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SHORT NOTE

Sodium-rich clay soil geophagy by common redpoll (*Carduelis flammea*) in New Zealand

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Common Redpoll (*Carduelis flammea*) was introduced to New Zealand from Europe between 1862 and 1875 and is now naturalized and abundant throughout most of the country (Gill *et al.* 2010; Angus 2013). In North America, Europe and New Zealand, the redpoll feeds primarily on seeds of birch (*Betula* spp.), willow (*Salix* spp.), alder (*Alnus* spp.), grasses (Poaceae) and various conifers, with a larger proportion of arthropods during the breeding season (Knox & Lowther 2000). In New Zealand, redpolls appear to favour habitats with a mixture of young conifers and open habitat (Clout & Gaze 1984).

Geophagy is the deliberate consumption of clay or soil by an animal (Diamond *et al*. 1999). Hypotheses proposed to explain geophagy include: 1) neutralizing plant secondary compounds that may be toxic or impede digestion (Diamond *et al.* 1999; Gilardi *et al.* 1999), 2) acquisition of essential minerals rare in the typical diet (March & Sadleir 1975; Jones & Hanson 1985; Sanders & Jarvis 2000), and 3) acquiring grit to aid in physical breakdown of coarse food in the gizzard (Gilardi *et al.* 1999; Gionfriddo & Best 1999). A common element to these hypotheses is that geophagy is a behaviour that is adopted as an aid to digestion and nutrient acquisition and absorption. Although a review of published literature would suggest that geophagy is more common among certain bird orders (e.g. psittaciforms), it is not clear whether this is an artefact of parrots being generally large, social, and conspicuous compared to most birds. Moreover, many mammals including elephants, antelope, and bats (Voigt *et al.* 2008) also eat or lick soil mineral sources (Cowan & Brink 1949; Klaus & Schmid 1998). Thus, such behaviour appears to be important for many species and may be essential for some populations living in areas where their diet lacks sufficient minerals (Brightsmith & Aramburú 2004) or where geophagy serves some other important digestive function. The implications of geophagy for animal movement, distribution, and individual fitness are intriguing and, for most species, poorly understood, especially among birds (Wiener 1975).

To our knowledge, geophagy has never been reported in the common redpoll in Europe, North America (*Acanthis flammea*), or New Zealand, although other members of the subfamily Carduelinae such as crossbills (*Loxia* spp.) are known to engage in this behaviour (Tozer 1994; Latta 2012). Comprehensive accounts of the diet of Redpolls make no mention of soil consumption in North America (Knox & Lowther 2000). Geophagy has been widely reported among psittaciforms

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including communal consumption of clay in the Neotropics (Gilardi & Munn 1998; Brightsmith & Aramburú, 2004) and charcoal in New Zealand (Galbraith 2018).

On 20 January, 2019 at 1045 h, while walking along a track on the southeast slope of Sugar Loaf in the Port Hills off Summit Road above Christchurch, New Zealand, I observed a small group of 2–4 Redpolls perching on, and flying in the vicinity of, an outcrop of soil on a cliff face about 8 m above the track. The birds appeared to be pecking or actively feeding on the vertical soil surface or something on the soil surface (Fig. 1a); the soil, which adhered to the rock cliff, appeared to have been deposited in a rock fissure and then exposed when the outer rock fell away (Fig. 1b). Based on numerous recent geological studies in the area, it is highly likely that collapse of the outer rock face occurred at some point during the earthquake sequence that the wider Christchurch area experienced from September 2010 until February 2016.

The soil in this location was observed to be a pale yellowish tan colour with a few protruding roots (Fig. 1a). This is consistent with reports from soil surveys undertaken in the general area where the redpolls were observed; soils were characterized as having loess parent material overlaying basalt, forming a local "summit series" of yellow-brown and yellow-grey friable silt loams (Griffiths 1974). Soils from this region are typically fine and silty with up to 45% clay (loess) and were created in part during cold climate episodes during the last million years (Bell 1981; Yates *et al.* 2018). Parent material in the Port Hills is primarily heavily eroded volcanic material with soil geochemistry further influenced by glacial deposits, aeolian dust deposition, and biological processes (Lawrence *et al*. 2011).

