NOTAS SOBRE

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Patterns of mineral lick visitation by Linnaeus's two-toed sloth *Choloepus didactylus* (Pilosa, Megalonychidae) in eastern Ecuador

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ABSTRACT
Geophagy involves the consumption of soil to supplement diets and to facilitate digestive processes. We used camera traps to document the use of a salt lick by Linnaeus's two-toed sloth *Choloepus didactylus* (Linnaeus, 1758) from December 2014 to November 2015 in a lowland Ecuadorian forest. We obtained 201 videos of sloths and analyzed if rain or lunar-phase influenced these visits. Visits were positively correlated with monthly rainfall and negatively correlated with lunar illumination, but correlations were not significant. We consider three hypotheses for visiting licks: (a) to supplement their diet, (b) to help digestion, and (c) to obtain water.

RESUMEN
La geofagia involucra consumo de tierra para complementar la dieta y facilitar procesos digestivos. Utilizamos cámaras para documentar el uso de un saladero por perezosos de dos dedos de Linnaeus *Choloepus didactylus* (Linnaeus, 1758), desde diciembre 2014 a noviembre 2015, en un bosque de tierras bajas ecuatoriano. Obtuvimos 201 videos y analizamos si la lluvia o la fase lunar influyeron en estas visitas. Estas se correlacionaron positivamente con precipitación mensual y negativamente con iluminación lunar, pero las correlaciones no fueron significativas. Consideramos tres hipótesis para visitar saladeros: (a) complementar dieta, (b) ayudar a la digestión y (c) obtener agua.

Geophagy is the deliberate and regular consumption of soils, clay, and related mineral substances (Abrahams & Parsons 1996; Wilson 2003), as a method for animals to supplement their diets (e.g., mineral supplements) or facilitate digestive processes (e.g., detoxification of plant secondary compounds), or both (Kreulen 1985; Gilardi et al. 1999; Krishnamani & Mahaney 2000; Voigt et al. 2008). As such, it is closely related to the health of individuals and populations (Molina et al. 2014). Reasons why a given taxon consumes a given soil at a given time are poorly understood (Brightsmith 2004), and remain speculative (Abrahams 1999). It is commonly agreed that the practice of geophagy may serve a wide variety of purposes for different taxa, and that there is no single explanation for it (Wilson 2003).

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Geophagy has been described in many species of mammals, birds and even reptiles (Marlow & Tollestrup 1982; Diamond et al. 1999; Matsubayashi et al. 2007; Voigt et al. 2008), but it seems to be more frequent in generalist herbivores, including folivores and frugivores (Kreulen 1985; Krishnamani & Mahaney 2000; Blake et al. 2010). Among New World monkeys, for example, *Ateles* spp. and *Alouatta* spp. have been reported to use mineral licks (Izawa 1993; Dew 2005; Blake et al. 2010), although the frequency of use by *Alouatta* varies geographically (Ferrari et al. 2008).

Salt licks, also known as “clay licks” or “mineral licks” are open areas within the forest or along riverbanks where the soil is uncovered. Animals consume materials from vertical surfaces, eventually forming small caves of varying depths (Molina et al. 2014). Salt licks within forests typically occur in sites with eroded soil layers, often along small drainages or irregular stream courses, where animals consume mud or muddy water on the ground surface (Blake et al. 2010; Molina et al. 2014).

In lowland forests of eastern Ecuador, mineral licks are regularly visited by a wide range of species that include birds (e.g., pigeons, cracids), monkeys (e.g., white-bellied spider monkeys *Ateles belzebuth* É. Geoffroy, 1806; red howler monkeys *Alouatta seniculus* (Linnaeus, 1766), ungulates (e.g., tapirs *Tapirus terrestris* (Linnaeus, 1758); peccaries *Tayassu peccari* (Link, 1795) and *Pecari tajacu* (Linnaeus, 1758); deer *Mazama americana* (Erxleben, 1777), and rodents (e.g., tree rats *Echimys* spp.; agoutis *Dasyprocta fuliginosa* Wagler 1832; pacas *Cuniculus paca* (Linnaeus, 1766) Blake et al. 2010, 2011; Mosquera et al. 2016).

