity (active or non-active), and likely residential species were recorded according to USFWS standard *Species Identification* criteria. The occupancy status was checked for all burrows observed based on similar standard *Occupancy* criteria (Williams et al. 2008).

2.4.5.3 Acoustic recording

Many burrow-nesting seabirds are present on the colony only at night, and vocalize in the vicinity of their burrows. We used passive acoustic monitoring as a measure of the

presence of nocturnal burrow-nesting seabirds. Potential nocturnal burrow-nester breeding areas, based on slope, soil depth, and vegetation, were identified and delineated with GPS. At each of three sites, two ARUs were deployed at least 200m apart (Appendix 3) for five to eight days. Sound files were recorded for ten minutes every hour, 24 hours per day. Analyses were conducted in the same manner as for passerines and rock ptarmigan (section 2.4.1.3) but corrections for wind noise were not used. Recordings were analyzed for ancient murrelet, crested auklet (as a surrogate for whiskered auklets), and Leach's storm petrel. Recordings will be reanalyzed for whiskered auklet in 2010.

2.4.5.4 Beach transects

Any seabirds observed while walking beach transects (section 2.4.1.2) were tallied by species. This information was documented in the annotated species list (section 2.6).

2.4.6 Shorebirds

No specific surveys targeted shorebirds but they were recorded when observed during lake, near shore skiff, point count, and beach surveys.

2.5 MARINE MAMMALS

2.5.1 Near shore skiff surveys

During the island circumnavigation survey by boat (section 2.4.5.1), the number of all marine mammals observed were recorded by species. In addition to this information, data gathered by the National Marine Fisheries Service (NMFS) and the U.S. Geologic Survey (USGS) during marine mammal surveys conducted every two years may be used to monitor populations on Rat Island.

2.6 INCIDENTAL OBSERVATIONS

Opportunistic observations of all species were recorded incidental to directed surveys. The number of individuals, their age class, the date and time, and a GPS location for any bird nests was also recorded. These observations were compiled into an annotated list of species (Appendix 11-13), which, following USFWS standardized annotation criteria (Table 1), includes information about the frequency of observation, breeding status, and index of general abundance.

Table 1. USFWS standard annotated key for species abundance and breeding status codes.

Species abundance	
Category	*Criteria*
Abundant	• greater than or equal to 50 individuals per day or 6 per hour
Common	• 10-49 individuals per day or 2-5 per hour
Fairly common	• 5-9 individuals per day or 1 per hour
Uncommon	• 2-4 individuals per day or less than 1 per hour
Rare	• 1 individual per day

Breeding status	
Category	*Criteria*
Confirmed	• observations of current nests, eggs, or chicks; recently fledged young; or distraction displays
Probable	• observations of pairs or territorial behavior
Possible but not likely	• species seen or heard, but no other evidence for breeding

2.7 INTERTIDAL INVERTEBRATES AND ALGAE

2.7.1 Photo plots

Surveys were conducted to describe the community structure of intertidal flora and fauna. Methods were similar to those developed by Kurle (2005), who previously conducted

studies to document the impacts of Norway rats on marine bird densities and rocky intertidal communities in the Aleutians Islands, including Rat Island. During our study, surveys were conducted in eight locations; five on the north side of the island and three on the south (Appendix 14).

At each location digital photos of the intertidal plots were taken every 5 m along a 30 m transects placed in the low and mid intertidal zones. Digital photos were taken of a 365 cm^2 quadrat to measure percent cover of algae, sessile, and mobile invertebrate organisms. For each plot a digital photo was first taken of the surface coverage. A second photo of the plot was taken with the algal layer removed to reveal the understory community. Low zones were categorized by *Alaria* and *Laminaria* algae, and the mid zone was categorized by *Rucus* and *Halosaccion* algae.

Digital photos were analyzed using Adobe Photoshop 6.0. A digital 6x9 rectangular grid was overlain on each photo and percent cover calculated as the ratio of the number of each species lying below an intersection of the gridline to the total number of intersections within each grid. Percent cover of sessile organisms was calculated for barnacles, sponges, and tunicates. The percent cover of larger kelps (coralline algae and all fleshy algal species) was estimated by counting the percent cover of stipes that remained after the removal of the large algal blades. The numbers of individual mobile invertebrates (anemones, chitons, herbivorous snails, limpets, mussels, urchins, crustaceans, and sea stars) were counted in each digital photo to estimate density.

3. Results

3.1 BIRDS

3.1.1 Passerines

3.1.1.1 Point counts

Indices of abundance for Lapland longspurs and gray-crowned rosy finches were similar in 2009 to prior years, but the winter wren index was slightly higher in 2009 than previous (Table 2). Only longspur was commonly encountered on this survey.

