Dissimilarities in species assemblages among Amazonian mineral licks

Brian M. Griffiths[1*], W. Justin Cooper[2], Mark Bowler[3,4], Michael P. Gilmore[1], & David Luther[2]

[1]School of Integrative Studies, George Mason University, 4400 University Drive, Fairfax, VA 22030, USA

[2]Department of Biology, George Mason University, 4400 University Drive, Fairfax, VA 22030, USA

[3]School of Science, Technology and Engineering, University of Suffolk, Waterfront Building, Neptune Quay, Ipswich, IP4 1QJ, UK

[4]Suffolk Sustainability Institute, Waterfront Building, Neptune Quay, Ipswich, IP4 1QJ, UK

* Corresponding author. Email: bgriffi7@gmu.edu. Address: 2 Heather Hill Ln., Elkton, MD, 21921

Received:_______; Revised:________; Accepted:_________.

ABSTRACT

Mineral lick elevation, size, and distance to the closest human community are all associated with mammal and bird species visitations. The most frequently hunted licks have similar species assemblages. Results indicate high variability in species assemblages at different mineral licks suggesting different species-specific resource needs at different licks.

Keywords: Amazon, bird, camera trap, conservation, geophagy, Loreto, mammal,

Mineral licks are natural geologic formations where animals visit and exhibit geophagical behavior (Klaus et al., 1998; Lee et al., 2010; Panichev et al., 2013). While mineral licks are widely used by animals around the world (Atwood & Weeks, 2002; Couturier & Barrette, 1988; Blake et al., 2011; Matsubayashi et al., 2007; Moe, 1993), the motivations behind geophagy are yet unclear for many species. It is thought that animals visit mineral licks to obtain key micronutrients missing in their diets or clays that aid in relieving indigestion caused by plant-based alkaloids (Bravo et al., 2008; Brightsmith et al., 2008; Diamond et al., 1999; Ghanem et al., 2013; Kreulen, 1985; Mahaney et al., 1997; Matsubayashi et al., 2007). Predators also visit mineral licks, presumably seeking prey (Griffiths et al., 2020b; Link & Fiore, 2013; Matsuda & Izawa, 2008). In the Amazon rainforest of South America, several elusive species visit mineral licks, including the lowland tapir (*Tapirus terrestris*), red brocket deer (*Mazama americana*), nocturnal curassow (*Nothocrax urumutum*), spider monkeys (*Ateles* sp.), and wild felids (Blake et al., 2010; Gilmore et al., 2020; Griffiths et al., 2020a; Link et al., 2011; Matsuda & Izawa, 2008; Montenegro, 2004). Overall, mineral licks represent hotspots of diversity, with a disproportionate number of species visiting discrete locations (Blake et al., 2011) and often being visited by human hunters (Gilmore et al., 2020). They are also ecologically important for a vast range of species from a variety of foraging guilds and habitat types in the Amazon (Blake et al., 2010; Tobler et al., 2009; Tobler, 2008; Voigt et al., 2008).

As Blake et al. (2011) pointed out, surveying animals at mineral licks could provide important insight into the broader regional diversity and conservation of animals. However, Amazonian mineral licks are often difficult to locate and identify; thus, the few mineral lick studies that do exist are based on fewer than ten sites (Blake et al., 2010; Blake et al., 2011; Link et al., 2012) and might not be representative of the greater community of organisms that visit mineral licks. Many species either visit mineral licks infrequently or visit a small proportion of mineral licks in a region, so they may not be recorded with a sample of only a few mineral licks (Griffiths, 2020). In this study, we use a relatively large sample size of mineral licks in the same river basin to assess the medium and large sized animals at mineral licks and investigate the variation in species assemblage at different licks by addressing the following questions:

1. How similar are the species assemblages between different mineral licks?

2. What features of the environment are associated with differences in species assemblages at different mineral licks?

Fieldwork was conducted in the northeastern Peruvian Amazon (about 120 km north by river of Iquitos, Peru) in the titled lands of the Maijuna community of Sucusari and the Maijuna-Kichwa Regional Conservation area (MKRCA), a 391,039 ha protected area (El Peruano, 2015; Gilmore et al., 2010) (Figure 1). The Sucusari River is a tributary of the Napo River. The Sucusari River basin includes both primary upland *terra firme* rainforest and floodplain forest (Gilmore et al., 2010). The region of the MKRCA is characterized by a mean annual temperature of 26^{o}C and average precipitation of 3100 mm per year (Marengo, 1998).

