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AVIAN MORTALITY ASSOCIATED WITH A VOLCANIC GAS SEEP AT KISKA ISLAND, ALEUTIAN ISLANDS, ALASKA

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ABSTRACT.—We identified natural pits associated with avian mortality at the base of Kiska Volcano in the western Aleutian Islands, Alaska in 2007. Living, moribund, and dead birds were regularly found at low spots in a canyon between two lava flows during 2001–2006, but the phenomenon was attributed to natural trapping and starvation of fledgling seabirds (mostly Least Auklets, *Aethia pusilla*) at a colony site with >1 million birds present. However, 302 birds of eight species, including passerines, were found dead at the site during 2007–2010, suggesting additional factors were involved. Most carcasses showed no signs of injury and concentrations of dead birds had accumulated in a few distinctive low pits in the canyon. Gas samples from these locations showed elevated CO_2 concentrations in late 2010. Analysis of carcasses indicated no evidence of blunt trauma or internal bleeding. Volcanic gases accumulating at these poorly ventilated sites may have caused the observed mortality, but are temporally variable. Most auklets breeding in the Aleutian Islands do so in recent lava flows that provide breeding habitat; our study documents a cost of this unusual habitat selection. *Received 17 March 2011. Accepted 28 September 2011.*

Active volcanoes frequently emit gases such as carbon monoxide (CO), and carbon dioxide (CO_2) from steam vents, fumaroles, and gas seeps that are toxic in sufficient concentrations but odorless and therefore not repellent to animal life. Ecological effects of volcanic activity, including gas emissions, are of interest because of their potential effects on species at risk or with restricted distributions (e.g., Short-tailed Albatross [*Phoebastria albatrus*] breeding at Torishima; Finkelstein et al. 2010).

There are 41 historically active volcanoes in Alaska, including 24 in the Aleutian Islands (Miller et al. 1998). The Aleutian Islands are also home to several million nesting seabirds (Byrd et al. 2005) and many species of land birds, including endemic subspecies and a vast array of migrants (Gibson and Byrd 2007). Least (*Aethia pusilla*) and Crested auklets (*A. cristatella*) are two of the most abundant seabirds in Alaska, but most breed in large mixed colonies at seven sites in the Aleutian Islands–all in lava flows and associated debris on recently active volcanoes (Jones 1993a, b). Volcanically active areas, such as the Aleutian Islands, pose greater risks to birds than in many other areas. The eruption of Kasatochi Volcano in the central Aleutian Islands in August 2008 likely killed thousands of auklets (Williams et al. 2010), and two dead adult Fork-tailed Storm-Petrels (*Oceanodroma furcata*) were found near a CO_2 seep one year following the eruption (J. C. Williams, pers. comm.) indicating that even non-breeding prospecting individuals are vulnerable.

There are few previous accounts of avian mortality specifically associated with volcanic gases (Lobkov and Nikanorov 1981, Durand 2007). Large and small mammals, and numerous bird species were found in 1974–1979 in a volcanic seep associated with Kikhpinych Volcano, Kamchatka, Russia. The authors inferred that mammals and large scavenging birds died of asphyxia after entering a gas seep to scavenge smaller prey that had previously died of asphyxia (Lobkov and Nikanorov 1981). At least four adult Kelp Gulls (*Larus dominicanus*) were likely killed by CO_2 or H_2S emissions from geothermal vents at Sulphur Bay, Rotorua on New Zealand's North Island (Durand 2007). Dead seabirds without visible external injuries have been found in natural depressions similar to those on Kiska at Bogoslof Island, Aleutian Islands, Alaska, (J. C. Williams, pers. comm.). The objectives of our paper are to: (1) characterize the gaseous emissions from Kiska Island, and (2) report the avian mortality observed from 2007 to 2010, especially that likely related to volcanic activity.

METHODS

Sirius Point, Kiska Island (52° 08′ N, 177° 36′ E; Fig. 1) is the site of a large seabird colony with >1 million Least and Crested auklets (Sowls et al. 1978). The auklet colony is on the westernmost active volcano in the Aleutian Islands: Kiska Volcano. A parasitic lava cone emerged from the sea adjacent to Sirius Point in 1964–1969, forming

