A survey of inland Least and Crested Auklet breeding colonies at Gareloi Island in the Delarof Islands, Aleutian Islands, Alaska during 2006

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Abstract: Collectively, the Least and Crested Auklet breeding colonies along the south and east sides of Gareloi Island, Delarof Islands, Aleutian Islands, Alaska (51º 46′ N 178º 45′ W) likely contained the largest concentration of breeding auklets in the Aleutian Islands in 2006. In order to provide information necessary to evaluate the significance of Gareloi compared to other Alaskan auklet colonies and to evaluate study techniques, we carried out a survey designed to precisely map the geographical limits and assess relative density of breeding birds within the two major inland colony sites at Gareloi (Southeast Point and East Point). We recorded presence or absence and density of auklets and vegetation cover at 1,195 20 m^2 survey plots, on a 50 m by 50 m UTM grid overlying the two colony sites. After we were familiar with the colony sites, we delineated the colony boundaries, defined by their outermost crevices. Most auklet breeding areas in beach boulders and adjacent cliffs of Gareloi (likely encircling most of the island's >30 km coastline) were not accessible to us and were not closely surveyed. Our survey data provide a delineation of the extent and density of the two major auklet breeding areas at Gareloi that will be useful for comparison with future surveys. Aside from extensive breeding areas in beach boulders, the majority of Gareloi's Least and Crested Auklets likely bred at two large inland colonies (Southeast Point and East Point) that had close to 100% vegetation cover (grasses) in 2006. We conservatively estimated the population as 460,350 pairs at Southeast Point, 453,550 pairs at East Point and perhaps 250,000 pairs in beach boulder colonies and cliffs, for a total of at least 2.3 million birds, about half Least Auklets and half Crested Auklets. There was apparently little opportunity for colony expansion, due to lack of unoccupied breeding habitat. We found no Glaucous-winged Gulls nesting on Gareloi Island, and observed relatively few gulls depredating auklets compared to other colonies. Our survey results underline the importance of two islands, Gareloi and Kiska, as the breeding location for most Least and Crested Auklets inhabiting the Aleutian Islands, and further emphasize the need to remove rats from Kiska Island, which has the largest remaining patch of ideal auklet breeding habitat in the western Aleutian Islands.

Introduction

Least and Crested Auklets apparently breed at only nine colonies in the Aleutian Islands (Buldir, Kiska, Segula, Semisopochnoi, Gareloi, Kasatochi, and Koniuji Islands, with small Crested Auklet colonies reported from Chagulak and Seguam Islands; US Fish and Wildlife Service surveys). Studies of auklet biology and/or colony surveys had been carried out at Buldir, Kiska, Semisopochnoi and Kasaotchi Islands prior to 2006, and these colonies were relatively well known, but other colonies have only been roughly surveyed and remain relatively poorly known. It has been generally agreed that that for management and conservation purposes, Alaskan auklet colonies should be mapped following a protocol designed to be repeatable and quantitative, allowing for detection of decadal changes in colony area and density. A survey protocol has been developed (Renner et al. 2006) that aims to quantify auklet density and vegetation cover at random points within the colony.

Why survey Least and Crested Auklet colonies? For management purposes, it is crucial to have quantitative information on the distribution and abundance of these species, which are two of the most abundant seabirds in Alaska. Because they nest in concealed breeding sites in rock crevices, auklets are difficult to count and their populations remain relatively poorly understood compared to cliff-nesting seabirds. Population monitoring has been attempted using surface counts, but these vary inconsistently from day to day, within seasons, and among years irrespective of population changes and immature and non-breeding birds are inordinately represented in surface counts, making this a questionable approach to population monitoring (Jones 1992, Sheffield et al. 2006). Nevertheless, some auklet colonies have changed in geographical area or disappeared entirely during historical time – leading to the suggestion that an approach that emphasizes mapping and photographic documentation of auklet colony locations and boundaries would be useful (Arthur L. Sowls, personal communication). Because auklets are highly gregarious when breeding and occupy ephemeral breeding habitat on coastal lava flows and talus slopes that is subject to encroachment by vegetation, the outer boundaries of their breeding colony sites can change rapidly, reflecting population changes. We urgently require documentation of auklet colonies in order to be able to interpret the effects of climate change on auklet breeding habitat and food supplies, the effect of plant succession on the availability of breeding crevices, the effects of non-indigenous predators (e.g., rats) that may be accidentally introduced to auklet nesting islands, and the severity of catastrophes such as oil spills. In the western Aleutian Islands, most Least and Crested Auklets bred at Sirius Point, Kiska Island, but this colony has suffered breeding failure in recent years due to introduced Norway rats *Rattus norvegicus*, underlining the need to quantify auklet populations and breeding habitat available on nearby rat-free islands.

Gareloi Island (52º N 179ºW) is the northernmost of the Delarof Islands, with dimensions of about 10 km by 8 km, recent volcanic eruptions (Sedlacek et al. 1981), and is part of the Alaska Maritime National Wildlife Refuge. Gareloi has no native land mammals. Arctic foxes (*Alopex lagopus*) were introduced to the island in about 1925 for 'fur farming' and removed by the Refuge in 1996 (Paragi 1996b) to restore a naturally functioning ecosystem free of non-indigenous species. Gareloi Island in 2006 is thus an island in the early stages of recovery from introduced Arctic foxes, with Aleutian Cackling Goose (*Branta hutchinsii leucopareia*), Rock Ptarmigan (*Lagopus mutus*) and most burrow-nesting seabirds (storm-petrels, Ancient Murrelets, Cassin's Auklets, Tufted Puffins) extirpated or nearly so. However, Gareloi did not suffer the ravages of WWII relative to some other Aleutian Islands and remained free of introduced Norway rats (*Rattus norvegicus*) and other harmful war debris.

Day et al. (1978) estimated that approximately 450,000 Least and 185,000 Crested Auklets were breeding at Gareloi Island in 1978 (46% of the estimated 1,160,000 Least Auklets and 230,000 Crested Auklets breeding at Sirius Point Kiska Island in 1978, Day et al. 1979). Auklets were noted as breeding at two large colonies at Gareloi island, located on the east and south facing slopes of Gareloi volcano (Paragi 1996a). The larger Gareloi southeast colony is located in recent lava flows and inside spectacular deep volcanic craters associated with a south-southeast trending fissure that extends from the shoreline to the southern summit of the island, formed during a major explosive eruption in 1929 (Coats 1959). Therefore, other than the large colony at Sirius Point, Kiska Island (massive eruption in 1969 producing the coastal lava dome, Alaska Volcano Observatory), the Gareloi southeast colony is located on ***the most recent (and therefore ideal for auklets) lava flows at any auklet colony site in the Aleutians.*** The other (east) colony on Gareloi seems to be located on a possibly older deposit of lava and other eroded material near 'Slide Falls Plateau' (Paragi 1996a). Paragi (1996b) also noted that "*Least Auklet (Aethia pusilla) nested in high densities… …in all the boulder beaches of the island.*"

Preliminary auklet surveys of Gareloi colonies were made in 1996 and results included rough maps of the colony boundaries (Paragi 1996a, Fig. 1). Prior to the present study, it was apparent that Gareloi was the site of very large auklet colonies, taken together perhaps containing populations second in size only to that located at Sirius Point, Kiska Island. Given the apparent status of Kiska as an auklet colony perhaps gravely threatened by introduced Norway rats, we believe assessment of the status of other large auklet colonies in the Rat Islands, especially those at Segula and Gareloi, is an urgent conservation priority.