Motion-activated camera traps (Bushnell Aggressor, Boly Scout Guard) were installed at 52 mineral licks that were identified during participatory mapping exercises with Maijuna hunters in July 2017 (Gilmore & Young, 2010, 2012; Young & Gilmore, 2013, 2014, 2017) or in the field with Maijuna hunters in August, 2018. We visited all mineral licks with a Maijuna hunter in August 2018 and placed camera traps in a series of four rotations, each of which was a minimum of 60 days. Camera traps placement achieved relatively even coverage of the whole basin during each rotation (Figure S1). Camera traps were all placed at mineral licks located in *terra firme* forest; placement and methods followed Griffiths et al. (2020a).

We identified all medium and large sized mammal and bird species in camera trap images, removed empty images, and organized data for analyses using CameraBase v1.7 (Tobler, 2015). Birds below 20 cm body size (Mere Roncal et al., 2019) and mammals below 0.5 kg weight were not included due to inconsistencies in detection from camera trap placement (Bowler et al., 2017). The number of individuals and species identity in instances where multiple individuals appeared in the same photograph was also recorded. Mixed species flocks of birds, primarily parrots (Psittacinidae) and pigeons (Columbidae), were also not considered for analysis since they often could not be identified to a species level. Images were sorted into independent events, with one hour separating visits by the same species noted as an independent event (Tobler et al., 2008). All aspects of this study were approved by George Mason University's Institutional Review Board, project #1288488-1.

To assess community similarities between mineral licks, we calculated a series of pairwise Jaccard's similarity indices (n = 1,326). We calculated a generalized dissimilarity model, which included the number of records of each species, to determine the factors that influence community similarities between mineral licks, following Ferrier et al. (2007). Generalized dissimilarity models were constructed using the *gdm* function in the *gdm* package in R (Fitzpatrick et al., 2020), version 3.6.1 (R Core Team, 2019). Generalized dissimilarity models are derived from matrix regression and allow comparisons of community similarity between sites based on geographic distance and continuous and categorical covariates (Ferrier et al., 2007). We included habitat-specific covariates (elevation, slope, geographic distance between licks, and lick size), survey-specific covariates (trapping effort), and three different proxies for hunting pressure, distance from the community, access points, and hunting camps (tested one at a time) (see Griffiths, 2020). All covariates were tested for collinearity before including them in the full model, with a correlation cutoff of 0.60 for inclusion (Dormann et al., 2013).

We constructed a full model and then proceeded with model selection following the approach described by Ferrier et al. (2007). We used a backward stepwise approach, dropping one covariate at a time, which resulted in marginal (< 0.1%) or no change in explained deviance, until an optimal model was obtained where dropping any more covariates resulted in a lower explained deviance. Then, we set the intercept of the model to 0 since mineral licks in the same location with the same environmental features would be expected to have the same community (Allnutt et al., 2008), and used this new model to make predictions of community similarity.

Across all 52 mineral licks, we had a total trapping effort of 5,379 camera nights. Once empty images and small-bodied species were removed, a total of 143,497 images of mammals and birds remained, describing 5,254 independent visitation events by mammals and 349 independent visitation events by birds. We detected 20 species of medium and large bodied terrestrial mammals and 10 species of terrestrial birds at mineral licks (Table S1).