Table 2. i) The mean number and standard deviation of birds detected point count by species before (n=74) and after (n=55) eradication. ii) The frequency of occurrence of birds detected on point counts by species before and after eradication.

Species	**Pre**	**Post**	**t**	**P**
i) Detections per point count				
Gray-crowned rosy finch	0.03 ± 0.16	0.02 ± 0.14	0.327	*ns*
Lapland longspur	4.5 ± 2.9	5.1 ± 1.9	1.444	*ns*
Winter wren	0.1 ± 0.4	0.3 ± 0.7	2.197	0.03
Species	**Pre**	**Post**	**χ^2**	**P**
ii) Frequency of occurrence				
Gray-crowned rosy finch	0.03	0.02	1.069	*ns*
Lapland longspur	0.92	1.00		
Winter wren	0.10	0.15		

3.1.1.2 Beach transects

Similar to the point count data, indices derived from beach transects suggested no differences between 2009 and earlier years for rosy finches and longspurs, but a higher index for winter wrens (Table 3).

Table 3. The mean number ± s.d. of birds per species observed on fixed beach transects prior to (n= 2 repetitions of 16 transects repeated 5 times) and following eradication (n= 16 transects repeated 5 times).

Species	**Pre**	**Post**	**t**	**P**
Gray-crowned rosy finch	1.3 ± 0.8	0.8 ± 0.8	1.993	*ns*
Lapland longspur	2.1 ± 0.6	2.6 ± 1.1	-1.963	*ns*
Winter wren	2.6 ± 0.7	3.3 ± 1.0	-2.469	0.026

3.1.1.3 Acoustic recording

After wind noise was removed from each sample, usable ARU recordings at each location ranged from 1 to 20 hours. Overall, 242.95 hours of data which was able to be analyzed was recorded with a mean of 11.57 ± 4.98 hours per location (mean ± SD). Occupancy and activity at each location, and overall mean calls per hour are reported for Lapland longspurs, winter wrens, and song sparrows (Table 4).

Lapland longspurs were present at all but one recording location in 2009. For the location where the species was detected, calls ranged from 0.38 to 119.88 calls/ hour. Song sparrows were detected on only three of the 21 sites where recorders were deployed, and on these sites calls ranged from 0.13 calls/hour to 2.57 calls/hour. Winter wren calls were detected at only three of 21 ARU locations and ranged from 0.1 calls/hour to 39.79 calls/hour.

Table 4. The occupancy and activity overall mean calls per hour measured from analyzable hours of acoustic recording on Rat Island, May- June 2009.

Species	Mean hours recorded ± SD	Site occupancy	Mean call per hour ± SD
Lapland longspur	11.57 ± 4.98	0.95	19.87 ± 28.31
Song sparrow (template 1)	11.57 ± 4.98	0.14	0.14 ± 0.56
Song sparrow (template 2)	11.57 ± 4.98	0.00	0.00 ± 0.00
Winter wren	11.57 ± 4.98	0.14	1.93 ± 8.68

3.1.1.4 Near shore skiff surveys

Passerines seen or heard during near shore skiff surveys are reported in Table 7 (section 3.1.5.1). Winter wrens were the only passerine species observed during these surveys. Passerines were not recorded during the near shore skiff surveys in 2007.

3.1.1.5 Strip transects (on the islet off Ayugadak Point)

Although Lapland longspurs were observed in upland habitats on the islet, they did not occur typically on the strip transects (Table 5). No longspurs were detected during directed on incidental surveys before eradication. In upland habitats no song sparrows were detected following eradication. While transiting the island no song sparrows were observed outside the transect area, while prior to the eradication an estimated 24-36 individuals were thought to occupy the islet (Williams 2008). In contrast there were similar numbers of winter wrens present after the eradication as before.

Table 5. The number of passerine birds by species observed on beach and upland line transects on the islet off Ayugadak Point before (2008; n=1) and after eradication (2009; n =2). The mean and standard deviation are reported for surveys conducted after eradication.

Species	Upland		Beach		*t*	P
	Pre	Post	Pre	Post		
Lapland longspur	0	0	0	2.0 ± 0.0	1.000	*ns*
Song sparrow	2	0	9	0	1.571	*ns*
Winter wren	1	2.7 ± 1.5	2	3.0 ± 0.0	4.000	*ns*

3.1.2 Game birds

3.1.2.1 Line transects

Our index of ptarmigan abundance was higher in 2009 than in earlier years for coastal and inland habitats (Table 6).

Table 6. A comparison of the relative abundance of rock ptarmigan detected using line transects conducted before (Pre) and nine-months after (Post) bait application. i) Birds detected across all transect types (fixed and random locations; Pre n = 58, Post n = 29). ii) Birds detected on fixed location transects; Pre n = 20 with 2 repetitions; Post n= 20). iii) Birds detected on transects located in coastal habitat (Pre n = 28; Post n = 17). iv) Birds detected on transects located in upland habitat (Pre n = 27; Post n =12).

