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Unusual feeding record for a Neotropical rodent: a common Andean lycophyte

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ABSTRACT
The Haggard's leaf-eared mouse *Phyllotis haggardi* is a rodent endemic to Ecuador and almost nothing about its ecology has ever been recorded in detail. In this note we report for the first time, that the diet of *P. haggard* includes spores of *Phlegmariurus crassus*, a common lycophyte of the Andean *Paramos*. This is a remarkable record since the consumption of lycophyte spores by mammals is rare, providing new insights on the feeding behavior of *P. haggardi*. With this finding, we contribute to the natural history of this rodent species, and highlight the presence of lycophytes as a potential food resource for the small mammals that inhabit Andean ecosystems.

RESUMEN
El ratón orejón de Haggard, *Phyllotis haggardi*, es un roedor endémico de Ecuador que carece de estudios detallados sobre su ecología. En esta nota, reportamos por primera vez que la dieta de *P. haggardi* incluye esporas de *Phlegmariurus crassus*, una licofita común de los páramos andinos. Este es un registro importante, ya que el consumo de esporas de licofitas por parte de mamíferos es raro, detallándose además un nuevo comportamiento para *P. haggardi*. Con este hallazgo contribuimos con la historia natural de esta especie de roedor y destacamos la presencia de licofitas como un potencial recurso alimenticio para los pequeños mamíferos que habitan los ecosistemas andinos.

Haggard's leaf-eared mouse *Phyllotis haggardi* Thomas,1898 is an elusive rodent endemic to Ecuador (Naylor & Roach 2016; Tirira 2017). It occurs on the upper slopes on both sides of the Ecuadorian Andes, typically between 1,900 and 4,500 m a.s.l. (Steppan & Ramírez 2015; Pardiñas et al. 2017; Tirira 2017). Despite its common presence (Tirira 2017), the behavior of this rodent is poorly studied. Almost nothing about its ecology, reproductive traits, or diet has ever been recorded in detail (Steppan & Ramírez 2015; Tirira 2017). Recent reports indicate that as other rodent species from the high Andes do, *P. haggardi* mainly feeds on seeds, stems, leaves, roots, and invertebrates (Pardiñas et al. 2017; Tirira 2017). Here we

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report for the first time, the inclusion of *Phlegmariurus crassus* (Humb. & Bonpl. ex Willd.) B. Øllg. spores, a common and conspicuous lycophyte of the Andean *páramos*, as part of *P. haggardi*'s diet. This behavior is the first and only reported interaction of this kind between a rodent and a lycophyte in the Neotropics.

Observational evidence for this novel behavior was registered in September 2018 during a survey in the Antisana Ecological Reserve, Napo Province (Ecuador), located on the northwestern slopes of Mount Chuzalongo at 4,482 m a.s.l. (latitude -0.475352 ; -78.220278). This is a small mountain northwest to Antisana volcano, and is mainly characterized by the presence of *Plantago rigida* cushions, *Chuquiraga jussieui* shrubs, and *Calamagrostis intermedia* grasslands (Fig. 1). During a field trip, we captured three specimens of *P. haggardi* on the Chuzalongo slopes using Sherman live capture traps (Forestry Suppliers, Inc.). We tracked the specimens afterwards using the spool-and-line technique (Miles et al. 1981; Boonstra & Craine 1986). After tracking them, two of the three individuals were re-captured and prepared as museum specimens. Throughout this process, we extracted their fresh scats and preserved them in 75% ethanol. All specimens were formally accessed to the Mammal Collection at Museo de Zoología, Pontificia Universidad Católica del Ecuador (QCAZM 18153 – QCAZM 18154).

Along the followed tracks, we noticed that the three individuals made several forays into groups of *P. crassus*, where we were able to identify plants with signs of herbivory, defined here as fresh stem areas stripped of sporophylls, gnawed to the base (Fig. 2A and Fig. 2B). Along these tracks, the absence of sporangia at the base of the sporophylls and the presence of this kind of microphylls discarded and scattered on the ground with evident gnawing signs, was considered feeding evidence.

Since we could not assert that these rodents consumed spores solely by finding damage in *P. crassus* plants, we decided to analyze alcohol-preserved feces using acetolysis. This protocol is widely used in palynology to obtain visible and identifiable pollen and spore samples (Erdtman 1960; Kearns & Inouye 1993). Each dropping was dissolved in 75% alcohol and then subjected to the aforementioned process, obtaining a total of seven individually processed samples (three from individual QCAZM 18153 and four from individual QCAZM 18154). Full spores and fragments of *P. crassus* were found under the microscope in all the prepared samples (Fig. 2C).

Our data indicates that these individuals of *P. haggardi* included spores of *P. crassus* in their diet. This is a remarkable behavioral record since the consumption of lycophytes or fern spores by mammals is very rare. So far, the New Zealand short-tailed bat (*Mystacina tuberculata*) and the European woodmouse (*Apodemus sylvaticus*) are the only mammals to consume spores of *Lycopodium* sp. & *Culcita macrocarpa*, respectively (Daniel 1976; Arosa et al. 2010). This new record shows that spore consumption may be more common than expected, and could occur in a wide variety of ecosystems, now including the Andean *páramos*.