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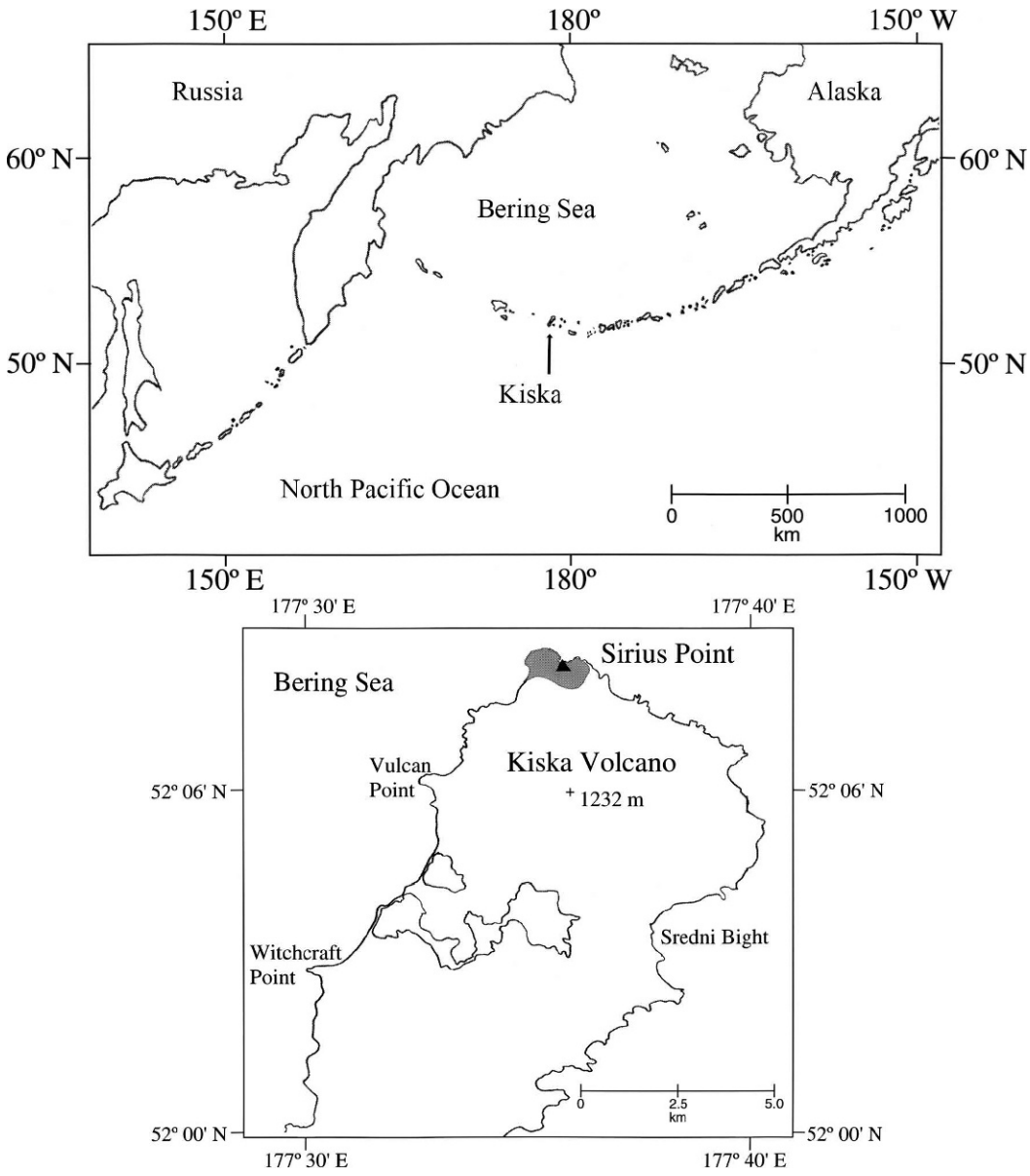

FIG. 1. Kiska Island and Sirius Point, the northern extremity, Aleutian Islands, Alaska. The triangle indicates the approximate location of the gas seep, the shaded area is the auklet colony, and the crosshairs show the summit of Kiska Volcano.

a steep-sided canyon with an older lava flow at the former north coastline (Coats et al. 1961, Simkin et al. 1981). This canyon continues for >1 km along the southern and eastern boundaries of the new lava dome and varies from 10–20 m depth with near vertical walls in places. Many living but weak, moribund, and dead Least Auklet fledglings (some with injuries caused by Norway rat [*Rattus norvegicus*] predation) were regularly found at points along this canyon during 2001–2006 (Major 2004; ILJ, pers. obs.). It was previously assumed these were weak fledglings that, unable to fly, tumbled into low points in the canyon and, unable to find their way to the sea, died of starvation and exposure. Our research team further investigated this phenomenon by walking the eastern third of

TABLE 1. Birds found dead in volcanic areas in 2007–2010 at Kiska Island, Alaska.