In contrast to primates and ungulates, records of two-toed sloths (*Choloepus didactylus*) visiting mineral licks are scarce (Blake et al. 2011). In this study, we present data on the occurrence of geophagy by free-ranging two-toed sloths in lowland forest of eastern Ecuador, the first systematic data on this type of behavior for this species. Visits to mineral licks may vary over time (seasonally, diurnally) depending on the species. Brightsmith (2004), for example, found significant month-to-month variation in lick use by birds at a mineral lick in the Peruvian Amazon, with peaks in the late dry season and lower use throughout the wet season. Temporal variation in occurrence at mineral licks in eastern Ecuador also has been noted for peccaries, primates, and other species (Blake et al. 2010, 2011) and may be related to risk of predation and short-term weather patterns (e.g., dry conditions), (Link et al. 2011, 2012). Based on this previous information, we developed several questions relating to use of mineral lick by sloths: (1) does lick use vary among months, and among hours of the night?; (2) is lick use influenced by rainfall?; and (3) is lick use related to lunar phase? (i.e., a proxy for level of illumination).

Study site

We conducted our research at Tiputini Biodiversity Station (TBS), Orellana Province, Ecuador (0° 38.221’ S, 76° 08.992’ W, 190-270 m a.s.l.). TBS is run by Universidad

San Francisco de Quito (USFQ) on a tract of undisturbed lowland rainforest within the *ca.* 2.7 million-ha Yasuní Biosphere Reserve, one of the most biologically diverse regions on earth (Bass et al. 2010). The station is dominated by *terra firme* forest but also includes smaller areas of *várzea* forest, as well as palm swamps and areas of succession that follow various natural disturbances (Blake et al. 2010).

Camera trapping

Camera traps (Bushnell Trophy Cam) triggered by an infrared motion and heat sensor were used to document the occurrence of animals visiting a salt lick located along the Tiputini River, ~4.5 km in a straight line from the station (0° 37.464' S, 76° 06.738' W). The lick is a shallow cave in a vertical wall, ~5 meters above surrounding ground level, 2.5 m wide x 1.2 m high, at ~15 meters from the river in *várzea* forest. No water runs through it.

A preliminary survey was carried out with two cameras between March and May 2014, to confirm nocturnal activity, and determine most suitable locations for cameras. Subsequently, three cameras were deployed at the site from December 2014 to November 2015. One camera was attached to a tree 6 m above the ground at ~6 m from the cave entrance. A second camera was placed on the left side of the cave at ~1 m from the cave entrance. The third camera was set at ~1.5 m above the cave, and attached to a tree that animal use to access the salt lick. This arrangement of cameras did not obstruct animals movements, and allowed us to capture the sequence of the visit (i.e., arrival, feeding, departure), and to guarantee captures in case one of the three cameras failed.

The three cameras were considered as a single unit to calculate trap effort (i.e., number of trap nights). We checked cameras weekly to replace memory cards and batteries. All three cameras remained active continuously (except when batteries failed, or other malfunctions occurred); date and time were stored on the metadata of each file. We set cameras to take video footage with a minimum time between videos of 1 second with durations of 30-60 seconds (depending on the size of the memory card). Videos were classified as belonging to independent events if more than 30 min had elapsed since the last video taken of a specific visit. We set cameras to record videos rather than still images because videos provide a more complete perspective on the way that animals access and use the lick area, and provide a more complete record of the time spent at the lick (see Mosquera et al. 2016; Bowler et al. 2017; Reyes et al. 2017 for comments on benefits of videos).

Analyses

We used rain data from a permanent weather station at TBS (Vantage Pro 2, Davis Instruments Corporation) to examine the influence of rainfall on visits of sloths to the salt lick. Precipitation during the study period (December 2014 through November

2015) was about 3,175 mm; rainiest months extended from March through June, with August being the driest month. We used correlation analyses (Pearson's *r*) to examine the relationship between number of visits and their specific hour/time, and monthly rainfall. Data were checked for assumptions of normality (Shapiro-Wilk test) before parametric tests were applied.