Survey	Pre	Post	t	P
i) All transects (distance: pre =41 km; post= 22 km)				
	1.2 ± 1.4	3.6 ± 1.6	-7.186	<0.001
ii) Repeated transects (distance: pre = 32 km; post= 16 km)				
	1.1 ± 1.4	3.6 ± 1.6	-6.626	<0.001
iii) Coastal transects (distance: pre = 21 km; post= 13 km)				
	1.4 ± 1.7	3.9 ± 1.4	-5.052	<0.001
iv) Upland transects (distance: pre = 20 km; post= 9 km)				
	1.0 ± 0.9	3.1 ± 1.9	-4.651	<0.001

3.1.2.2 Acoustic recording

Two different templates (t2 and t3) were used to identify rock ptarmigan calls from acoustic recordings. Both templates found ptarmigan present at all but one ARU location (Table 7). Call rate was highly variable within and between templates, with total calls per hour ranging from 0.15 to 10.75 (t 2) and from 0.57 to 2393.3 calls/hour (t 3).

Table 7. The occurrence and overall mean calls per hour measured from analyzable hours of acoustic recording for rock ptarmigan on Rat Island, May- June 2009.

Species	Mean hours recorded ± SD	Site occupancy	Mean call per hour ± SD
Rock ptarmigan (t 2)	11.57 ± 4.98	0.95	2.05 ± 2.25
Rock ptarmigan (t 3)	11.57 ± 4.98	0.95	163.7 ± 523.3

3.1.3 Birds of prey

3.1.3.1 Coastline survey on foot

During the walking survey of the coastline approximately 31 km was surveyed for nesting birds of prey. Each previously known nesting territory was revisited and carefully checked (Table 8). In 2008, eight active bald eagles nests were delineated with a total of twelve chicks. No active eagle nests were found in 2009. One pair of adult eagles was observed on the island, but it was not known whether a territory was maintained. Four peregrine falcon pairs were encountered in 2009 with at least two of the pairs actively breeding. In 2008, three peregrine falcon pairs were observed, but no nests were seen.

Table 8. The average number of bald eagle (i) and peregrine falcon (ii) by breeding pair (defined as pair with active nest), non-breeding pair (territorial pair without an active nest), or chicks (visually observed) encountered during island circumnavigation surveys by foot on Rat Island before (Pre, 2008) and after rat eradication (Post, 2009).

Species	Pre	Post
i) Bald eagle		
Territorial pair	8	0
Non-territorial pair	4	1
Chicks	12	0
ii) Peregrine falcon		
Territorial pair	0	4
Non-territorial pair	3	2
Chicks	0	0

3.1.3.2 Near shore skiff surveys

Observations of birds of prey during near shore skiff surveys are reported in Table 11 and 12 in section 3.1.5.1. Five peregrine falcons and one bald eagle were observed. No nests or territorial behavior were noted for eagles. One falcon nest was observed along a cliff face using binoculars, although the nest contents were not visible.

3.1.4 Waterfowl

3.1.4.1 Lake surveys

Few waterfowl were detected during lake surveys in 2009 or in earlier years (2007 and 2008) (Table 9). In both 2008 and 2009, a few Aleutian cackling geese were observed at the lakes, and a single teal and an unidentified duck were seen in 2009.

Table 9. The number of waterfowl by species observed during lake surveys before (n = 60) and after (n = 60) rat eradication.

Species	Pre	Post
Aleutian cackling goose	13	2
Green-winged teal	0	1
Duck unid.	0	1

3.1.4.2 Beach transects

The most common waterfowl species observed in near shore marine waters during beach transects were harlequin ducks and green-winged teal (Table 10). No significant difference in abundance of waterfowl on these surveys were detected between 2009 and earlier years.

Table 10. The mean abundance and standard deviation of waterfowl by species detected on beach transects before and after rat eradication (n = 16 transects, 5 repetitions).

Species	Pre	Post	t	P
Green-winged teal	0.2 ± 0.5	0.2 ± 0.4	0.145	*ns*
Harlequin duck	6.0 ± 10.8	5.8 ± 9.5	-0.071	*ns*

3.1.4.3 Near shore skiff surveys

The total number of waterfowl observed by species during near shore skiff surveys is reported with the results from these surveys (Table 11-12). Five waterfowl species were observed. Harlequin ducks and common eiders were the most common species observed.