To assess the similarity among species assemblages at different mineral licks we summarized Jaccard’s similarity indices between mineral lick communities to capture an overall idea of variation in species visiting mineral licks. The community similarity between mineral licks was low, with a mean Jaccard’s similarity index of 0.332 (SD = 0.174, range 0 - 1.0). Overall, 87.14% of the comparisons had a similarity index value between 0 and 0.5 (Figure 1), excluding same-site comparisons. The species recorded at these three sites were the red brocket deer, paca, Brazilian porcupine, agouti, and tapir.

The optimal model of environmental factors associated with species assemblage similarity at different mineral licks included elevation, slope, lick size, trapping effort, and distance from community (a proxy for hunting pressure) as important covariates with an explained deviance of 0.198 (Table S2). Model results showed that distance from community was the greatest contributor to ecological distance and, therefore, community dissimilarity, followed by elevation, lick size, and trapping effort (Figure 2, Table S3). Slope had a relatively small effect on community dissimilarity (Figure 2, Table S3).

Similarity results showed high variation between mineral licks. Higher hunting pressure was associated with higher similarity among assemblages such that it homogenized species assemblages at mineral licks (Blake et al. 2013), or alternatively, hunters focus on those licks with the specific animals that they prefer to hunt. The homogenization of species communities due to hunting has been reported in other locations, where the removal of preferred large bodied species lowers species diversity of an area (e.g. Endo et al., 2010; Peres, 2000).

The natural variation in assemblages between licks is likely due in part to habitat preferences of species (Tobler et al., 2009). Variation could also be due to small-scale changes in soil content. For example, in Borneo, mineral licks as close as 16m of each other differed in composition, which could provide different mineral nutrients to animals that visit licks (Matsubayashi et al. 2007). However, we were not able to gather explicit data on soil composition though we encourage future studies to assess the importance of different minerals in the soil for different species at mineral licks. Species might also need different minerals at different times of the year, if they exhibit dietary shifts, thus visiting licks more frequently or different mineral licks depending on seasonal differences. However, since the model had a relatively low explained deviance of 0.198, habitat features are not the most important factors determining species assemblages at mineral licks. This may indicate that species may travel across habitats to reach mineral lick sites periodically. For example, lowland tapirs walk over 10 km to visit mineral lick sites, and actively shift their movement to include palm swamps when the fruit of the aguaje palm (*Mauritia flexuosa*) is in season (Cabrera et al., 2016; González et al., 2017; Tobler, 2008).

The majority of species not detected were not expected to display geophagy such as armadillos (e.g. *Dasypus kappleri*), and anteaters (e.g. *Myrmecophaga tridactyla*). Several carnivores, such as jaguars (*Panthera onca*), ocelots (*Leopardus pardalis*), and pumas (*Puma concolour*), were recorded at mineral licks in our study and in other studies (Izawa, 1993; Link & Fiore, 2013; Matsuda & Izawa, 2008). These species were likely foraging or searching for prey at mineral licks since they do not exhibit geophagy because of their diet. Only three frugivorous or folivorous mammals were not detected at the mineral licks: the Allen's olingo (*Bassaricyon alleni*), Spix's night monkey (*Aotus vociferans*), and three-toed sloth (*Bradypus variegatus*). Several primates which have a heavily frugivorous, but overall omnivorous diet, were not detected, including the common woolly monkey (*Lagothrix lagotricha*), the monk saki monkey (*Pithecia monachus*), the white-fronted capuchin (*Cebus albifrons*) and the Spix's night monkey (Hawkes & Peres, 2014). These species would be expected to exhibit some geophagical behavior. However, primates have been recorded consuming soil from arboreal termite nests and other sources rather than descending to feed at mineral licks (Ferrari et al., 2008), which might explain their absence from the mineral licks. The risk of predation may also contribute to avoidance of mineral licks by some primates, a phenomenon previously reported for spider monkeys and howler monkeys (Link et al., 2011).