Additionally, we obtained data on lunar phase for Orellana Province from the website www.timeanddate.com to calculate the percent of lunar illumination for each sampling night. Ten categories of moon light were established, ranging from 0% or no illumination (new moon) to 100% illumination (full moon). These data were used to evaluate whether level of illumination affected visits to the mineral lick.

We obtained a total of 201 videos of two-toed sloths capturing the arrival, feeding and departure (see supplementary video) at the mineral lick. These videos represented 45 independent events from December 2014 through November 2015 (approx. 370 trap/nights; approximately 12 visits/100 trap-nights). November 2014 and March and September 2015 experienced the highest number of visits, with 7 events each (Fig. 1). Sloths visited the salt lick at least twice during all other months. Visits occurred during night hours, starting at 7.00 pm onwards until 3.30 am, with a peak at around 10.00 pm; there was one visit at 6.00 am (Fig. 2). We obtained complete data on the duration of 35 visits, recording arrival, feeding activity, and departure from the mineral lick. Data were incomplete for 10 visits, and those visits were excluded from calculations of visit length. Individual visits lasted between 3 and 92 minutes, with an average visit of 41 ± SD 24.4 minutes. Although we were not able to distinguish individual sloths, on two occasions we recorded two sloths visiting the lick at the same time. We also recorded sloths feeding in the cave simultaneously with bi-colored porcupines *Coendou prehensilis* (Linnaeus, 1758) on three occasions.Visits to the mineral lick were positively correlated with monthly rainfall (r= 0.47, *d.f.*= 11, p= 0.10), and negatively with lunar illumination (r= -0.38, *d.f.*= 8, p= 0.27), but correlations were not significant. Although sloths visited the mineral lick throughout the lunar cycle, there were more visits when there was less illumination: 13 events with 0 to 10% moonlight (Fig. 3).

Videos also recorded a number of other animals visiting the same mineral lick. Frequent visitors during the day included red howler monkeys and white-bellied spider monkeys, and several species of birds, including common piping guan *Pipile cumanensis* (Jacquin, 1784), plumbeous pigeon *Patagioenas plumbea* (Vieillot, 1818), speckled chachalaca *Ortalis guttata* (Spix, 1825), and mealy amazon *Amazona farinosa* (Boddaert, 1783). Frequent visitors at night, apart from two-toed sloths, included the bi-colored porcupine *Coendou prehensilis*, and the dark-tree rat *Echimys saturnus* Thomas, 1928.

A few studies on the natural history of sloths are available (e.g., Plese et al. 2016), but there is still little information available on population dynamics, behavior and activity patterns of sloths in the wild (Chiarello 2008; Peery & Pauli 2012). Results of this study contribute to a better understanding of the factors that influence behavior of sloths, information that is important for their conservation.

Two-toed sloths exhibited temporal variation in their visits to a mineral lick in lowland forest of eastern Ecuador, at both hourly and monthly scales. Such variation in lick use appears to be relatively common among species that visit licks in the same area (Blake et al. 2010, 2011; Link et al. 2011, 2012), although the pattern of visitation varies among species (e.g., diurnal *versus* nocturnal). In contrast to three-toed sloths (*Bradypus* spp.) which can be active both day and night, two-toed sloths (*Choloepus* spp.) are largely nocturnal (Howarth & Toole 1973; Sunquist & Montgomery 1973; Emmons & Feer 1997), and their use of the lick in this study followed that pattern. There were no visits to the lick before 7.00 pm, and only one after 3.30 am, which was the only visit during early daylight hours (6.00 am). Visits were fairly evenly spread among hours from 7.00 pm through to 3.30 am, although there was somewhat of a peak around 10.00 –11.00 pm. Other nocturnal species at the same study area also show hourly variation in activity (Blake et al. 2011); tapirs, for example, had a peak in activity around 9.00 pm at one lick, and a less pronounced peak from 12.00 to 3.00 am at a second lick. Thus, temporal patterns of activity may vary spatially. The time sloths spent at the lick varied from only a few minutes to over an hour, with an average of 40 minutes during each visit. This is considerably more time than is typically spent by tapirs and pacas at a different lick in the same area (Link et al. 2012).