In summary, the primary aims of our project were to: 1) precisely and accurately delineate the geographical boundaries of the Least and Crested Auklet colonies of Gareloi Island; 2) quantify relative auklet breeding-site density and vegetation cover throughout the colony site using representative survey plots; 3) experimentally examine the detectability and persistence of auklet droppings on different types of breeding habitat, and 4) use the data collected to evaluate the status of the Gareloi auklet colony and its significance and relationship to other Aleutian island auklet colonies.

Methods

Study areas

We established two campsites at Gareloi Island. Our Main Camp (at 51° 45.841 N 178° 45.071' W, 5736024 N 379149 E NAD27 Alaska) was located by an easterly-facing cobble beach near the large Southeast Colony. We placed our weatherport at the same floor site previously used in the 1996 fox removal project (Paragi 1996b). Our Spike Camp (at 5739667 N 379771 E) was located at the East Colony (easternmost point on Gareloi Island), near another east-facing beach, also close to where fox trappers camped in 1996.

Mapping

ILJ obtained a digitized WWII era 1:25,000 topographic map of Gareloi Island and georeferenced it based on its UTM grid for initial survey grid preparations using GPSy Pro X software for Macintosh. Using Microsoft Excel, ILJ generated UTM survey points on two 50 m grids, one each for the southeast (970 points) and east (673 points) colonies on Gareloi, as sketch mapped by Paragi (1996a, Fig 1.). The grids were set up to generously overlap Paragi's (1996a) sketch mapped colony boundaries, to account for inaccuracies or changes in colony boundaries and for the topographic map being off datum. After arriving at Gareloi, we took position fixes on conspicuous landmarks (camp locations, Mt. Gareloi summit, western bench mark) that were visible both in the field and on the topographic map, using a hand-held GPS unit. From these fixes the topographic map was re-referenced so that positions on it are on datum.

Inland auklet colony surveys

At the Southeast and East Colony sites, we visited each survey point, recording presence or absence of breeding auklets on each circular (8 m radius) plot (based on presence of one or more of: birds standing on the surface, adult vocalizations from underground, wear, displacement and trampling of vegetation and mud near crevice entrances, feathers shed from adults' brood patches, chick calls, droppings, feathers, dandruff, and spilled chick meal remains). We also estimated density using ILJ's method (0, 1-10, 11-100 or >100 occupied crevices on a 10 m by 10 m area centered on the survey point). Finally, we estimated vegetation cover for each plot (by % to the nearest 5%, for the following categories: *Elymus* sp., *Calamagrostis* sp. (likely also including *Poa* sp. at some locations), *Puccinellia* sp., *Carex* spp., Herb (mostly *Anemone narcissiflora, Lupinus nootkatensis and Angelica lucida*), *Salix* spp., *Empetrum nigrum,* Heath (mostly *Cassiope lycopodioides*), Moss, Lichen, Fern, *Juncus* sp., Grass spp.). We visited all plots that we could access safely – a few plots (on cliffs and crater bottoms) were assessed from a distance. For a few plots, auklet sign (droppings and feathers) were counted using the methods suggested by Renner et al. (2006), but it was rapidly apparent that counts of sign were not reflective of occupied crevice density at Gareloi (see below) so this methodology was abandoned. Quantification of auklet sign would be usable for relative density measurement if we could correct for seasonal effects, substrate type, and birds' use of deep versus shallow crevices, but these sources of variation seemed to us to be insurmountable at Gareloi (see below).

Minimum population estimates for the inland auklet colony areas were derived from the number of low, medium and high density 100 m^2 plots (Ian Jones' method – Jones et al. 2001, Jones and Marais 2004) found within the 50 m by 50 m cells within each inland colonies' boundaries. Minimum colony size (occupied crevices) was thus the sum of: ((# of low density plots x 1) + (# of medium density plots x 11) + (# of high density plots x 101)) x 25. The multiplication factor 25 was based on the relative size of each plot for the Jones density estimate (100 m^2) to the 50 m by 50 m grid cell area (2500 m^2).

The ratio of Least to Crested Auklets in breeding populations at Gareloi was estimated from the proportion (in flight) of the two species present in flocks arriving at the colonies during the incubation period. Ratios in surface counts (i.e., of birds standing on the surface on display rocks or grass pads) are likely to be deceptive because Crested Auklets are underrepresented.

Beach boulder and sea-cliff breeding areas

For the purpose of this discussion, we defined *Beach boulder colony* as any area with rounded beach boulders disturbed (and rearranged) by each winter's storm waves. These areas of breeding habitat were extremely distinctive and different from inland sites, given the smooth rounded nature of the rocks, complete lack of vegetation cover, predominant use by Least Auklets, and possibility of change every year. Beach boulder colonies are often backed by *coastal talus slopes and cliffs*, defined here as inland locations directly produced by marine erosion. No survey of the auklet breeding colonies of Gareloi would be complete without a thorough examination of areas of occupied beach boulders and nearby shoreline cliffs and talus slopes. Paragi (1996a) stated that "*Least Auklet (Aethia pusilla) nested in high densities… …in all the boulder beaches of the island.*" Unfortunately we were unable to survey or map the island's extensive shoreline colony areas. Most of these areas were not safely accessible to us (reachable only by small boat) or too far from our camps to visit. We were only able to make limited guesses about the extent of beach boulder colonies based on what we could see from land during our hikes, and from observations from Tiglax made at the times of our arrival and departure from Gareloi.

Feasibility of using auklet sign as a density index

Renner et al. (2006) suggested that auklet sign (counts of visible droppings and feathers on the colony surface) should be used as an index to quantify relative density of breeding auklets within a colony site within a particular study (but not between years). Here we informally evaluated some assumptions of this suggestion: 1) that dropping and feather counts are likely to be stable during a study period (i.e., not much affected by weather or other seasonal factors), 2) that areas of different vegetation cover reveal droppings and therefore auklet breeding density in a similar manner, 3) that areas of different breeding habitat type (i.e., differing in block size and crevice depth) reveal droppings and underlying auklet breeding density in a similar manner, and 4) dropping counts are comparable (i.e., repeatable) across different observers.

To evaluate the effect of date on abundance of auklet droppings, we repeatedly photographed ten display rocks, located near our field camp at the southeast colony, on different days during our visit to Gareloi. Daily variation in the total counts of sign at these rocks were believed to indicate the effects of rain, wind and other causes of seasonal variation in auklet sign.