While the study of geophagy is well established for parrots and macaws at rainforest clearings and edges of riverbanks (Brightsmith et al., 2008; Brightsmith & Muñoz-Najar, 2004; Lee et al., 2010), the observations of forest interior bird species at mineral licks are less known. A few avian species that we did not detect but would have expected to record at mineral licks based on their diet include three tinamou species and the wood quail (*Odontophorus gujanensis*). Of the three species of tinamou not detected, two of them, the little tinamou (*Crypturellus soui*) and Bartlett's tinamou (*Crypturellus bartletti*), tend to prefer thickets and secondary forest habitats (del Hoyo et al., 2018), which were not in the vicinity of the studied mineral licks. The absence of the white-throated tinamou (*Tinamus guttatus*) and the wood quail at mineral licks might be explained by their omnivorous diets, which could provide enough micronutrients that they don't need to visit mineral licks, but this hypothesis warrants further investigation.

Our results show that there is high natural variability in species assemblages at different mineral licks, indicating that each of these key resources provide different benefits to different species. Information gleaned from sampling medium and large sized animals at mineral licks can provide insight into the health of tropical forest systems, including the impacts of hunting.

ACKNOWLEDGEMENTS

We would like to acknowledge the Maijuna community of Sucusari for their expertise in identifying mineral licks and their eagerness to collaborate. We would like to thank OnePlanet, Inc. for providing financial and in-kind support to this project, as well as the Fulbright Association for providing a Fulbright U.S. Student Grant to BMG to conduct this research. We would like to thank the Morpho Institute and Explorama Lodges for providing in-kind support.

AUTHOR CONTRIBUTION STATEMENT

BMG: Conceptualization, data curation, funding acquisition, formal analysis, investigation, writing – original draft, visualization

MB: Funding acquisition, methodology, supervision, writing – review and editing, resources

MPG: Funding acquisition, methodology, supervision, writing – review and editing, resources

WJC: Formal analysis, methodology, software, writing – original draft

DL: Writing – original draft, methodology, data curation

DISCLOSURE STATEMENT

The corresponding author confirms on behalf of all authors that there have been no involvements that might raise the question of bias in the work reported or in the conclusions, implications, or opinions stated.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in Dryad Data Repository at http://doi.org/doi:10.5061/dryad.bcc2fqzb2.

REFERENCES

Allnutt, T. F., Ferrier, S., Manion, G., Powell, G. V. N., Ricketts, T. H., Fisher, B. L., Harper, G. J., Irwin, M. E., Kremen, C., Labat, J. N., Lees, D. C., Pearce, T. A., & Rakotondrainibe, F. (2008). A method for quantifying biodiversity loss and its application to a 50-year record of deforestation across Madagascar. *Conservation Letters*, *1*(4), 173–181. https://doi.org/10.1111/j.1755-263X.2008.00027.x

Atwood, T. C., & Weeks, H. P. (2002). Sex-and age-specific patterns of mineral lick use by white-tailed deer (*Odocoileus virginianus*). *The American Midland Naturalist*, *148*(2), 289–296.

Blake, J. G., Mosquera, D., Guerra, J., Loiselle, B. A., Romo, D., & Swing, K. (2011). Mineral licks as diversity hotspots in lowland forest of eastern Ecuador. *Diversity*, *3*(2), 217–234. https://doi.org/10.3390/d3020217

Blake, J. G., Mosquera, D., & Salvador, J. (2013). Use of mineral licks by mammals and birds in hunted and non-hunted areas of Yasuní National Park, Ecuador. *Animal Conservation*, *16*(4), 430–437. https://doi.org/10.1111/acv.12012

Blake, J. G., Guerra, J., Mosquera, D., Torres, R., Loiselle, B. A., & Romo, D. (2010). Use of mineral licks by white-bellied spider monkeys (*Ateles belzebuth*) and red howler monkeys (*Alouatta seniculus*) in eastern Ecuador. *International Journal of Primatology*, *31*(3), 471–483.

Bowler, M. T., Tobler, M. W., Endress, B. A., Gilmore, M. P., & Anderson, M. J. (2017). Estimating mammalian species richness and occupancy in tropical forest canopies with arboreal camera traps. *Remote Sensing in Ecology and Conservation*, *3*(3), 146–157.