Visits to licks were negatively correlated with illumination (lunar phase), but the relationship was relatively weak and not significant, although almost 30% of the visits occurred when illumination was <10%, suggesting that sloths may tend to prefer nights with low illumination. Given that lunar phase may not accurately represent the actual amount of illumination, which varies with cloud cover and precipitation, a more detailed examination of light levels would be useful to further investigate the possible influence of light levels on sloth activity (e.g., for risk of predation).

Sloth visits to the mineral lick at Tiputini also varied among months, with fewer visits from April through August (two visits each month), and more visits (seven per month) during December, March, and September. Visits per month were positively correlated with monthly rainfall, but the relationship was not strong enough to draw any firm conclusions. Seasonal variation in lick use has been noted for other species, including birds (Brightsmith 2004; Blake et al. 2011), primates (Blake et al. 2010), some ungulates (Blake et al. 2011), and bats (Voigt et al. 2008). In contrast, Link et al. (2012) found that tapirs and pacas did not show a distinct seasonal pattern of lick use, and suggested that lack of pronounced seasonality in rainfall and/or fruit production (a major resource) could explain the lack of seasonal lick use. Monthly variation in lick use was more pronounced in white-lipped than collared peccaries at other licks in the TBS area (Blake et al. 2011), and may reflect the fact that the larger species moves, often seasonally, over longer distances (Emmons & Feer 1997).

We briefly consider three different and non-exclusive hypotheses to why sloths visit licks: (a) to obtain nutrients, (b) to help in their digestion, and (c) for water. Additional studies are needed to clarify the importance of licks to sloths and other species.

Nutrients

Herbivores such as sloths, typically lack some important elements such as sodium (Lundquist & Varnedoe Jr. 2005; Voirin et al. 2013) in their diet. Geophagy is a method for animals to supplement their diets or facilitate their digestive processes and likely is a major reason for why sloths were observed visiting the lick in this study. The mineral lick in this study was located on a vertical bank close to the river. Mineral licks also occur within the forest at TBS, typically along small drainages, but sloths rarely have been recorded at such licks (Blake et al. 2011). The difference in visitation rates among licks may be related to nutrient levels. Molina et al. (2014) found that licks along steep banks in Colombia had higher levels of sodium, potassium, and phosphorus but less iron and organic carbon when compared to licks along drainages. Both types of mineral licks had similar levels of calcium and magnesium. This might be one reason why sloths are uncommon visitors to salt licks found in the forest, and frequent visitors to licks found in steep river banks. Soil samples from the two types of licks might shed light on this possibility.

Digestion

Leaves can be rich in nutrients and proteins, but also may contain toxic or digestion-inhibiting compounds such as alkaloids, phenols, terpenes, and lignin (McNab 1978; Belovsky & Schmitz 1994). Consumption of soil may give protection from toxins or inhibit the digestion of plant secondary compounds (Diamond et al. 1999; Gilardi et al. 1999). These compounds require a low rate of absorption for proper detoxification (McNab 1985; Merrit 1985), and given the slow rate of digestion in sloths (Briton 1941; Gilmore et al. 2001), consumption of clay from mineral licks may help eliminate, rather than absorb those compounds that otherwise might be harmful.

Water supply

Sloths obtain water from fresh leaves and fruits (Foley et al. 1995), from licking dew or rain from leaves (Martínez et al. 2004), and they have been recorded drinking water in captivity (Gilmore et al. 2000). Hence, it is possible that sloths may visit some licks to obtain water, especially licks that are within the forest. The lick in the present study was not a good source of water, except on rainy nights, so it was probably not a major influence on visitation rates. Further studies are needed to explore the idea that sloths may visit some licks for water, as well as other substances.

This is the first study to demonstrate regular visitation by two-toed sloths to a salt lick, although there are other reports of sloths visiting licks (e.g., Blake et al. 2011).