The unusual nature of herbivory events in the Lycopodiaceae may be mainly due to the phytochemical defenses of these plants. It is well-known that many species within this family have rich sources of diferent bioactive metabolites, alkaloids in particular (Ma & Gang 2004; Konrath et al. 2013; Armijos et al. 2016). The physiological mechanisms that prevent rodents from the detrimental effects of alkaloids remain unknown. However, spore consumption is not limited by the chemical defenses of sporophylls. We believe that the effort to reach the sporangia may be favored by the absence of alkaloids in the reproductive structures. Most of the mature spores in the Lycopodiaceae are rich in starch, cellulose, carboxylated polysaccharides, pectic acids, and oil (Arana et al. 2014; Rincón et al. 2014). These compounds allow spores to resist and stay nourished underground, germinating only after a long time, and developing into slowly maturing, mycotrophic, subterranean gametophytes (Øllgaard 1990). *Phyllotis haggardi* individuals may then take advantage of these compounds, by obtaining rewarding nutrients that may allow them to endure in an ecosystem with extreme conditions and limited food resources. However, the extent to which it is possible for these rodents to extract these nutrients from the spores should be explored.

Another characteristic that could discourage the consumption of *P. crassus* spores may be related to its threatening morphology. The individual stems have leathery and thorn-like simple sporophylls, arranged in low alternating spirals (Øllgaard 1990), that form a shield to protect the sporangia. In contrast, rodents have unique and successful feeding and buccal adaptations with a wide range of motion and chisel-shaped teeth (Cox et al. 2012; Arregoitia 2016; Tirira 2017). The combination of behavior and buccal adaptations enable the rodents to mechanically avoid the thorny tips of the microphylls and gnaw them at the base, where it is easier for them to reach the sporangia. Furthermore, the aggregate growth habit of *P. crassus* forms small islands in open areas amid cushion plants and grasses. These lycophyte aggregations could provide temporary shelters that keep rodents safe from predators while foraging.

Although the benefits that *P. haggardi* obtains by consuming spores of *P. crassus* are somehow clear in terms of nutritional value and shelter, the nature of this interaction is not yet fully understood. We still do not know whether *P. crassus* is benefited or harmed by the rodent's behavior. In principle, having found spores in the scats indicate that these rodents could act as possible dispersing agents. To our knowledge, there are no endozoochory cases reported to compare our data with. This is a limitation for documenting interactions because of the scarcity of registered cases of mammal-dispersed spores in Lycopodiaceae or related groups (Arosa et al. 2010; Barbé et al. 2016). Moreover, the damage on the sporophylls does not necessarily indicate herbivore specialization of any kind. In other words, predation could also account for the reported case here, where rodents only take advantage of the available resource, and the potential dispersion of the spores would only be a secondary and occasional by-product of foraging. However, further research should be carried out to completely describe this behavior, as the evidence presented here is still fragmentary.

Finally, we emphasize the importance of this unique interaction, and encourage continuing to explore threatened ecosystems like the *páramo*, especially since the presence of *P. crassus* or other lycophytes could lead to new discoveries in rodents' behavior.

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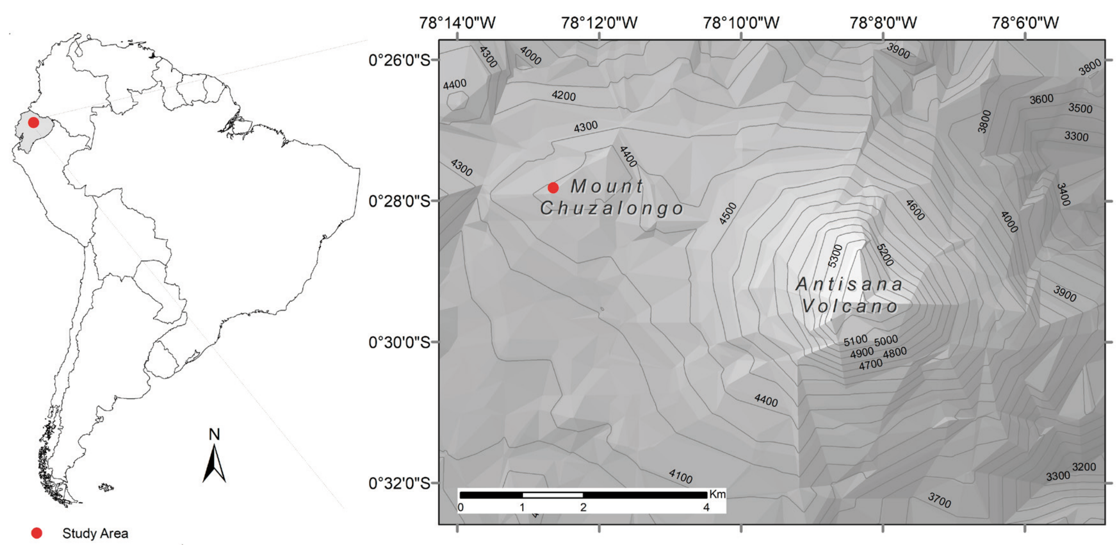

Figure 1. Study area in Ecuador. The red dot indicates the northwestern slope of mount Chuzalongo, located northwest of the Antisana volcano, where consumption of the lycophyte *Phlegmariurus crassus* by *Phyllotis haggardi* was documented.