To evaluate the effects of substrate type on dropping conspicuousness we conducted a field experiment. Random numbers (between 10 and 50, generated by Microsoft Excel) of artificial droppings (white latex artist's paint, mixed to a consistency approximating auklet droppings, to produce 1-2 cm diameter splash marks on a smooth surface) were delivered by ILJ with a plastic syringe to 90 randomly located 1 m^2 quadrats near the Southeast Colony site (an area including beach boulders, talus, lava flow and grass), 30 with 0% vegetation cover, 30 with approximately 50% vegetation cover, and 30 with 100% vegetation cover (none with any pre-existing natural droppings). The number of visible white paint drops was counted at each plot by KAH (blind to the number of drops applied). The average proportion of drops detected (number counted/number applied) and counted by KAH was then compared between the 0, 50 and 100% vegetated plots.

To evaluate the effects of habitat type, we informally asked the question: "Where are droppings deposited?" as we visited different habitat types within the colony sites (beach boulders, cliff crevices, tussock-covered lava flows, et c.). Specifically, we were interested in whether birds defecation behaviour in different habitats would result in equally-visible droppings. We also considered the question: "Where are auklet feathers likely to appear and be countable in and near their colony site?" and we examined a sample of feathers found in the colony to determine the type of feathers present and their likely origin.

Results

Survey results for Southeast Colony

Our work on this colony site took place between June 14 and July 16, 2006 (13 full work days). We surveyed a total of 766 plots on the 50 m grid, 297 (39%) of which were occupied by breeding auklets, and 440 (57%) of which were within the colony boundary as defined by its outermost crevices. Among plots classified as occupied, 85 plots were scored as high density, 41 as medium density and 171 as low density. The extent of the Southeast Colony (Fig. 2) for the most part closely matched the area of recent volcanic activity related to the 1930s era eruption described by Coats (1959), but limited to areas less than 308 m (1000') elevation. All densely-occupied areas in the Southeast Colony corresponded to the craters and lava flows associated with this eruption, and all these areas had close to 100% cover of >1 m high grass tussocks (by mid-July, see below). The highest densities were observed at the following locations: 1) the lava flow forming Southeast Point and within its associated breached crater; 2) within the next two deep craters along the 1930s fissure line and immediately above the Southeast Point crater; and 3) on the large blocky lava flow immediately to the northeast of these areas. In all three of these locations, we found extensive areas of extremely high-density occupancy (likely >1000 occupied crevices per 100 m^2)! However, the Southeast Colony was not limited to the areas of recent activity, but also encompassed a very old lava flow with scattered porous outcrops in a subalpine meadow on the colony's northwestern quarter (north of a canyon formed by the creek running through the northern part of this colony to our Main Camp site).

The *minimum* estimate of the size (breeding pairs) of the Southeast Colony based on Jones' assessment of densities was 230,175 pairs. Due to the conservative methods used to derive this guess about colony size the true size was likely much larger, perhaps double the above number (see Discussion). During the incubation and chick rearing period we observed 250,000 or more auklets passing by our camp each evening between 2000 h and 2300 h in a continuous stream coming from Tanaga Pass to the northeast, heading to the Southeast Colony. Other less easy to see streams of comparable or higher magnitude arrived from the south (pass between Kavalga and Unalga) and west (Amchitka Pass). Based on flocks flying to the colony the ratio of Least to Crested Auklets was close to 50/50.

The Southeast Colony site was nearly completely covered in vegetation, with unvegetated areas (exposed mud and dirt or bare rock) comprising less than 5% of the surface area. Only 170 (39%) of the 439 survey plots within the colony boundaries had any bare surface present. Similarly, only 119 (40%) of the 297 plots with active breeding crevices present had any bare surface present. Vegetation cover on the entire colony site averaged 94.4% on study plots and consisted of grasses (*Calamagrostis* sp., *Poa* sp. [these two lumped by us due to similarity], *Elymus* sp. and *Puccinnellia* sp.) (mean of 71.5% of the area of survey plots), mosses (5.8%), *Empetrum* (5.4%) and herbs (10.1%). Vegetation cover on survey plots with medium and high density auklet breeding crevices (mean 92.7%) consisted of grasses (84.0%), mosses (0.7%), *Empetrum* (0.6%) and herbs (3.0%). Vegetation cover in the densest areas of the colony was predominantly high tussock grasses (*Calamagrostis* sp. and *Poa* sp., reaching > 1 m height by mid-July), and compressed mats of *Puccinnellia* sp. grass. In medium and high density areas, auklets' access to crevices was through deep cracks between the tussocks. In some areas birds landed first on the *Puccinnellia* mats before descending; in other (most?) areas birds dropped straight into deep openings between high tussocks. In a few low density areas outside of the major craters and lava flows, auklets gained access to underlying rock crevices through small (5 – 20 cm diameter) openings in the vegetation that appeared to be maintained by birds forcing themselves through the dense vegetation cover (usually grass) on isolated tussocks over lava rocks. Herbs (broad-leaved vegetation) for the most part consisted of *Anemone narcissiflora*, *Angelica lucida* and *Lupinus nootkatensis*.

Survey results for East Colony

Our work on this colony site took place between July 10 and July 25, 2006 (7 full work days). We surveyed a total of 429 plots on the 50 m grid, 211 (49%) of which were occupied by breeding auklets, and 222 (52%) of which were within the colony boundary as defined by its outermost crevices. Among plots classified as occupied, 82 plots were scored as high density, 66 as medium density and 63 as low density. The extent of the East Colony (Fig. 3) for the most part closely matched the area of a recent lava flow described by Coats (1959), limited to areas less than 466 m (1513') elevation. Gareloi had unusually high occupied areas (1200' – 1500' a.s.l.) with unique vegetative cover consisting of *Salix* shrub mats. All densely-occupied areas in the East Colony were on lava, with very distinct colony boundaries (along edges of the recent lava flow) surrounded by uniformly unsuitable habitat (ash and mud slopes). The highest densities were observed at two locations: 1) the low (<250 m) parts of the hillside lava flows; and 2) a coastal lava dome or lava flow forming the northern half of a rounded point (Fig. 3). In all both locations, we found extensive areas of extremely high-density occupancy (likely >1000 occupied crevices per 100 m^2).

The *minimum* estimate of the size (breeding pairs) of the East Colony based on Jones' assessment of densities was 226,775 pairs. Due to the conservative methods used to derive this guess about colony size the true size was likely much larger (see Discussion). Based on flocks flying to the colony the ratio of Least to Crested Auklets was also close to 50/50.

The East Colony site was heavily vegetated, with unvegetated areas (exposed mud, dirt or bare lava) comprising 15% of the surface area and occurring almost entirely above 300 m elevation. Only 82 (37%) of the 222 survey plots within the colony boundaries had any bare surface present. Similarly, 72 (34%) of the 211 plots with active breeding crevices present had bare surface present. Vegetation cover on the entire colony site averaged 70.2% on study plots and consisted of grasses (*Calamagrostis* sp. and *Poa* sp.