3.1.5 Seabirds

3.1.5.1 Near shore skiff surveys

Twenty marine bird species (including shorebirds) and one passerine species were observed during the island circumnavigation. For comparison, the total number of seabirds encountered by species during surveys conducted in 2008 is provided in Table 11. The numbers of birds by species observed per survey segment are provided for 2009, since transect locations differed in 2008 (Table 12). Similar surveys were conducted in August 2007 before the eradication, however because of different time of the breeding season when the surveys were conducted (August in 2007, and June in 2008 - 2009) the results are excluded from this analysis. In 2009, a greater number of ancient murrelets, glaucous-winged gulls, and common eiders were detected, whereas numbers of harlequin ducks, pigeon guillemots, and horned and tufted puffins were lower. Winter wrens audibly detected were greater in 2009 than 2008.

Table 11. Number of birds by species observed during near shore skiff surveys before (2008) and after (2009) eradication.

Order	Species	Common Name	Code	Pre (2008)	Post (2009)
Anseriformes	*Branta hutchinsii leucopareia*	Aleutian cackling goose	ACGO	0	40
	Somateria mollissima	Common eider	COEI	79	113
	Anas carolinensis	Green-winged teal	GWTE	6	2
	Histrionicus histrionicus	Harlequin duck	HADU	1052	387
	Mergus spp.	Merganser spp.	MESP	7	0
Charadriiformes	*Larus glaucescens*	Glaucous-winged gull	GWGU	615	1027
	Haematopus palliates	Black oystercatcher	BLOY	22	22
	Calidris ptilocnemis	Rock sandpiper	ROSA	1	4
	Uria aalge	Common murre	COMU	5	2
	Uria spp.	Murre species	MUSP	2	4
	Brachyramphus brevirostris	Kittlitz's murrelet	KIMU	0	2
	Synthliboramus antiques	Ancient murrelet	ANMU	179	473
	Stercorarius parasiticus	Parasitic jaeger	PAJA	7	0
	Stercorarius spp.	Jaeger species	JASP	0	1
	Cepphus columba	Pigeon guillemot	PIGU	304	178
	Phalaropus lobatus	Red-necked phalarope	RNPH	1	0
	Fratercula corniculata	Horned puffin	HOPU	140	74
	Fratercula cirrhata	Tufted puffin	TUPU	83	23
	Aethia pusilla	Least auklet	LEAU	1	0
	Aethia pygmaea	Whiskered auklet	WHAU	0	2
Passeriformes	*Troglodytes troglodytes*	Winter wren	WIWR	75	91
Pelicaniformes	*Phalacrocorax pelagicus*	Pelagic cormorant	PECO	0	180
	Phalacrocorax urile	Red-faced cormorant	RFCO	6	3
	Phalacrocorax spp.	Unidentified cormorant	COSP	398	364
Procellariformes	*Puffinus spp*	Shearwater species	SHSP	0	1
	Phoebastria immutablis	Laysan albatross	LAAL	3	4

Table 12. Number of birds by species observed by transect (A-F and Ayugadak islet) during near shore skiff surveys in 2009.

Common Name	Code	A	B	C	D	E	F	islet
Aleutian cackling goose	ACGO					40		
Common eider	COEI	15	10	18	70			
Green-winged teal	GWTE						2	
Harlequin duck	HADU	114	79	80	36	78		
Merganser spp.	MESP							
Glaucous-winged gull	GWGU	203	165	75	26	493	53	12
Black oystercatcher	BLOY		10	3	3	4		2
Rock sandpiper	ROSA		4					
Common murre	COMU	2						
Murre species	MUSP						4	
Kittlitz's murrelet	KIMU						2	
Ancient murrelet	ANMU	70	121	15	36	204	26	1
Parasitic jaeger	PAJA							
Jaeger species	JASP			1				
Pigeon guillemot	PIGU	48	29	29	17	38	10	7
Red-necked phalarope	RNPH							
Horned puffin	HOPU	2	1	2		50	19	
Tufted puffin	TUPU	8				1	10	4
Least Auklet	LEAU							
Whiskered auklet	WHAU		1			1		
Winter wren	WIWR	13	38	19	21			
Pelagic cormorant	PECO	107	19	21	4	24	4	1
Red-faced cormorant	RFCO	2				1		
Cormorant species	COSP	28	12	22	35	102	109	56
Shearwater species	SHSP					1		
Laysan albatross	LAAL	3	1					

3.1.5.2 Nest surveys

3.1.5.2.1 Ledge-nesting seabirds

During the island circumnavigation although cormorants were observed no nests were seen.

3.1.5.2.2 Surface-nesting seabirds

Two glaucous-wing gull breeding areas were identified on Rat Island. A complete colony survey was conducted at one location (GWGU colony 1) inland from the western side of Gunner's Cove. Active nests and chicks were encountered during the survey in 2009 (Table 13). Nests and juvenile gulls were observed in previous years in this area, although no formal surveys were conducted. At the other location, located towards the central-east side of the island in close vicinity to a freshwater lake system, only a nest was encountered however several fresh nest bowls were seen. Therefore the area was not classified as a colony.