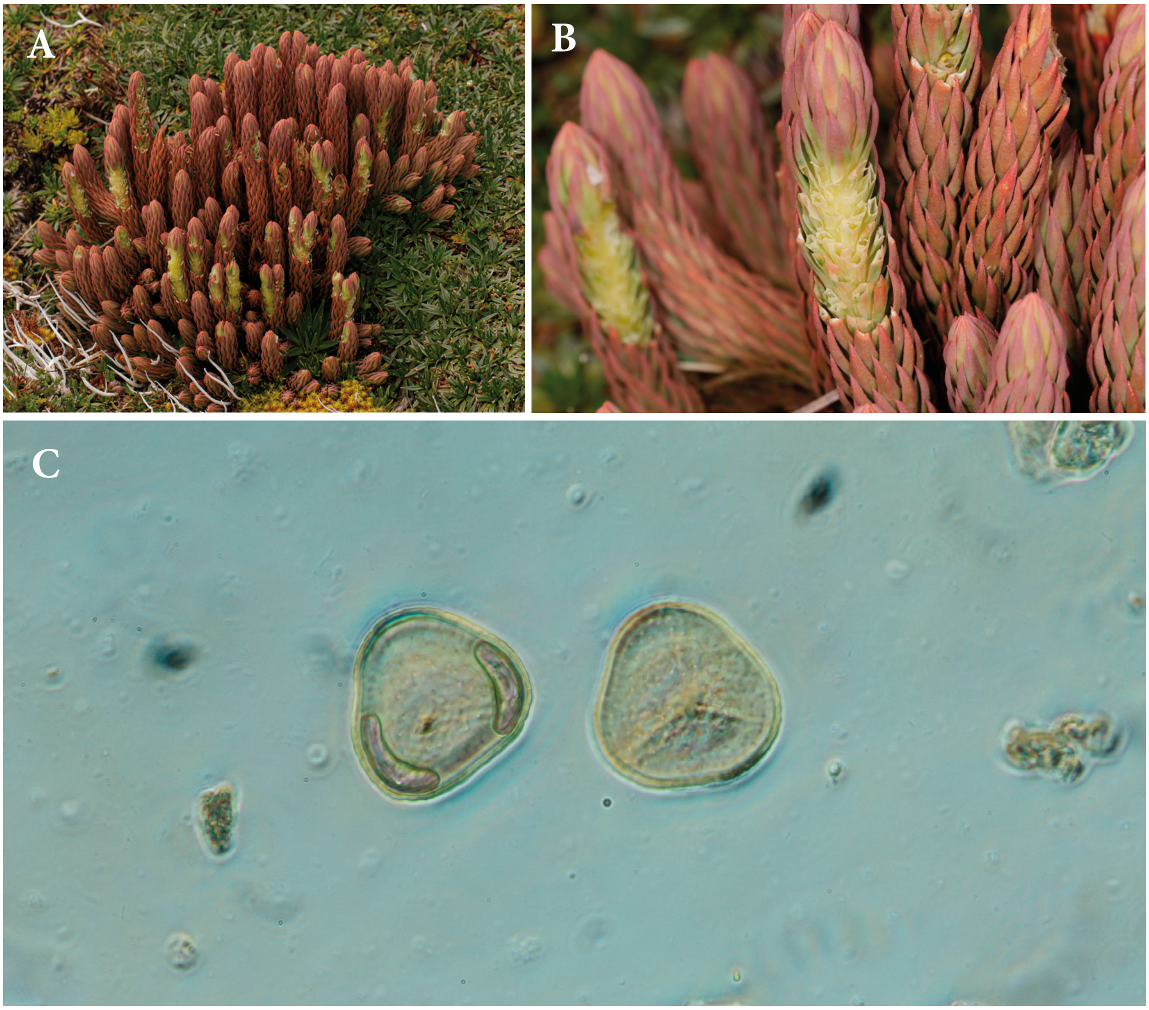

Figure 2. Observed evidence of spore consumption by *Phyllotis haggardi* on *Phlegmariurus crassus*. A) *P. crassus* clump showing several fresh stem areas stripped of sporophylls; B) Gnawed area on the stem, were the sporangia have been consumed; C) *Phlegmariurus crassus* spores found in a microscope sample of the QCAZM 18153 specimen. Photo credits: Ricardo Zambrano-Cevallos (A, B); Manuela Ormaza (C).

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