[these two lumped by us due to similarity],*Elymus* sp. and *Puccinnellia* sp.) (mean of 51.6% of the area of survey plots), mosses (0.9%), *Salix* (3.0%) and herbs (3.1%). Vegetation cover on survey plots with medium and high density auklet breeding crevices (mean 93.9%) consisted of grasses (79.6%) in tussocks that reach > 1 m height by mid-July, *Salix* (2.7%) and herbs (2.9%). Vegetation cover in the densest areas of the colony was predominantly high tussock grasses (*Calamagrostis* sp. and *Poa* sp.), and mats of *Puccinnellia* sp. grass. In medium and high density areas, auklets' access to crevices was through deep cracks between the tussocks. Large (> 5 m^2) mats of willow shrub up to 30 cm height were found on parts of the colony above 350 m elevation.

Beach boulder and sea-cliff breeding areas

We found no evidence to contradict Paragi's (1996a) assertion that breeding Least Auklets occupy all boulder beaches on the island. The shoreline (east side of Gareloi) between our Main and Spike camps appeared to support a nearly continuous high density auklet colony (>90% Least Auklets), with extensive areas of cliff face and coastal talus occupied by high densities of breeding Least and Crested Auklets. North of the East colony we could see many Least and some Crested Auklets on beach boulders and nearby talus as far as we could see. The shoreline between the Southeast Colony and the western extremity of Gareloi (extensive beach boulder areas and coastal talus below high cliffs) also appeared to have patches of high density breeding Least and Crested Auklets (observations from Tiglax June 11). We were unable to make any observations on the north and northwest shorelines of Gareloi. A skiff and calm weather would be required for a thorough survey of the extensive shoreline auklet breeding colonies of Gareloi Island.

Feasibility of using auklet sign as a density index

Gareloi experienced a night of light rain on June 17-18 and heavy rainfall events (> 2.5 cm of rain in 24 h period) on June 24-25, July 3-4, July 14-15, July 21 and July 26. The effect of the June 17 rain was documented with photographs that show dropping present on June 16 that disappeared after the rain (Fig. 4). The heavy rainfall events were accompanied by drastic loss (likely > 50%) of visible droppings on all parts of Gareloi occupied by breeding auklets. New droppings steadily accumulated on auklets' surface display rocks between the rainfall events.

Our simple dropping detectability experiment showed that close to 90% of artificial droppings were detected on substrates free of vegetation, while about 55% of droppings were detected with 50% vegetation cover and about 50% were detected on plots with 100% vegetation cover (Fig. 5). Dropping detectability was thus strongly inversely related to vegetation cover.

We had difficulty counting droppings on display rocks used by auklets. Due to the dense vegetation predominating away from beach boulder areas, the few rocky surfaces available were heavily used and thus had extensive continuous white splashes covering them, making individual droppings difficult or impossible to discern. An internet-based survey to test the repeatability of dropping counts in progress and will be covered in the final draft of this report.

At Gareloi, auklet droppings were found on and near surface display rocks where birds alighted to engage in social behaviour. These areas were very conspicuous in beach boulder colonies (Fig. 4) and absent or nearly so in densely occupied areas with dense vegetation (grass tussocks, Fig. 6). Droppings were either nearly absent or very difficult to detect on these tussocks and on pads of trampled *Puccinellia* grass where auklets alighted to enter deep caves and crevices below. The most densely occupied inland auklet breeding areas at Galeloi were characterized by dense tussock grass on the surface (Fig. 6) and extensive underlying caves (3 – 5 m depth *or more*) entered through narrow cracks between lava blocks. These caves were not safely accessible to our inspections. Large numbers of auklets were heard socializing beneath the surface in these areas, but few droppings were visible or countable.

Feathers were conspicuously present in areas of shallow (< 1 m depth) occupied breeding habitat during mid June, immediately following laying. Most feathers were found in clusters immediately adjacent to (< 30 cm from) a shallow (and therefore visible) Least Auklet crevice breeding site. Examination of these feathers showed they were almost all Least Auklet belly contour feathers shed from the area of brood patches (100/103 = 97%). No Crested Auklet brood patch feathers were found, likely because Crested Auklet breeding sites tended to be deeper underground and much less visible and accessible. Few feathers of any kind were found in areas of deep-dwelling high density auklet colony because of the depth of the breeding sites (2 – 5 m *or more*). Brood patch feathers became much less visible and had generally disappeared by early July, likely to the effects of wind and rain. Other feather piles resulted from prey plucking by Peregrine Falcons *Falco peregrinus* (excluded from this analysis). These feather piles, which were very conspicuous, were found on the surface on perching sites both within and outside the auklet colony boundaries.

Discussion

Survey results for the two inland colonies

The two large inland auklet colonies at Gareloi occurred on the most recent lava flows, each 75 – 100 years old in 2006. Like the older part of the colony at Kiska ('Bob's Plateau', Jones et al. 2001) and the entire colony at Semisopochnoi (Jones and Marais 2004), the inland colonies at Gareloi have close to 100% vegetation cover (tussock grass) in a late stage of succession. Due to the structure of the underlying lava (more recent flows with larger blocks, greater depth, extensive caves), the colony site at Gareloi would appear to be capable of supporting breeding auklets for at least several more decades. We observed relatively few sites at Gareloi where auklets were burrowing through dense vegetation to reach underlying lava crevices. Instead, many of the densest areas of both colonies coincided with areas of tall grass tussocks on top of lava blocks, so auklets flew directly into deep cracks between the tussocks. This caused the unusual situation of some of the densest areas of the colony sites having no surface activity (i.e., auklets standing around on display rocks on the colony surface). The East Colony was unique among Aleutian auklet breeding sites for its extensive occupied area above 1200′ and extending to over 1500′ elevation. The 50 m grid used provided a high-resolution dataset that allowed a very satisfactory delineation of the inland colonies, in our opinion far more useful than the 100 m grid with random plot placement used at Semisopochnoi island (Jones and Marais 2004).

Estimates of population size for Gareloi

Auklet breeding population estimates are by necessity speculative, but nevertheless may have some useful application to management and to our understanding of auklet biology: Our survey suggested that Gareloi Island had the largest extant Least and Crested Auklet breeding colonies in the Aleutian Islands in 2006, being larger in area and likely numbers than two other large Aleutian auklet colonies, at Kiska (Jones et al. 2001) and Semisopochnoi (Jones and Marais 2004). Our minimum population estimates for the two inland colonies based on density estimates from the survey plots were 230,175 (Southeast Colony) and 226,775 (East Colony) pairs. Because these estimates were based on the lower limits of the density estimates, we believe a figure of about double is a more likely population estimate for the inland colonies (total of 913,900 pairs using inland sites). Although we were unable to delineate the shoreline (mostly beach-boulder) colonies of Gareloi, these apparently occupy most of the 30-50 km (scale-dependent measure) of the island's shoreline and likely support at least another 250,000 pairs. Combining these guesses we suggest that at least 2.3 million Least and Crested Auklets comprised the breeding population at Gareloi Island in 2006. The proportion of Least to Crested Auklets varied by habitat type (more Cresteds at inland high density areas, more Leasts in low density areas and in beach boulders), but overall we believe about half the auklets at Gareloi were Least Auklets and half Crested Auklets.