Bravo, A., Harms, K. E., Stevens, R. D., & Emmons, L. H. (2008). Collpas: Activity hotspots for frugivorous bats (Phyllostomidae) in the Peruvian Amazon. *Biotropica*, *40*(2), 203–210. https://doi.org/10.1111/j.1744-7429.2007.00362.x

Brightsmith, D. J., & Muñoz-Najar, R. A. (2004). Avian geophagy and soil characteristics in southeastern Peru. *Biotropica*, *36*(4), 534–543.

Brightsmith, D. J., Taylor, J., & Phillips, T. D. (2008). The roles of soil characteristics and toxin adsorption in avian geophagy. *Biotropica*, *40*(6), 766–774.

Cabrera, J. A., Molina, E., González, T., & Armenteras, D. (2016). Does Plan B work? Home range estimations from stored on board and transmitted data sets produced by GPS-telemetry in the Colombian Amazon. Revista de Biologia Tropical, 64(4), 1441–1450.

Couturier, S., & Barrette, C. (1988). The behavior of moose at natural mineral springs in Quebec. *Canadian Journal of Zoology*, *66*(2), 522–528.

Diamond, J., Bishop, K. D., & Gilardi, J. D. (1999). Geophagy in New Guinea birds. *Ibis*, *141*(2), 181–193. https://doi.org/10.1111/j.1474-919X.1999.tb07540.x

del Hoyo, J., Elliott, A., Sargatal, J., Christie, D. A., & de Juana, E. eds. (2018). Handbook of the birds of the world alive. *Barcelona: Lynx Edicions*.

Dormann, C. F., Elith, J., Bacher, S., Buchmann, C., Carl, G., Carré, G., Marquéz, J. R. G., Gruber, B., Lafourcade, B., & Leitao, P. J. (2013). Collinearity: A review of methods to deal with it and a simulation study evaluating their performance. *Ecography*, *36*(1), 27–46.

Endo, W., Peres, C. A., Salas, E., Mori, S., Sanchez-Vega, J.-L., Shepard, G. H., Pacheco, V., & Yu, D. W. (2010). Game vertebrate densities in hunted and nonhunted forest sites in Manu National Park, Peru. *Biotropica*, *42*(2), 251–261.

El Peruano. (2015). Establecen área de conservación regional Maijuna Kichwa, ubicada en el departamento de Loreto. Decreto No. 008-2015. http:// www.elperuano.com.pe/NormasElperuano/2015/06/17/1252025-2.html.

Ferrari, S. F., Veiga, L. M., & Urbani, B. (2008). Geophagy in New World monkeys (Platyrrhini): Ecological and geographic patterns. *Folia Primatologica*, *79*(5), 402–415.

Ferrier, S., Manion, G., Elith, J., & Richardson, K. (2007). Using generalized dissimilarity modelling to analyse and predict patterns of beta diversity in regional biodiversity assessment. *Diversity and Distributions*, *13*(3), 252–264.

Fitzpatrick, M.C., Mokany, K., Manion, G., Lisk, M., Ferrier, S., & Nieto-Lugilde, D. (2020). gdm: Generalized dissimilarity modeling. R package version 1.4.2. < https://CRAN.R-project.org/package=gdm>

Ghanem, S. J., Ruppert, H., Kunz, T. H., & Voigt, C. C. (2013). Frugivorous bats drink nutrient- and clay-enriched water in the Amazon rain forest: Support for a dual function of mineral-lick visits. *Journal of Tropical Ecology*, *29*(1), 1–10.

Gilmore, M. P., Griffiths, B. M., & Bowler, M. (2020). The socio-cultural significance of mineral licks to the Maijuna of the Peruvian Amazon: Implications for the sustainable management of hunting. *Journal of Ethnobiology and Ethnomedicine*, *16*(1), 1–10.

Gilmore, M. P., Vriesendorp, C., Alverson, W. S., del Campo, Á., Von May, R., López Wong, C., & Ríos Ochoa, S. (2010). *Perú: Maijuna. Rapid biological and social inventories report 22*. Chicago: The Field Museum.