Table 13. The number of active nests, eggs, chicks, and fresh nestbowls found at glaucous-winged gull colony plot.

Location	**#active nests**	**total eggs (mean eggs/nest)**	**total chicks**	**# nest bowls**
GWGU colony 1	12	27 (2.7 ± 0.7)	4	56

3.1.5.2.3 Burrow-nesting seabirds

Three seabird burrow plots were established in an area with perceived potential for burrowing seabirds, although no active burrows were detected (Table 14). The majority, if not all, burrows appeared to be rat burrows based on size (<10 cm diameter) apparently now abandoned based on new vegetation or spider webbing at the burrow entrance.

Table 14. The numbers of burrows indexed by potential occupant species and diameter size measured in three permanent burrow-nesting seabirds plots on Rat Island.

Seabird plot	Burrow entrance diameter (cm)		Potential species occupancy
	<10	>10	
Plot 1	7	8	abandoned rat (15)
Plot 2	2	4	abandoned rat (6)
Plot 3	0	1	abandoned rat (1)

During a boat trip around Rat Island biologists visited ten vegetated offshore rocks to search for signs of rats and nesting birds. Nests were recorded by species, and a photo of the nest and GPS waypoint taken. Encountered during these surveys were: four pigeon guillemot nests, each with two eggs in the nest, one common eider nest with five eggs; and one rock sandpiper nest with two eggs.

3.1.5.3 Acoustic recording

Overall, 260.8 analyzable hours were recorded for nocturnal seabirds with a mean of 43.46 ± 19.28 hours per location. No calls were detected at any of the ARU sampling locations.

3.1.6 Shorebirds

3.1.6.1 Lake surveys

No nests, chicks or eggs of shorebirds were observed during 2009 lake surveys, although breeding activity was observed incidentally and is reported in the annotated species list (Appendix 11-13). One rock sandpiper was seen at lake system 10 (see Appendix 6).

3.1.6.2 Near shore skiff surveys

Shorebirds seen or heard during near shore surveys are reported together with results of all avifaunal species from skiff surveys (Table 11-12). Black oystercatchers were the most abundant species observed during surveys, with rock sandpipers also reported.

3.1.6.3 Point counts

No shorebirds were seen or heard during point counts during 2009 surveys.

3.1.6.4 Beach transects

Three species of shorebirds were observed on beach transects. Black oystercatchers and rock sandpipers, both breeding at Rat Island, were seen regularly, and migrant wandering tattlers were seen occasionally (Table 15). There were no differences in abundance indices between years.

Table 15. The mean abundance and standard deviation of shorebirds by species detected on beach transects prior to (n = 2 repetitions of 16 transects repeated 5 times) and following rat eradication (n = 16 transects repeated 5 times).

Species	**Pre**	**Post**	**t**	**P**
Black oystercatcher	0.24 ± 0.20	0.11 ± 0.18	-2.076	*ns*
Rock sandpiper	0.46 ± 0.93	0.59 ± 1.07	0.825	*ns*
Wandering tattler	0.03 ± 0.08	0.06 ± 0.18	0.689	*ns*

3.2 MARINE MAMMALS

3.2.1 Near shore skiff surveys

Marine mammals were recorded incidentally during near shore boat surveys even though this survey was not designed specifically for these species. The survey boat stayed well offshore the Steller sea lion rookery, therefore the numbers in Tables 16 and 17 are simply provided for documentation of relative abundance and distribution. No pups were seen during these surveys, although an effort was made to distinguish adult Steller sea lions from pups.

Table 16. The number of marine mammals by species observed during near shore skiff surveys before (2008) and after eradication (2009).

Order	Species	Common Name	Code	Pre (2008)	Post (2009)
Carnivora	*Phoca vitulina*	Harbor seal	HASE	33	26
	Enhydra lutris	Sea otter	SSL	1	0
	Eumetopias jubatas	Steller sea lion	SEOT	106	46

Table 17. Number of marine mammals observed by transect (A-F and Ayugadak islet) during near shore skiff surveys in 2009.

Common Name	Code	A	B	C	D	E	F	islet
Harbor seal	HASE	11	0	0	0	11	0	0
Sea otter	SEOT	0	0	0	0	0	0	0
Steller sea lion	SSL	6	0	1	5	3	0	31

3.3 INCIDENTAL OBSERVATIONS

Incidental observations were compiled into an Annotated list of species (Appendix 11-13), which, following USFWS standardized annotation criteria, includes information about the frequency of observation, breeding status, and index of general abundance. To provide information about spatial distribution, all nests incidentally encountered while

transiting across the island were mapped (Appendix 15). In total seven black oystercatcher nests (two with chicks), six rock sandpiper nests (one with two chicks), two common eider nests, two Aleutian cackling goose nests, one parasitic jaeger nest, and one snow bunting nest were encountered.