The status of auklet colonies at Gareloi, Semisopochnoi and Kiska compared

Although population estimates made by different observers are not directly comparable due to differences in methodology, some comparisons of past and present estimates may be useful. For example, in surveys in 1977 and 1978, Robert H. Day (Day et al., 1978, Day et al. 1979) estimated Gareloi and Kiska Least and Crested Auklet populations to be 635,000 and 1,390,000 birds respectively. Thus, Robert H. Day thought that Kiska had about twice as many breeding auklets as Gareloi in the 1970s. However, during the 2000s, Ian L. Jones (Jones et al. 2001, this paper) estimated the Gareloi and Kiska Least and Crested Auklet populations to be 2,387,800 and 1,800,000 birds respectively (i.e., Gareloi's population exceeding Kiska's). If the two observers' perceptions of relative colony size were accurate, then over the last 29 years either Kiska's auklet population has declined, Gareloi's has increased, or both. A decline of the Kiska auklet population fits many people's perceptions of the trend there (ILJ, Kevin Bell, many others' personal observations) and is likely resulting from predation of eggs and chicks by introduced Norway Rats. An increase of the population at Gareloi is consistent with the removal of introduced Arctic foxes in 1996 and the absence of breeding Glaucous-winged Gulls (but note that Kiska's Arctic foxes were also eliminated, in 1987). At least, the results of past surveys and this survey suggest that auklet colonies are not permanent or stable features, but rather many be changing in size on a decadal time scale.

The status of auklet breeding habitat on different islands is likely to be important in their future ability to support large populations. The two largest auklet colonies are located at islands with the two most recent volcanic activity that produced lava flows: Gareloi 1929 (Coats 1959) and Kiska 1969 (Coats et al. 1961). An older (19^{th} century) lava flow at Semisopochnoi supports the next largest colony after Gareloi and Kiska. Among these three colony sites, only Kiska has extensive areas of ideal (sparsely vegetated) lava. Gareloi's auklet colonies are situated on lava flows at the final successional vegetation stage before they turn into meadows (unsuitable for auklet breeding). Semisopochnoi's colony site was very close to becoming a meadow in 2004 (Jones and Marais 2004), and only Semisopochnoi's colony has a large breeding Glaucous-winged Gull population depredating auklets onsite. One very interesting observation was the extensive use of beach boulders at Gareloi, which had a nearly continuous beach boulder colony (predominately Least Auklets) running around the complete (> 30 km) circumference of the island. In contrast, Kiska, Semisopochnoi and all other Aleutian Island auklet colonies have little or no use of beach boulders. Whether this relates to geology or some ecological factor is unknown. We hypothesize that the extensive use of beach boulders at Gareloi relates to abundant auklet food near the island. Gareloi auklets' use of beach boulders would seem to render the colony immune to extirpation by vegetation overgrowth, as seems likely for other colonies.

Putting recent studies together, we speculate that 1) among the three largest auklet colonies in the Aleutians, Kiska's is declining due to rats (and possibly other factors, offset by immigration from Segula) despite having the largest area ideal habitat (recent unvegetated lava) of any single colony site, 2) Semisopochnoi's is in decline due to habitat loss by plant succession (possibly exacerbated by intense gull predation), and 3) Gareloi's is large and stable due to abundant suitable habitat (although without further volcanic activity the inland sites will not persist for many more decades). Taken together, this underlines Jones and Marais's (2004) management-related suggestion that the removal of rats from Kiska would benefit the Aleutian Least and Crested Auklet metapopulation by securing the largest patch of suitable breeding habitat.

How to survey auklet colonies

We believe a 50 m resolution presence-absence survey with rough order-of-magnitude density estimates for every plot provides the best method for delineating auklet colonies. This method documents the colony boundaries and relative density of occupation to a degree that will provide ample data for future comparisons. Would that we had such surveys for Ulakaia Ridge, St. George Island from the 19th century, Round Mountain Buldir Island from the 1970s, and Gula Point, Segula Island, from the 1970s. With such data we would now be able to understand the rate of change of auklet habitat and populations in a quantitative way far beyond our current speculations. Nevertheless, the 50 m grid misses most occupied areas in beach boulder colony sites, suggesting a more direct mapping procedure (e.g., as used by Jones 1988 in the Proibilofs) may be appropriate.

At Gareloi, we found numerous pitfalls inherent in the protocol suggested by Renner et al. (2006): auklet droppings and brood patch feathers were subject to rapid loss due to rain, had unequal detectability with different vegetation cover, were differentially visible to observers according to habitat depth and thus overestimated auklet density in shallow substrates, and varied seasonally. We believe such counts of sign are likely to be useful for quick studies of small colony sites (that can be surveyed in a day or two) with minimal vegetation cover, as occurs at colonies north of the Pribilof Islands.

Conclusions and recommendations

• Gareloi Island supports very large Least and Crested Auklet colonies of more than two million birds occupying 75 - 100 year old lava flows that are nearly completely covered by vegetation, and also beach boulder colonies around the entire circumference of the island.

• The combined geographic area of the colony sites at Gareloi are greater than 3 km^2, making this the largest Aleutian Island colony site, but rapidly advancing plant succession will soon affect the viability of many inland breeding sites.

• Colony mapping using a 50 m survey grid and hand-held GPS receivers provided an accurate and precise delineation of Gareloi's inland auklet colony sites. Further survey work to delineate the full extent of beach boulder and coastal talus breeding areas is required.

• Ideally, similar surveys and mapping of each major Aleutian auklet colony (Kiska, Segula, Semiosopochnoi and Gareloi) should be repeated once every ten years.

• Our Gareloi auklet colony survey results underlines the need to remove rats from Kiska Island, which has the largest remaining patch of ideal auklet breeding habitat in the Aleutian Islands.