For example, *C. hoffmanni* was recently reported licking a mineral-covered rock, adjacent to a water stream in the Java River in Costa Rica (Gómez-Hoyos et al. 2017). Consequently, use of licks by sloths might not be as rare as previously suggested, but rather a consequence of our lack of information about their behavior in the wild. While there is a need to better understand the potential benefits of geophagy in the diet of sloths, additional field studies are needed to determine if all sloth species show this behavior, and to learn about the potential benefits of consuming soil.

Yasuní represents a unique place because of its biodiversity, size, and lack of human intervention in most of the area. Given the clear importance of salt licks to wildlife communities, it may be necessary to include them as areas under special management, where traditional practices (i.e., subsistence hunting by local communities) are controlled and, in some cases, human activity is restricted. Only continued protection will ensure that populations of sloths and other species remain viable, guaranteeing the maintenance of the ecological functions of the forest.

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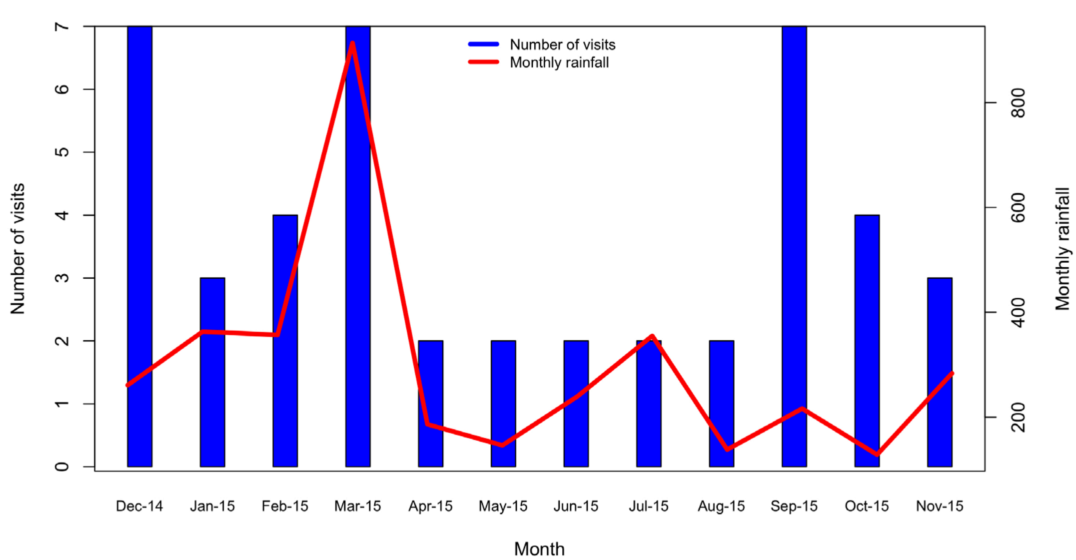

Figure 1. Monthly visits by Linnaeus's two-toed sloth (*Choloepus didactylus*) to a salt lick at Tiputini Biodiversity Station, Ecuador. Monthly rainfall during the same period is shown.