3.4 INTERTIDAL FLORA AND FAUNA

3.4.1 Photo plots

The relative abundance of intertidal organisms measured in 2009 is compared with data collected before the eradication (Table 18). Fleshy algae were less abundant than detected prior to eradication, whereas the more snails were detected after eradication than in previous years. There were no differences detected in the abundance indices for sea anemone, tunicate, sponges, sea stars, and limpets measured in 2009 when compared to surveys conducted before eradication.

Table 18. The relative abundance of intertidal organisms measured before and after rat eradication on Rat Island.

Species type	Pre	Post	*t*	P
% cover fleshy algae	28.7 ± 22.3	22.1 ± 19.5	-3.735	<0.001
sea anemone m^{-2}	61.9 ± 170.4	36.3 ± 158.5	-1.856	*ns*
% cover tunicate	1.7 ± 5.7	1.8 ± 6.9	0.343	*ns*
% cover sponge	9.0 ± 18.1	10.8 ± 20.3	1.131	*ns*
sea stars m^{-2}	9.7 ± 71.3	4.2 ± 24.0	-1.130	*ns*
snails m^{-2}	352.1 ± 1671.1	933.5 ± 4168.0	2.495	0.013
limpets m^{-2}	19.1 ± 52.2	21.6 ± 48.8	0.581	*ns*

4. Discussion

4.1 BIRDS

4.1.1 Passerines

For surveys conducted after eradication there was no evidence of a significant difference in Lapland longspur or gray-crowned rosy finches, although longspurs were more abundant after eradication. Low sample sizes and high variability make detecting any pattern difficult.

There was evidence of an increase in winter wren abundance following eradication. Kelp wrack and debris deposited on beaches provides high quality habitat for winter wrens, making them the most commonly observed passerine species along the coast. Winter wrens were the only passerine species recorded during near shore skiff surveys. The loud vocalizations of males calling along the shoreline make detections relatively easy during periods of calm weather in the early morning. Higher winds in the late morning and afternoon made hearing vocalizations more difficult. Therefore, the survey protocol was adapted to frequently turn off the engine inside coastal coves to listen for calling males.

Before eradication song sparrows occurred rarely on Rat Island, but were the most abundant passerine species on the islet off Ayugadak Point. The islet prior to eradication was thought to be rat-free, but lies within rat swimming distance from Rat Island therefore could have contained rats or provided a source for reinvasion back to Rat Island during or after eradication. The original eradication operations strategy in fall 2008 included treatment of the islet with bait stations to reduce the risk of rodenticide exposure to non-target birds, particularly song sparrows that are known to directly consume the bait (Buckelew et al. 2006). However permits needed to access the islet were not received in sufficient time to deploy stations. Therefore, the islet was treated with an aerial broadcast of rodenticide bait.

It appears song sparrows may have been adversely affected during the aerial baiting operation, although no dead birds were found during surveys in 2009. Song sparrows were confirmed to still occur or have recently moved onto the island. Song sparrows calls were detected using acoustic recording and by aural detection by a Refuge biologist who revisited the island in late June 2009 and heard sparrows calling (J. Williams, pers. comm.). Notably song sparrows had not been detected in previous years using acoustic recording. Previous year's acoustic recording data need to be re-analyzed with the revised sampling templates used in 2009 to make comparisons between pre and post eradication abundances. It is likely that song sparrow populations will recover after rat removal on Rat Island and reach much higher population levels than could be sustained with rats present.

The increased numbers of longspurs and wrens observed is a promising preliminary indication of population change likely attributed to rat eradication. Passerine birds, including song sparrows, are expected to become more abundant either through a direct release in rat predation pressure, or as a result of increased food availability.

4.1.2 Game birds

Ptarmigan detected in coastal and upland habitats were significantly more abundant following eradication. The numbers detected on line transects were 105% higher after eradication than before, indicating that ptarmigan abundance did not appear to be adversely impacted by the eradication operation. Although no nests were physically observed, hens rearing young were observed on the island.

Interannual fluctuations in ptarmigan density have been observed on other islands in the Aleutians (V. Byrd, pers. comm.). These changes are most likely related to differences in regional wintertime conditions, such as snow cover or temperature, which may affect food availability or overwinter survival (V. Byrd, pers. comm.). Future surveys of ptarmigan abundance on Rat Island are necessary to determine whether the observed increases are associated with rat removal.