Seen through Leica 10x50 binoculars, it appeared that the redpolls were using their bills to take bites of the soil itself (supplemental video).[1] Using a Canon 80D camera with a 100–400 mm lens, I videoed the birds at the highest magnification for approximately 1.5 minutes. During this time, at least one male foraged at the soil and at least one female/juvenile also perched on the soil cliff face or on protruding roots and repeatedly bit at the soil. On 29 January, at 0930 h, I again videoed a single male redpoll at the same site foraging on the soil surface while clinging to the soil and/or roots (see supplemental video).[1] The video was edited to reduce shaking and to slow down time periods when a bird was actively pecking and biting on the soil cliff face. The video clearly shows pieces of the friable soil falling away as the redpoll repeatedly pecks at the surface to take "bites" of the soil.

[1] A composite edited (for stability and slow motion) supplemental video 3 min 47 sec. long can be viewed at: https://www.youtube.com/watch?v=1YogzjS6iP4

In total, I spent 2 h 57 min observing this soil cliff site and during that time saw visits by an estimated 4–5 redpolls. Only once were there two birds at the site simultaneously, so the exact number of individual birds cannot be determined from these observations. However, it does seem clear that redpolls return to this site with some regularity.

Because some birds appear to select soils with particular chemical characteristics (Powell *et al*. 2017), we decided to collect and analyze soil samples from the cliff site and from an accessible site with exposed soil of the same "summit series"

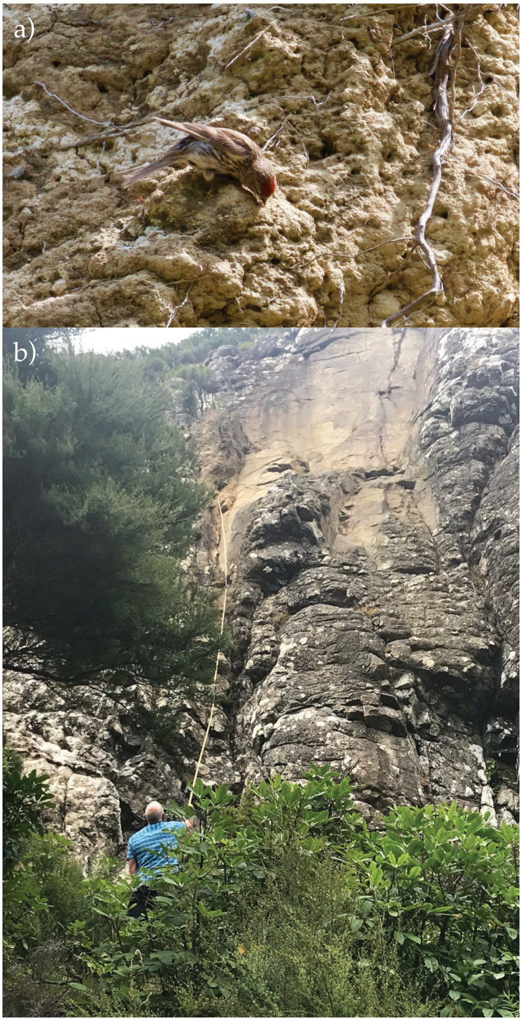

Figure 1. a) A common redpoll consuming soil on cliff face, Port Hills, Canterbury, New Zealand, b) Flaspohler using a bamboo pole to sample soil adhering to rock face (a sheet below was used to collect fallen soil) in Port Hills. The smooth, less weathered, and paler section of the cliff can be seen at top centre where the rock recently fell away to reveal the soil.

approximately 1 km away. On 1 February 2019, we used a long bamboo pole and a sheet to collect samples of the soil at the spot where the redpolls had perched and consumed soil (Fig. 1a). These two soil samples were sent to the Scion analytical laboratory in Rotorua to determine elemental concentrations (Mahaney & Krishnamani 2003).