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Table 1 Comparison of vital statistics of the auklet colonies at Gareloi, Semisopochnoi (Semis) and Kiska Islands, Aleutian Islands, Alaska

	Gareloi Southeast	Gareloi East	Gareloi all[1]	Semisopoch-noi[2]	Kiska[3] Old lava	Kiska[3] New lava	Kiska[3] all
Area (flat) km^2	c. 1	c. 1	>3	1.9	0.8	0.8	1.6
Facing direction	South	East	360° (all)	South	north	north, west	north, west
Highest crevices	1000′	1550′	1550′	1250′	1200′	300′	1200′
Population estimate (pairs)	460,350	453,550	1,163,900	500,000	-	-	900,000
CrAu/LeAu%	60/40	60/40	50/50	10/90	-	-	20/80
Length of beach cobble colony (km)	-	-	>30	0.250	0	0.400	0.400
Mean % vegetation (within boundaries)	94.4	85.4	91.3	99.7			
Mean % vegetation (occupied plots)	94.4	85.3	91.5	99.8			
Mean % mosses (within boundaries)	5.8	1.2	4.2	12.1	very high	some	high

Figure captions

Fig. 1 Locations of major Least and Crested Auklet colony sites on Gareloi Island, Aleutian Islands, as indicated by Paragi (1996)

Fig. 2 Least and Crested Auklet survey results for the Southeast Colony, Gareloi Island, in 2006, overlaid on the 1:25,000 topo map. Red dots indicate high density, orange dots medium density and yellow dots low density, on the 50 m grid. Small black dots indicate plots checked that had no evidence of breeding auklets. Location of beach boulder and sea cliff colony areas is indicated by a purple line. The limits (by outermost crevices) of the colony are indicated by a black line. Colony boundary indicated by Paragi (1996) is shown by a faint green line.

Fig. 3 Least and Crested Auklet survey results for the East Colony, Gareloi Island, in 2006, overlaid on the 1:25,000 topo map. Red dots indicate high density, orange dots medium density and yellow dots low density, on the 50 m grid. Location of beach boulder and sea cliff colony areas is indicated by a purple line. The limits (by outermost crevices) of the colony are indicated by a black line.

Fig. 4 Dissolution of Least Auklet droppings by an evening of light rain (June 17-18, 2006), on two beach boulders (right = before, left = after) at Gareloi Island, Aleutian Islands.

Fig. 5 Box plot showing detectability of artificial auklet droppings placed experimentally onto substrates with three vegetation classes at Gareloi Island, Aleutian Islands (showing proportions of known numbers of droppings placed).

Fig. 6 Appearance of high density Least and Crested Auklet breeding habitat at the East Colony, Gareloi Island, Aleutian Islands (upper photo show typical tussock grass on large lava blocks, lower photo shows nearby landing/takeoff pad of compacted *Puccinellia*)

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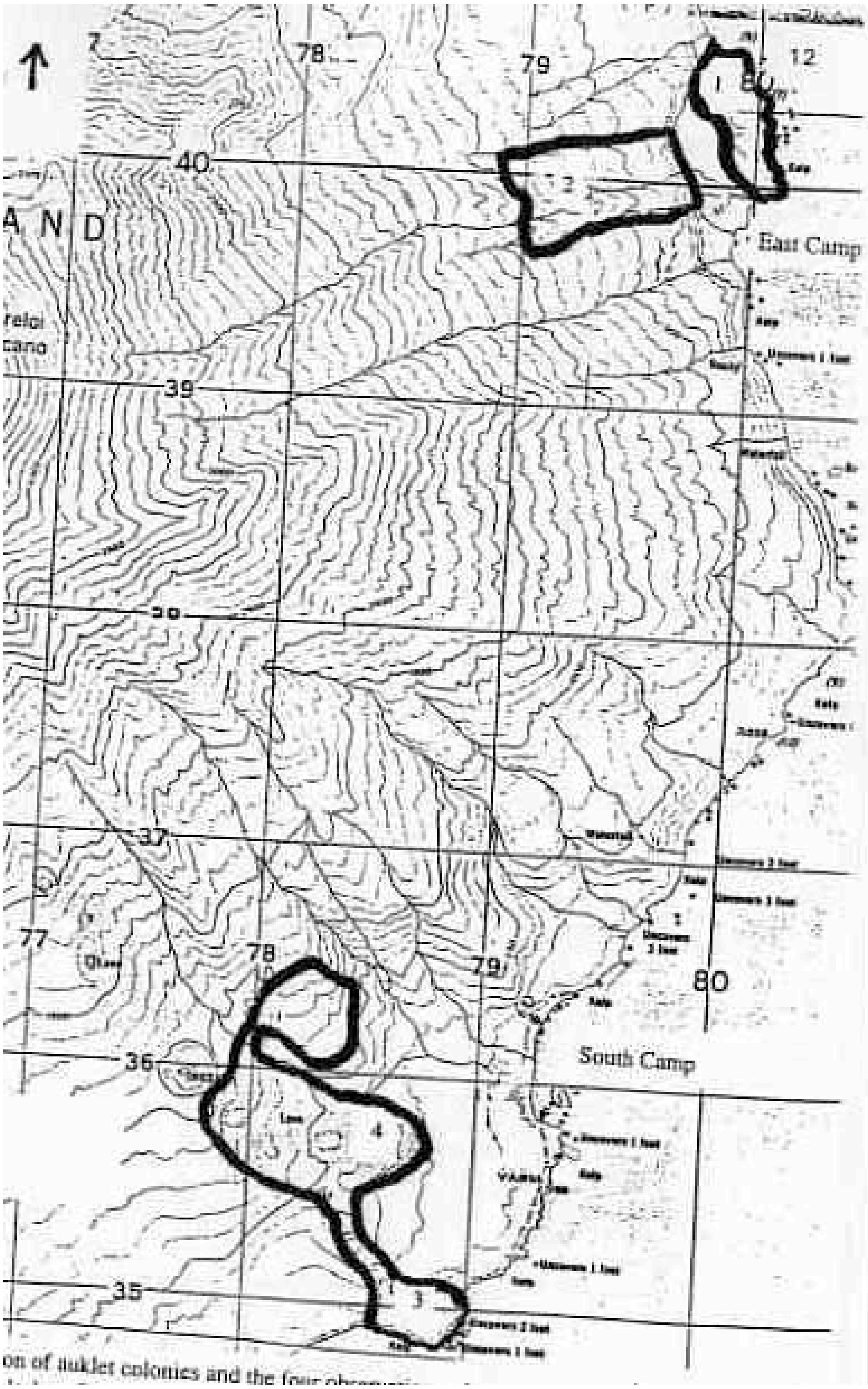

