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SHORT NOTE

Toxic gases and dead birds at Sulphur Bay, Rotorua, North Island, New Zealand

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Sulphur Bay, the southernmost inlet of Lake Rotorua, in the central North Island, New Zealand, is unusual in being a loafing and roosting site for many bird species in an active geothermal area. The shores of the bay including, Motutara Point refuge and the nearby Sulphur Point Wildlife Sanctuary, are home to, among others, black-billed (*Larus bulleri*) and red-billed (*L. novaehollandiae*) gulls, New Zealand scaup (*Aythya novaeseelandiae*), black swan (*Cygnus atratus*), grey duck (*Anas superciliosa*), bittern (*Botaurus poiciloptilus*), New Zealand dabchick (*Tachybaptus rufopectus*), banded dotterel (*Charadrius bicinctus*), cormorants (*Phalacrocorax* spp.), pied stilt (*Himantopus leucocephalus*), and Caspian tern (*Sterna* caspia). The birds roost and feed amongst geothermal features that include clear-flowing hot springs, hot ground, and fumaroles that emit carbon dioxide (CO_2), hydrogen sulphide (H_2S), water vapour (H_2O), and other gases into the atmosphere. Birds can be observed loafing and roosting in large groups near fumaroles and close to drifting plumes, seemingly untroubled by the gas emissions.

During a survey of geothermal air pollution in Rotorua (Durand & Scott 2005), on 20 Feb 2003, I found 2 recently-dead black-backed gulls (*Larus domincanus*) (Fig. 1). The bodies were on bare ground on the southern margins of the Ngapuna sulphur flats. The apparently sudden death of these birds very near sources of toxic gas suggested they may have been poisoned or asphyxiated.

The 2 black-backed gulls (B1, B2) found in Feb 2003 were found at Ngapuna Sulphur Flats, in a clearing *c.*30 m in diameter in an area of scrub. There was a small fumarole complex (Fig. 1A) near the centre of the clearing, *c.*0.7 m above the edge of the clearing. B1 was in the open, resting on unvegetated pumice dust and fine gravel (Fig. 1A, B). The bird's torso was upright, with the bill and head in front of the body, and the wings were slightly open and resting on the ground. The 2nd bird (B2, Fig. 1C) lay < 1 m from the edge of the scrub, beneath vegetation *c.* 0.6 m high, which did not hide the bird. This gull lay in a similar attitude to B1, with its wings slightly open, but its head and bill were tucked partially under the left wing. Both birds appeared to be only slightly decomposed, there was no noticeable smell of decay near either, they were undisturbed by predators, and both had probably died in the preceding 48 h.

Two more dead black–backed gulls were found in different parts of the same clearing in Jul 2005. The circumstances of their deaths appeared similar to those of the 1st 2 birds, but the bodies were more decomposed. Other dead birds have been seen at Ngapuna (A. Cody, pers. comm.; C. Werner, pers. comm.), but no details are available.

On 20 Feb 2003 when the birds were discovered, CO_2 and H_2S concentrations were measured using active infra–red monitors: a Rae Systems Multi–RAE IR infrared analyser (0–200 parts per million (ppm) H_2S, 0.1 ppm resolution) and an Environmental Instruments Anagas CD98 (CDA 1.2P) infrared analyser (0–60% CO_2; 0.1% resolution). Real–time gas concentrations were measured at the scene at *c.*1800 h in calm, dry weather. Near B1, the air at ground level contained 7–8 ppm H_2S and 0.5–1% CO_2. Repeated measurements showed that the air at ground level near B2 contained *c.*4 ppm H_2S and 0.3–0.5% CO_2. In addition, the concentrations of these gases were measured at the degassing fumarole complex: 100 mm from the vent H_2S concentrations reached > 200 ppm; CO_2 was > 60%. Ambient air within 5 m of the fumarole, at 1 m above ground, contained < 1% CO_2 but *c.*10 ppm H_2S. These gas measurements are consistent with others made elsewhere in the Sulphur Bay area (Durand & Scott 2004, 2005).

On 21 Feb 2003, 6 passive gas-detector tubes were placed at the scene (Dositubes 2D and 4D; Gastec Corp., Japan) to record time-averaged CO_2 and H_2S concentrations for 10 h and 48 h, respectively, before being collected. Both periods were within maximum permissible recording times. Each tube was placed with its inlet at ground level. The 2 CO_2

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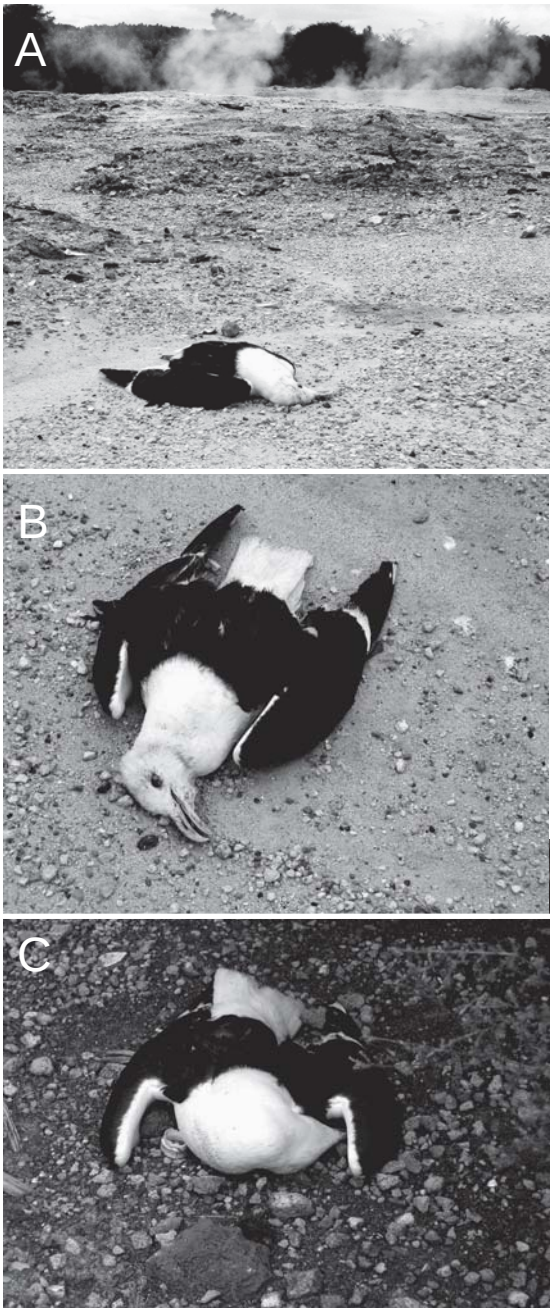