A small subsample was used to test allophane content; this showed a moderate to strong reaction, agreeing well with the soil description in Griffiths (1974). Elemental analysis (LECO CNS-2000, Mehlich-3 extraction followed by ICP-OES analysis) determined that the "eaten" soil contained 2.32% carbon and 859 mg/kg sodium while the "not eaten" soil contained 0.98% carbon and 377 mg/kg sodium.

Many North American finch species regularly eat mixtures of salt and sand including gravel spread on winter roads for automobile traction (Flaspohler, *pers. obs*.). Finches also eat clay (Latta 2012) for reasons that remain poorly understood; the motivation for such geophagy may vary from species to species or even between populations. A closely related behaviour, lithophagy is defined as the ingestion of small stones and although we could find no mention of this behaviour among redpolls, it seems likely that, as with other finches, they engage in this behaviour to aid physical breakdown of food or as an antiparasite behaviour (Knezevich 1998; Robinson *et al*. 2008).

Because only two samples were collected, statistical analyses were not possible, but it is worth noting that the differences in sodium concentrations identified here agree very well with a more extensive study of soil properties that concluded that sodium content were an important factor in parrot geophagy (Powell *et al.* 2009); Powell *et al*. (2009) found that the mean sodium concentrations in a clay lick in Amazonian Peru was 1,137 mg/kg compared to 859 mg/kg for the soil eaten by redpolls in this study. The mechanism responsible for the greater sodium content in the "eaten" soil is not clear, but is likely related to the physical environment in which the soil formed prior to exposure following the rock slide. Sodium is highly soluble and is readily released from rock exposed to rain. The fissure may have allowed dissolved sodium to accumulate, gradually concentrating this element to levels exceeding that in nearby soils.

The difference in the carbon content between the soil samples is also likely an outcome of the physical environment of the soil prior to the earthquakes. The fissure in which the "eaten" soil formed would have trapped considerably more plant litter than the "not eaten" soil collected from a more exposed location; such inputs (and retention) of organic matter are often associated with increased soil carbon content (Smaill *et al.* 2008).

Many previous studies have suggested that sodium compounds are common in soils chosen by mammals for geophagy (Stockstand *et al*. 1953; Weeks & Kirkpatrick 1978), and this appears to be true for birds as well. In Peru, Brightsmith & Muñoz-Najar (2004) found that soil consumed by 15 species of birds (mostly parrots) had seven times more exchangeable sodium ions compared with unconsumed soil. Sodium supplementation is the most commonly reported reason for vertebrates to engage in geophagy (reviewed in Klaus & Schmid 1998). For birds, the preponderance of published studies suggests that the need for sodium is the primary driver of geophagy (Brightsmith *et al.* 2018).

The redpolls observed in the Port Hills may be deriving other benefits from soil consumption such as physical breakdown of coarse food in the gizzard or toxin absorption. However, the soils we collected were uniformly fine silt and clay with few particles larger than 0.1 mm, suggesting that their value as grit would be minimal. It seems likely that different bird species engage in geophagy for multiple and sometimes complimentary reasons (Symes *et al*. 2005). Birds may choose soils that have more than one appealing characteristic, and further experimental research is needed to clarify whether these soils provide other benefits beyond augmenting sodium in the diet.

More reporting of observations of geophagy among all birds would improve our understanding of this behaviour and how widespread it is among bird orders. We concur with Galbraith (2018) who recently wrote: "*I encourage other researchers to document and report any observations (historical as well as future) of charcoal consumption, or geophagy, among the wider New Zealand avifauna, so that we might better understand the prevalence of this behaviour and discuss what importance it may have in this region for avian herbivores in particular*."

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