Species	Age[a]	Number found				Totals
		2007	2008	2009	2010	
Peregrine Falcon	SY	0	1	0	0	1
Glaucous-winged Gull	ASY	3	0	0	0	3
Least Auklet	HY	80	104	51	67	302
Least Auklet	SY	3	0	2	0	5
Least Auklet	ASY	11	0	0	0	11
Crested Auklet	HY	3	2	2	2	9
Crested Auklet	ASY	3	0	0	0	3
Brown Hawk-Owl	AHY	0	1	0	0	1
Pacific Wren	HY	12	0	0	0	12
Pacific Wren	AHY	4	0	0	0	4
Gray-crowned Rosy-Finch	AHY	3	0	0	0	3
Snow Bunting	AHY	2	0	0	0	2

[a] HY: Hatch year, SY: Second year, AHY: After hatch-year, ASY: After second-year.

this valley (~200 m) at least once every 6 days during daylight hours from May to August in 2007–2010. All bird carcasses were identified, collected, weighed, and measured throughout the season, and examined for evidence of rat predation or other causes of death (Major and Jones 2005, Major et al. 2007).

Three gas samples from the depressions were collected at ~2-week intervals during June–July 2009, and three additional samples were taken 1 month apart from June to August 2010. Briefly, a 3 to 5-m Tygon tube was lowered into the seep, the air was suctioned out with a large syringe, and a gas sample was taken into a pre-evacuated glass sample cylinder. Samples were sealed and transported to the U.S. Geological Survey (USGS) in Menlo Park, California, for identification and quantification of the following gases: He, H_2, Ar, O_2, N_2, CH_4, CO_2, C_2H_6, H_2S, CO, C_3H_8, and C_4H_{10}. Gas samples were analysed for bulk composition by gas chromatography, and the CO_2 fraction was dried and purified cryogenically, using methods described by Evans et al. (1988). A CO_2 split was analysed for the ratio of $^{13}C/^{12}C$ at the USGS Reston Stable Isotope Laboratory using methods described by Révész and Coplen (2008). The remaining CO_2 was reduced to graphite on a Fe catalyst at the USGS laboratory in Reston, Virginia, USA to ascertain the volcanic and biogenic fraction of bulk C, and analysed for the ratio of $^{14}C/^{12}C$ at the Lawrence Livermore Center for Accelerator Mass Spectrometry.

Statistical tests were performed in SPSS 16.0.2 (SPSS Inc. 2008), and results were considered significant at $P < 0.05$. We used analysis of variance to test differences among years in deceased Least Auklet wing chord and mass, as well as differences in gas composition between our samples and normal atmospheric concentrations. We used Games-Howell (GH) tests for multiple comparisons (Games and Howell 1976) of auklet measurements as variances were not homogeneous (Levene 1960, Day and Quinn 1989).

RESULTS

Dead birds (mostly fledged juvenile Least Auklets) were found in the canyon during 2001–2006. Other species, including passerines, gulls, and raptors began appearing in the canyon in 2007, suggesting factors other than natural deaths associated with a large seabird colony might be involved (Table 1). Most auklets appeared on 1–2 days each year: 30 July 2007, 1 August 2008, 2–3 August 2009, and 30 July 2010. Other species included: Peregrine Falcon (*Falco peregrinus*), Glaucous-winged Gull (*Larus glaucescens*), Brown Hawk-Owl (*Ninox scutulata*) (Bond and Jones 2010), Crested Auklet, Pacific Wren (*Troglodytes pacificus*), Gray-crowned Rosy-Finch (*Leucosticte tephrocotis*), and Snow Bunting (*Plectrophenax nivalis*) (Table 1).

The mass of individual dead Least Auklet fledglings ranged from 35 to 84 g and differed among years ($F_{3,297} = 79.42$, $P < 0.001$). *Post-hoc* tests revealed the mass of dead fledglings differed each year with 2009 < 2010 < 2008 < 2007 (GH tests, all $P < 0.003$). Fifty-six birds in 2007 (69%), 96 in 2008 (91%), and all birds in 2009 ($n = 52$) and 2010 ($n = 67$) were below the asymptotic

TABLE 2. Atmospheric composition of gas samples at Kiska Island, Alaska, in 2009 and 2010 (elevated CO_2 in the sample from 30 Jul 2010, indicated in bold). Data are presented as the percent composition of samples; gases representing <0.001% of samples are not included. Normal atmospheric composition is from NASA Global Climate Data Center.

Gas	19 Jun 2009	4 Jul 2009	18 Jul 2009	31 May 2010	30 Jun 2010	30 Jul 2010	Air
Ar	0.944	0.933	0.913	0.905	0.913	0.890	0.934
O_2	21.044	20.875	21.115	21.257	21.083	20.717	20.946
N_2	77.974	78.025	77.872	77.759	77.964	77.035	78.084
CO_2	0.037	0.166	0.099	0.079	0.039	**1.358**	0.039

weight of 73.0 ± 2.2 g reported in a chick growth study on Kiska by Major et al. (2006).