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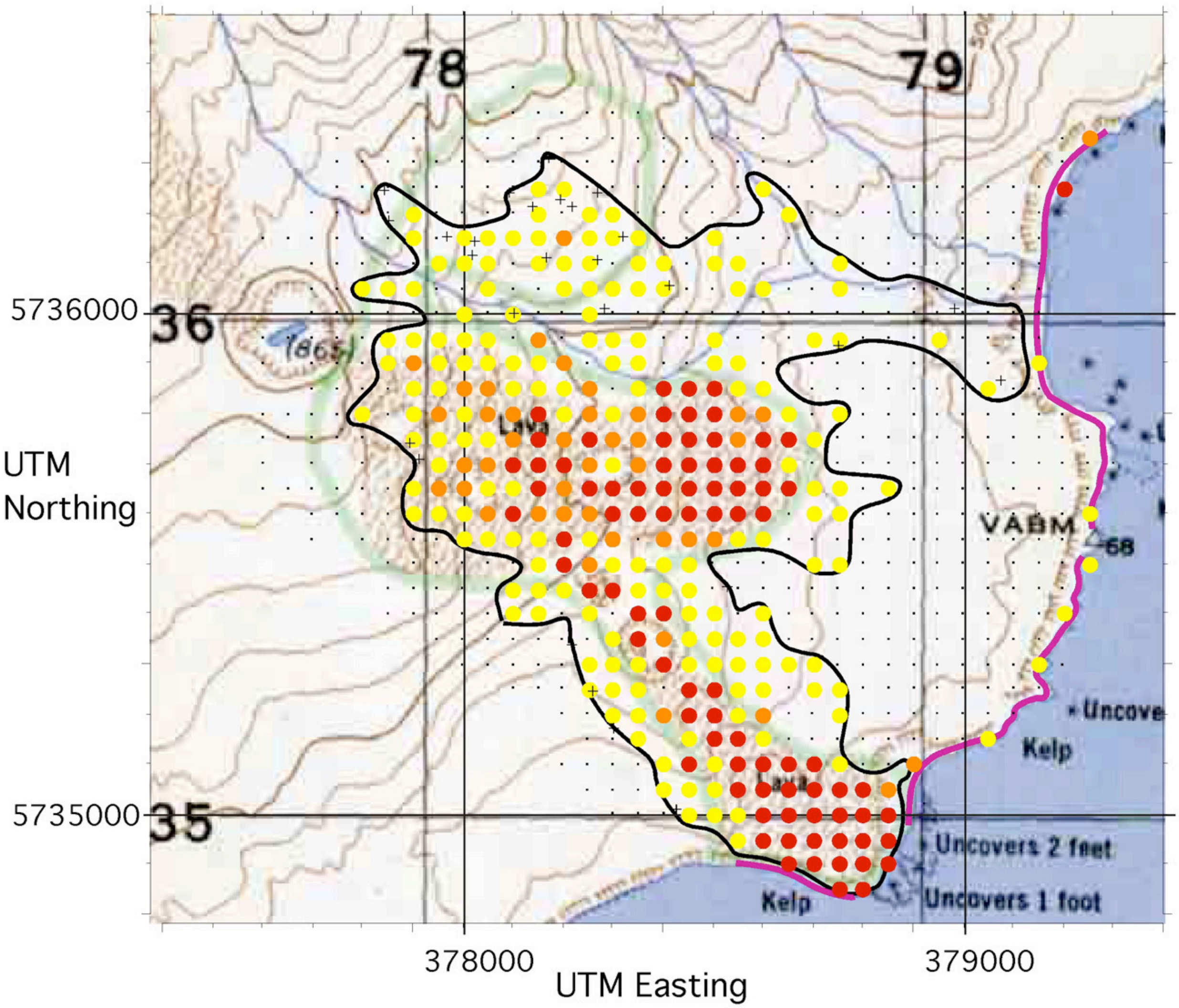

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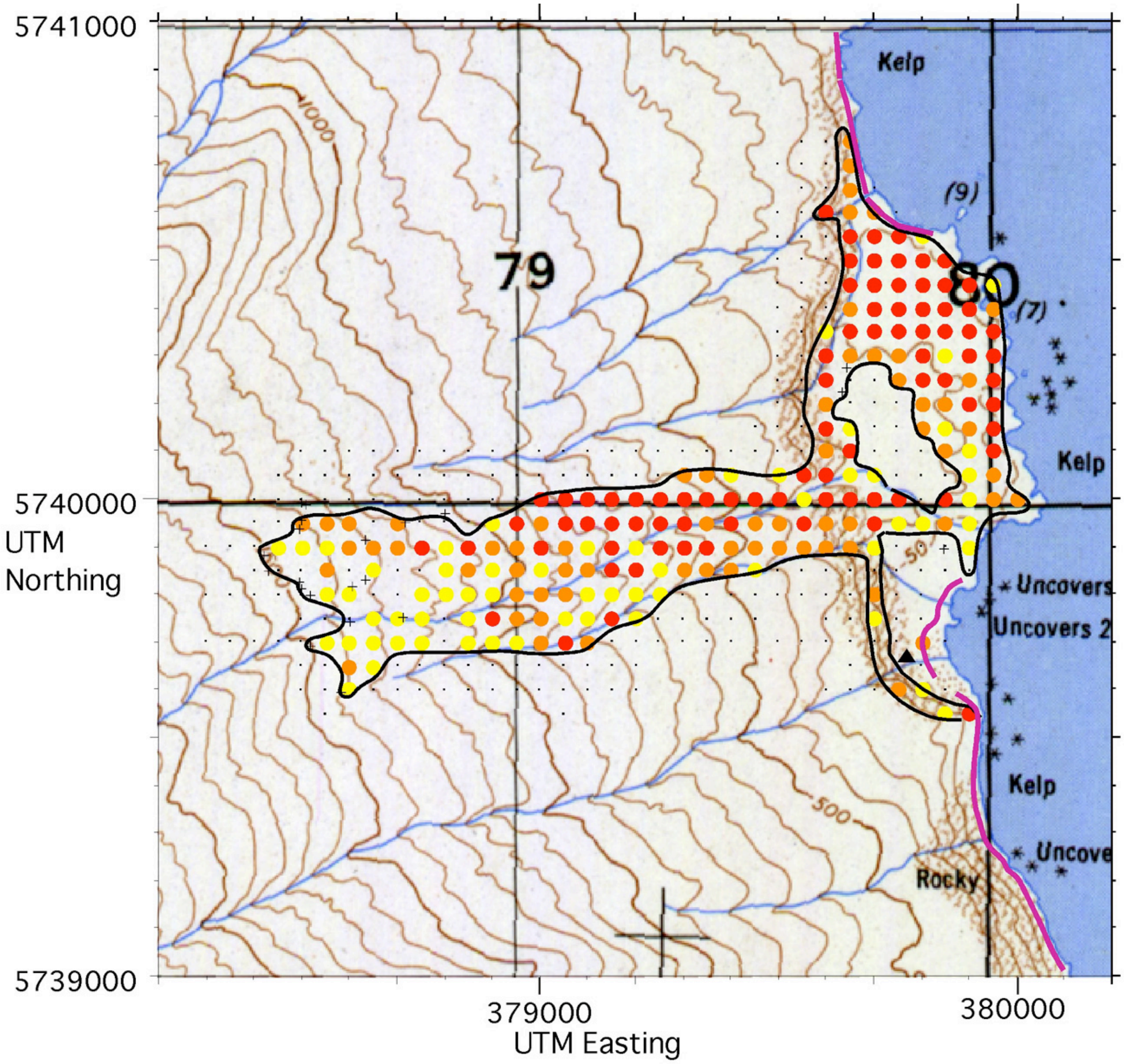