Acoustic surveys for rock ptarmigan indicated they were present in highly variable amounts across the island. Because a different template was used to detect ptarmigan calls in 2009, data from 2008 need to be reanalyzed before pre and post eradication comparisons can be made.

4.1.3 Birds of prey

In May-June 2009, an unexpectedly high number of bald eagle carcasses were encountered (Buckelew et al. 2009). Necropsy and tissue residue analyses indicated that all eagles tested were exposed to brodifacoum and most likely succumbed to anti-coagulant poisoning. Eagles likely suffered secondary poisoning from scavenging on rat or glaucous-winged gull carcasses, also found on the island in high numbers during these surveys. In total, 43 eagle carcasses were collected on Rat Island, which exceeds the estimated bald eagle population on Rat Island (Curl and Buckelew 2008). During 2008, eight eagle nests were discovered on Rat Island. Subadults were frequently seen perched in upland areas surrounding breeding eagle territories. In 2009, no nests were found on the island, although observers visited each former nest site. One pair of adult eagles was observed flying over the highest hill located on the western end of the island. One adult eagle perched occasionally on the ridgetop in this area, however no indications of nesting activity were observed. Numerous adult and subadult eagles were observed flying over the island and resting on offshore rock stacks or precipices. The apparent lack of eagle territories makes estimating the exact numbers of individuals observed difficult, however four independent sightings of adult eagles and six sightings of subadults were made.

At least six pairs of peregrine falcons were observed on the island. Four of the pairs exhibited nest defense behaviors. Only one nest was directly observed, although the nest location on a cliff face made determination of its contents difficult. In 2008, three pairs of peregrine falcon were observed on the island suggesting that falcons, while vulnerable to anti-coagulant poisoning, did not suffer the same impact as eagles and are still actively breeding.

4.1.4 Waterfowl

It is not known how suitable the habitat on Rat Island was for nesting waterfowl prior to rat introduction, but clearly the wetlands were not highly productive for ducks in 2007-2009. Nevertheless, some green-winged teal bred as we saw three teal broods during these surveys. The other nesting species of waterfowl included common eider (three nests were found along the coast or on offshore islets) and Aleutian cackling goose. Other species of ducks that might be expected to nest on Rat Island include mallard and red-breasted merganser, but we did not see any of either species in 2009.

4.1.5 Seabirds

Seabird numbers and species diversity in waters around Rat Island were not different between 2008 and 2009. In 2008, 3,175 total birds were recorded. In 2009 3,075 birds were observed. A greater number of ancient murrelets, glaucous-winged gulls, and common eiders were detected during surveys in 2009. Variation in the numbers of seabirds observed is most likely an artifact of differences in weather conditions, proximity of the boat to shore, observer aptitude, and time of day. Additionally there were differences in effort in 2008 and 2009. In 2008 the survey was completed in three days, but only two days were spent surveying in 2009. Also, in 2009 survey segments from Dragoo and Deines (1983) were used, but those segments were not used in 2008. Survey results may reflect these differences.

In 2009, an unexpectedly high (>230) number of glaucous-winged gull carcasses were encountered along the coastline and around freshwater lakes. Tissues from some of the carcasses tested positive for brodifacoum, suggesting that some gulls died from anti-coagulant exposure. It is assumed that the impact to gulls was short-term and the population will recover quickly. No difference in gull abundance was detected during beach transect and near shore skiff surveys. Continued breeding activity of gulls on the island is a positive indication of this recovery.

During 2008 a small glaucous-winged gull colony was suspected to occur above Gunner's Cove. Gull breeding activity was first surveyed in 2009. Nests with eggs or nest bowls were indentified in the colony plot however surveys were conducted too early to quantify nest productivity. Two of the 12 nests in the colony had newly hatched chicks at the time the crew departed the island.

No suspected seabird burrows were identified on the island or in established plots, nor were nocturnal seabirds detected at any of the ARU sampling locations. Burrows thought to be abandoned rat burrows were common in survey plots. It is anticipated that burrowing seabirds, including pigeon guillemot, ancient murrelet, tufted puffin, fork-tailed storm petrels, and perhaps whiskered auklet, will increase in numbers after rat removal. The active seabird breeding colony on the islet off of Ayugadak Point could provide a population from which these birds may recolonize Rat Island.

Fig 11a. Pigeon guillemot nesting in a crevice on a vegetated rock stack offshore Rat Island.

Fig 11b. Eggs incubated by adult pigeon guillemot on vegetated rock stack offshore Rat Island.

Several other areas on the island were opportunistically searched during this survey, including the coastal berms along the two far eastern coves on the south side of the island, and the grassy coastal knolls abutting and directly on the small islet on the south-western side of the island. No burrow-nesting seabirds were found nesting on the island.