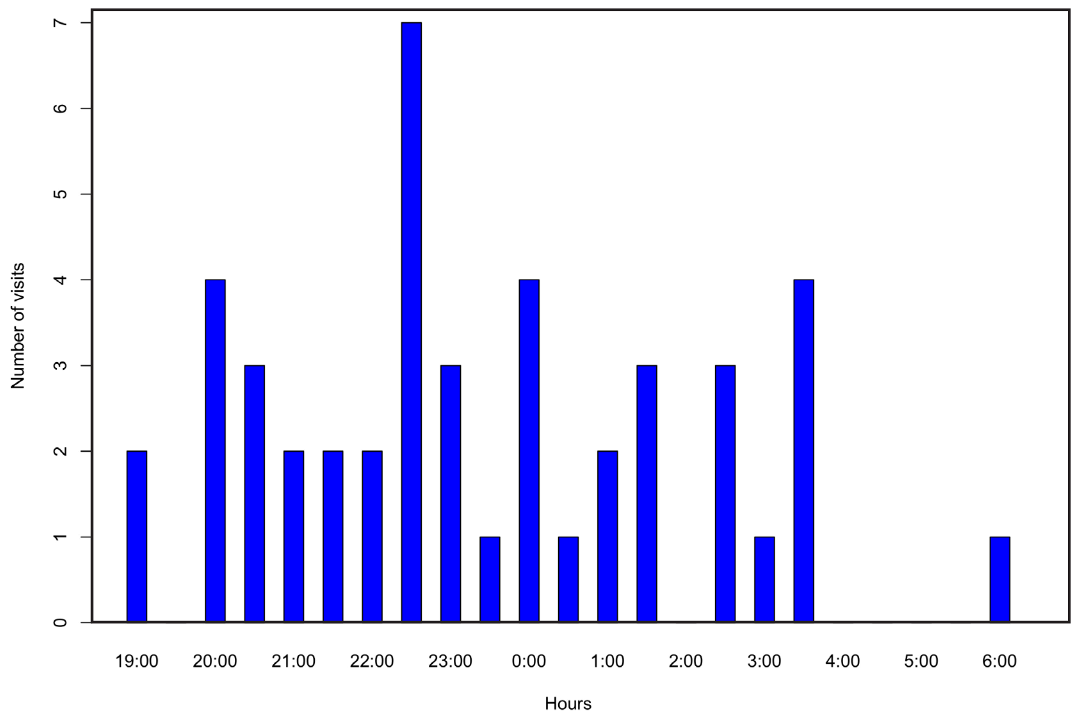

Figure 2. Nocturnal activity patterns of Linnaeus's two-toed sloth (*Choloepus didactylus*) at a salt lick, Tiputini Biodiversity Station, Ecuador.

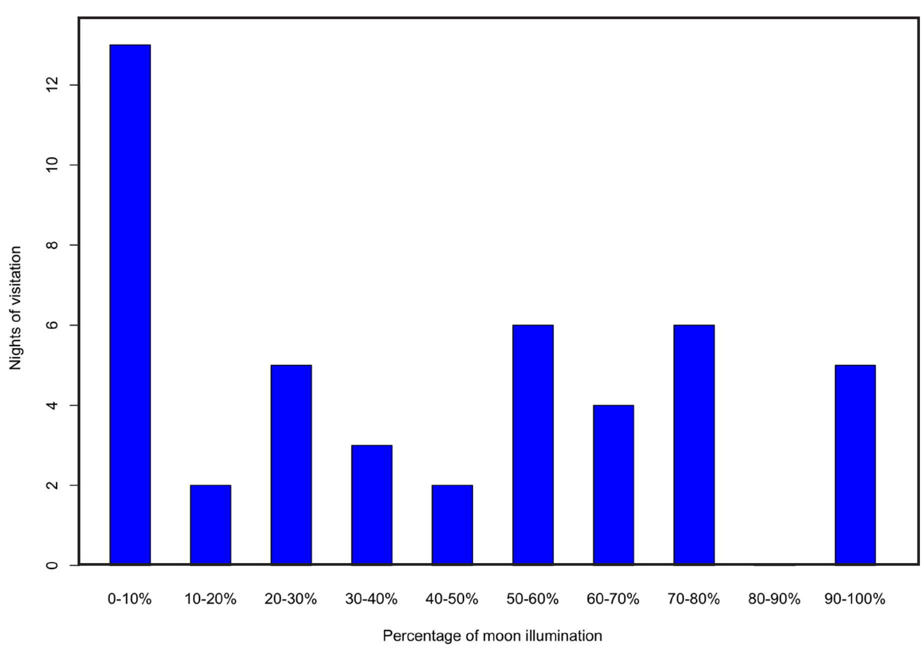

Figure 3. Activity of Linnaeus's two-toed sloth (*Choloepus didactylus*) at a salt lick related to moon illumination, Tiputini Biodiversity Station, Ecuador.

Supplementary video 1. Linnaeus's two-toed sloth (*Choloepus didactylus*) at a salt lick, Tiputini Biodiversity Station, Ecuador.
https://youtu.be/219MaR2TGq4

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