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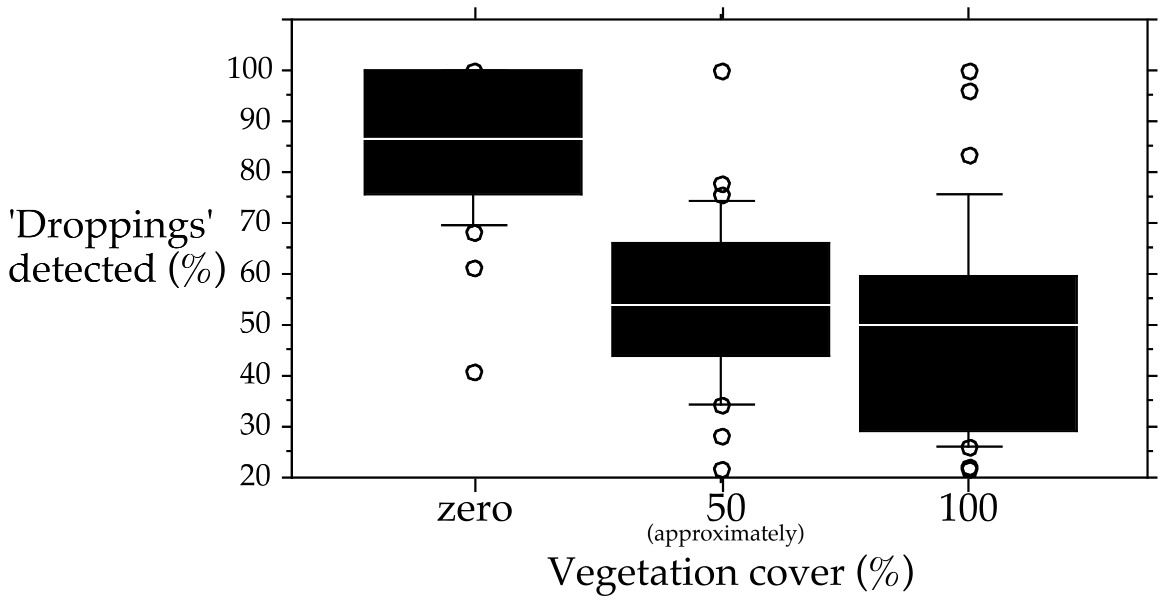

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Appendix 1 Annotated list of birds seen at Gareloi, June 10 – August 10, 2006

Fork-tailed Storm Petrel *Oceanodroma furcata* Birds were regularly heard calling while flying over land at night over our both our camps at night. A species likely to be rapidly recovering from the removal of foxes.

Leach's Storm Petrel *Oceanodroma leucorhoa* Birds were regularly heard calling while flying over land at night over our both our camps at night. A species likely to be rapidly recovering from the removal of foxes.

Pelagic Cormorant *Phalacrocorax pelagicus* Common, presumably breeds locally.

Red-faced Cormorant *Phalacrocorax urile* Common, presumably breeds locally.

Aleutian Cackling Goose *Branta hutchinsii leucoparia* Flocks flying by Southeast auklet colony regularly in June, with a few droppings found near the colony site in June. No birds were seen inland or heard after late June.

Harlequin Duck *Histronicus histronicus* Uncommon near shore.

Common Eider *Somateria mollisima* Three birds (a molting male and two females) were in the bight near our Main Camp August 3.

Black Oystercatcher *Hematopus bachmanii* Uncommon breeder along rocky shorelines. Two nests were detected, one near each of our camps. The Main Camp pair had two large flying chicks in early August. Maximum numbers of birds seen at each location was six.

Rock Sandpiper *Calidris ptilocnemis* Uncommon breeder in subalpine meadows and vegetated alpine areas, mostly between 100 and 400 m asl. Perhaps 150 pairs breed on the island.

Glaucous-winged Gull *Larus glaucescens* Uncommon. No evidence of breeding. At most 10-15 birds were observed hunting auklets at the Southeast auklet colony; none were seen hunting on the East auklet colony. We suspected that Bald Eagles may be displacing gulls from the auklet colonies. Numbers increased in late July coincident with auklet chick fledging. Presumably this species may recolonize Gareloi (as a breeding species) due to the removal of foxes.

Slaty-backed Gull *Larus shistisagus* One adult was present in the roosting gull flock near our camp August 1.

Pigeon Guillemot *Cepphus columba* Uncommon near rocky headlands on the south and east sides of the island. Birds were seen delivering prey items to breeding sites near both our camps in late July.

Ancient Murrelet *Synthliboramphus antiquus* Three observations over land: single birds were heard calling at night near our main camp. Two adults were observed feeding two large downy chicks near shore by the Main Camp in early August. This is a species likely to begin recovering from the removal of foxes.

Parakeet Auklet ***Cyclorhynchus psittacula*** Abundant breeder on cliffs adjacent to both large inland Least and Crested Auklet colonies. Population likely exceeds 10,000 pairs.

Crested Auklet ***Aethia cristatella*** Abundant breeder.

Least Auklet ***Aethia pusilla*** Abundant breeder.

Horned Puffin ***Fratercula corniculata*** Uncommon to rare along grassy seacliff-faces. A dozen birds were occasionally seen circling around cliffs near both major auklet colony sites. A species likely to be recovering from the removal of foxes.

Tufted Puffin ***Fratercula cirrhata*** Uncommon to rare along grassy seacliff-faces. A dozen birds were occasionally seen circling around cliffs near both major auklet colony sites. A species likely to be recovering from the removal of foxes.

Bald Eagle ***Haliaeetus leucocephalus*** Common at Gareloi. Up to ten birds frequented the Southeast Colony and perhaps fifteen the East Colony. One nest had a single large chick in it, north end of camp beach.

Peregrine Falcon ***Falco peregrinus*** Uncommon breeder. Territorial pairs were observed at two locations.

Northern Raven *Corvus corax* Up to four birds seen regularly together at auklet colonies and near camp.

(Rock Ptarmigan *Lagopus mutus* Absent. No evidence of this species was detected anywhere on Gareloi Island in 2006.)

Winter Wren ***Troglodytes troglodytes*** Uncommon along shoreline, in dense vegetation at auklet colonies (much scarcer at the East colony site).

Lapland Longspur ***Calcarius lapponicus*** Common to abundant in meadows. Three nests found in meadow between camp and Southeast colony lava in mid-June .

Snow Bunting ***Plectrophenax nivalis*** Uncommon in stony habitat on mountainsides and lava flows, mostly above 200 m asl.

Aleutian Song Sparrow ***Melanospiza melodia*** Common in well-vegetated areas along shorelines, in the auklet colonies up to 200 m asl.

Gray-crowned Rosy Finch ***Leucosticte arctoa*** Uncommon nearly everywhere on island.

Oriental Greenfinch *Carduelis sinica* A single male was observed at a damp spot near a snowbed at about 200 m asl on June 13.