A small number of pigeon guillemots were found nesting during an opportunistic survey of vegetated offshore rocks around Rat Island. Rock stacks had not specifically been surveyed for burrowing nesting seabirds in previous years so it is not known whether they were absent before

eradication. All four nests encountered had adults actively incubating eggs (Figure 11a-b). The rock stacks are located < 200 m offshore of Rat Island which is within easy distance of Rat Island for rat swimming or moving across the kelp at low tide. Studies of rat ecology in the Aleutian Islands have suggested that rats move frequently between islands (Dunlevy and Scharf 2006). Rat droppings were observed on rocks offshore Rat Island, suggesting they visited or occupied these areas (S. Buckelew, pers. comm.). While it is not clear whether these nests are a response to rat removal, the location of at least one of the guillemot nests is suggestive of recolonization. A guillemot nest was located in the entrance of a burrow believed to have belonged to a rat (identified by small pile of chewed invertebrate shells located beneath a small overhang; a potential rat feeding station).

Archaeological surveys have identified seabird bone fragments in Aleut middens on Rat Island (Funk 2009), which suggests that seabirds may have historically occurred on the island. The introduction of rats is a plausible explanation for the extirpation of the seabird colony or colonies on Rat Island. Following rat removal seabirds on and around Rat Island are expected to increase due to release from chick predation by rat or improved breeding habitat.

4.1.6 Shorebirds

It is not known how productive Rat Island was for nesting shorebirds prior to rat introduction, but clearly the wetland and upland areas were not highly productive for shorebirds in 2007-2009. Nevertheless, black oystercatchers (Fig. 12) and rock sandpipers were detected in equal numbers to previous years. While transiting the island biologists made incidental observations of rock sandpiper and black oystercatcher nests. While breeding was recorded

Figure 12. A pair of black oystercatchers observed on the rocky coastline around Rat Island during near shore boat surveys.

previously, this is the first record of chick hatching for both species. In total, seven black oystercatcher nests and six rock sandpiper nests were encountered. A single chick or a pair of chicks were observed in two oystercatcher nests and two chicks observed in one sandpiper nest (Fig. 13).

Figure 13. A black oystercatcher chick observed in a nest along the coastline of Rat Island.

It is assumed that a release from rat predation pressure will result in shorebird population growth on Rat Island. Studies by Kurle et al. (2008) identified a similar pattern, where the relative abundance of marine birds (including shorebirds) was significantly lower on rat-infested compared to rat-free islands.

4.2 MARINE MAMMALS

All common marine mammal species were less abundant in 2009 than in 2008, although differences for harbor seals and sea otters were small (1-7 animals fewer animals). However, Steller sea lions were substantially less abundant in 2009 than in 2008. In 2009 the islet off Ayugadak Point was omitted from the near shore survey, but it was surveyed in 2008. The islet is a known Steller sea lion rookery and persistent haul site with approximately 100-150 animals present during the summer months.

4.3 INTERTIDAL FLORA AND FAUNA

In 2009 abundances of intertidal algae and invertebrates were similar to those measured before eradication. The only difference was in coverage of fleshy algae and abundance snails, which were different in 2008. This difference could be attributed to low sample size or interannual variation in environmental conditions.

Rats in the coastal zones of the Aleutian Islands are known to feed on terrestrial vegetation, marine birds, marine amphipods, and dead algae (Kurle et al. 2008). This suggests that invasive rats directly reduce bird densities through predation and indirectly affect invertebrate and marine algal abundance in the intertidal area by changing the community structure from an algal to an invertebrate dominated system. In the years following rat eradication intertidal communities are expected to respond to the release from rat predation pressure by shifting from an invertebrate to an algal dominated system, as invertebrate grazers are depredated by increasing shorebird populations.

5. Conclusions

This study provides a snapshot view of the ecosystem on Rat Island nine months after a rat eradication campaign. The data here preliminarily index ecosystem impacts of rat removal, and assess impact to non target species. At the time of this survey, the eradication had not yet been declared a success or failure. Despite extensive trap effort no rats were detected in 2009 which provides preliminarily evidence that the island may be rat-free. If, indeed, Rat Island is now rat-free, 2009 is the last season in which species on the island may have been impacted by rats. Continued monitoring in future years will further document ecosystem changes on Rat Island.

Some non-target birds were exposed to the rodenticide, and likely died as a result. However, post-eradication monitoring suggests that all species other than bald eagles are present in greater or equal numbers than before the eradication. Bald eagles are expected to recover fully following recruitment of new individuals into the breeding population. Populations for most native island bird species were as high or higher than detected prior to eradication, particularly for rock ptarmigan and winter wrens. Additionally, successful nesting by some species was documented, including pigeon guillemots, rock sandpipers, common eiders, and black oystercatchers.

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