Flattened wing chord also varied by year ($F_{3,298} = 33.39$, $P < 0.001$) with corpses from 2009 and 2010 having shorter wings than those in 2007 and 2008 (GH, $P < 0.001$). The mean (± SD) wing chord in 2007 and 2008 was 91 ± 5 mm and 92 ± 5 mm respectively, while in 2009 and 2010, the mean was 86 ± 5 mm and 85.5 ± 6 mm. There were 3 (4%), 3 (3%), 9 (17%), and 13 (19%) fledglings with wing chords shorter than the mean wing chord reported by Major et al. (2006) of 80.3 ± 3.4 mm in 2007, 2008, 2009, and 2010, respectively.

Gas concentrations and composition were similar to normal atmospheric levels in all samples, except for slight enrichments in CO_2, which reached 1.358% on 30 July 2010. Elevated CO_2 was found on other days, but quantities were insufficient to perform isotopic analysis (Table 2). Isotopic analysis of this single sample gave a $\delta^{13}C$ of −9.55‰, within the range of magmatic gas from Aleutian Arc volcanoes (Symonds et al. 2003). A low ^{14}C value of 0.0399 (Fraction Modern Carbon; 0.052% of the total sample volume) of the July 2010 sample had only a trace component of biogenic CO_2 with the remainder (1.306% of the total volume, or 96% of the total CO_2) volcanic in origin.

DISCUSSION

The 2009–2010 samples from the gas seep on Kiska Island contained only low levels of CO_2 and mostly auklets were found dead (Table 2). We suspect there is significant interannual variation in emissions, and that emissions were higher in 2007 and 2008 when larger numbers of small land birds were found dead (Table 1). Dead passerine birds without obvious external or internal injuries, and no alternative explanations for numerous deaths in such a small area over a small temporal scale were the first indication of a possible environmental or geological cause of death. Toxic gas concentrations may only be present in lethal concentrations on certain days with light wind; all our sampling occurred when average wind speed was >25 km/hr, typical for the area during summer. Cold gas seeps that emit nearly pure CO_2 are known in many volcanic areas, such as Mammoth Mountain, California, where emission rates have been shown to vary on time scales ranging from diurnal to decadal in response to both magmatic unrest and meteorological forcing (Lewicki et al. 2007).

Nearly all confirmed breeding species at Sirius Point have been recovered in the valley containing the pits; exceptions being species that breed in much lower density in this area of Kiska Island such as Snow Buntings, which are uncommon local breeders in alpine areas of the volcano (Bond et al. 2010). The only vagrant found was a Brown Hawk-Owl (Bond and Jones 2010).

Many dead Least Auklet fledglings were underweight, yet few had underdeveloped wing feathers compared to chicks in a growth study on Kiska in 2002 and 2003 (Major et al. 2006). This suggests they were in poor condition (Øyan and Anker-Nilssen 1996) and were likely trapped in the valley. They could not fly or take off once trapped by the tall vegetation (mainly *Puccinellia* spp., *Carex* spp., and *Calamagrostis* spp.), while attempting to depart to the sea. We believe a combination of starvation, poor condition, and noxious gases contributed to auklet deaths. Fledgling alcids have a natural inclination to descend while fledging, presumably an adaptation for nesting on slopes and cliffs (Gaston and Jones 1998). It is difficult, without detailed necropsies, to know if the auklets continued to descend into the gas-filled depression and died because they could not emerge to go to sea and feed, or from asphyxia. In contrast, the large number of land birds found, and that large numbers of seabirds were found on only 1 or 2 days each year suggests that gaseous emissions had a role in avian mortality in some years.

This gas seep had a weak feed of magmatic CO_2 that was only readily detectable in one of six

monthly samples. $\delta^{13}C$ analysis of the single sample with substantially elevated CO_2 placed the ratio of $^{13}C/^{12}C$ in the range of other Aleutian volcanoes, and higher than biogenic carbon isotope ratios in CO_2 (Cerling et al. 1991, Symonds et al. 2003). Of the 1.358% CO_2, 0.052% originated in air/soil, and 1.306% (or 96% of all CO_2) was magmatic in origin. It was apparently sufficiently strong to produce concentrations lethal to birds at certain times (i.e., calm winds), even if only for a few days each year. We conclude that, while these gaseous emissions do not present an immediate threat to the large auklet population, birds could be particularly susceptible in some years, and especially if future volcanic eruptions occur at this site.

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