Fig. 1 Dead southern black-backed gulls (*Larus dominicanus*) found at Ngapuna, Rotorua, Feb 20 2003: A, B1, degassing fumarole complex in background; B, B1; C, B2. Photographs: Author.

tubes placed near the birds recorded < 3% CO_2 by volume; the H_2S tubes near the birds recorded *c*.10 ppm (B1) and *c*.15 ppm (B2), H_2S, respectively. Gas concentrations in the CO_2 and H_2S tubes placed on the ground *c*.100 mm from the fumarole exceeded the measurement limits of the tubes.

The gas survey results supported the possibility that the birds had been either asphyxiated by CO_2 or poisoned by H_2S. CO_2 is a colourless, odourless, asphyxiant. Concentrations in clean outdoor air are typically *c*.350 ppm or 0.03%, but the gas poses a risk to human health at > 3% in ambient air; human asphyxia follows at *c*.10% CO_2. The gas is denser than air (relative gas density 1.53) and can flow and pool in low-lying areas, displacing the breathable air. Outdoors, CO_2 pools usually form in topographical depressions when there is no breeze (hence often at night), and may form some distance from the emission source. In volcanic and geothermal areas in Iceland, Hawaii, and elsewhere, animals that have walked into such pools have been found dead (Thórarinsson 1979). In the Alban Hills volcanic and geothermal area near Rome (Italy), CO_2 asphyxiated 30 cows in a single event in 1999 and the gas has also been responsible for a number of human fatalities in the area (Beaubien *et al*. 2003). In Furnas (Azores), a small town built inside the crater an active volcano, the air in ditches and trenches contained up to 50% CO_2 (Baxter *et al*. 1999). Elevated CO_2 levels in enclosed spaces have also been recorded in settlements around Vulcano, an active volcanic island off Sicily, and at Mammoth Mountain, a dormant volcano in California (Baxter *et al*. 1990; Farrar *et al*. 1995).

H_2S is an acidic, corrosive, and irritant gas that has the distinctive odour of rotten eggs; it is this smell that characterises the area in and around Rotorua (Durand & Scott 2005). For humans, the odour threshold is *c*.80 parts per billion (ppb) but the gas may cause eye irritation and headaches at *c*.1 ppm. Severe toxic effects of acute exposures are limited to much higher concentrations (> 200 ppm) and include pulmonary oedema, respiratory arrest, coma, and death. Sudden deaths associated with H_2S poisoning have been well documented in investigations of industrial accidents, and in Rotorua the gas has been implicated with several suspicious fatalities. Critically (in humans) the olfactory system is paralysed by concentrations of *c*.200 ppm. Once the gas reaches immediately hazardous concentrations, therefore, the victim may not be able to detect the hazard by smell. H_2S is also denser than air (relative gas density 1.19), and so it may reach high concentrations in a stratified or undisturbed atmosphere. Forensic examinations of H_2S poisonings show that, in many instances, victims lost consciousness without resistance and either were unaware of the hazard, or were overcome too rapidly to escape, or to be rescued by others.

The evidence, although limited, therefore suggests that toxic gas emissions may occasionally

kill birds roosting on geothermal ground. The gas survey measurements did not identify immediately dangerous gas concentrations near the dead birds. However, ground gases and emissions from the nearby fumarole were sufficient to elevate gas concentrations in ambient air. It is possible that much higher and potentially dangerous concentrations of CO_2 and H_2S may have built up in this area when atmospheric conditions were calm, and especially under a shallow temperature inversion. During these conditions, fumaroles and ground gas emissions may have been trapped in this enclosed area. The birds were found downslope from the fumarole complex from which the relatively dense CO_2 and H_2S would drain when the air was still. The birds could have been roosting on the thermal ground and a pool of CO_2 and H_2S built up around them, or they may have landed in an existing pool of gas and then been overcome. Their body positions and locations were not consistent with their being sick or injured before death and seeking shelter, although that is possible.

Other explanations are, however, possible and the finding of 4 dead black-backed gulls, without autopsy evidence for cause of death, is of course not conclusive evidence for gas kills. Similarly, the actual gas concentrations that are possible in the geothermal area are not well known, and nor is the susceptibility of black-backed gull and other species to CO_2 and H_2S. However, toxic gases in geothermal emissions are becoming better known as sources of mortality of humans and other vertebrates, and they are another potential source of mortality for birds in New Zealand's geothermal areas.

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