Gilmore, M. P., & Young, J. C. (2010). The Maijuna participatory mapping project: Mapping the past and the present for the future. *Perú: Maijuna, Rapid Biological and Social Inventories Report*, *22*, 233.

Gilmore, M. P., & Young, J. C. (2012). The use of participatory mapping in ethnobiological research, biocultural conservation, and community empowerment: A case study from the Peruvian Amazon. *Journal of Ethnobiology*, *32*(1), 6–29.

González, T. M., González-Trujillo, J. D., Palmer, J. R., Pino, J., & Armenteras, D. (2017). Movement behavior of a tropical mammal: The case of *Tapirus terrestris*. Ecological Modelling, 360, 223–229. https://doi.org/10.1016/j.ecolmodel.2017.07.006

Griffiths, B. M. (2020). *Assessing the drivers, magnitude, and implications of hunting pressure in an Amazonian indigenous community*. George Mason University.

Griffiths B. M., Bowler, M., Gilmore, M.P., Luther, D.A. (2020a). Temporal patterns of visitation of birds and mammals at mineral licks in the Peruvian amazon. Ecology and Evolution. https://doi.org/10.1002/ece3.7006

Griffiths, B. M., Gilmore, M. P., & Bowler, M. (2020b). Predation of a Brazilian porcupine (*Coendou prehensilis*) by an ocelot (*Leopardus pardalis*) at a mineral lick in the Peruvian Amazon. *Food Webs*, *24*, e00148. https://doi.org/10.1016/j.fooweb.2020.e00148

Hawes, J. E., & Peres, C. A. (2014). Ecological correlates of trophic status and frugivory in neotropical primates. *Oikos*, *123*(3), 365–377. https://doi.org/10.1111/j.1600-0706.2013.00745.x

Izawa, K. (1993). Soil-eating by Alouatta and Ateles. *International Journal of Primatology*, *14*(2), 229–242.

Klaus, G., Klaus-Hügi, C., & Schmid, B. (1998). Geophagy by large mammals at natural licks in the rain forest of the Dzanga National Park, Central African Republic. *Journal of Tropical Ecology*, *14*(6), 829–839.

Kreulen, D. A. (1985). Lick use by large herbivores: A review of benefits and banes of soil consumption. *Mammal Review*, *15*(3), 107–123. https://doi.org/10.1111/j.1365-2907.1985.tb00391.x

Lee, A. T., Kumar, S., Brightsmith, D. J., & Marsden, S. J. (2010). Parrot claylick distribution in South America: Do patterns of “where” help answer the question “why”? *Ecography*, *33*(3), 503–513.

Link, Andrés, & Fiore, A. D. (2013). Effects of predation risk on the grouping patterns of white-bellied spider monkeys (*Ateles belzebuth belzebuth*) in Western Amazonia. *American Journal of Physical Anthropology*, *150*(4), 579–590. https://doi.org/10.1002/ajpa.22230

Link, A., Fiore, A. D., Galvis, N., & Fleming, E. (2012). Patrones de visita a saladeros por el tapir (*Tapirus terrestris*) y la paca (*Cuniculus paca*) en la selva Amazonica de Ecuador. *Mastozoologia Neotropical*, *19*(1), 63–71.

Link, A., Galvis, N., Fleming, E., & Di Fiore, A. (2011). Patterns of mineral lick visitation by spider monkeys and howler monkeys in Amazonia: Are licks perceived as risky areas? *American Journal of Primatology*, *73*(4), 386–396.

Mahaney, W. C., Milner, M. W., Sanmugadas, K., Hancock, R. G. V., Aufreiter, S., Wrangham, R., & Pier, H. W. (1997). Analysis of geophagy soils in Kibale Forest, Uganda. *Primates*, *38*(2), 159–176.

Marengo, J. (1998). Climatología de la zona de Iquitos, Perú. *Geoecologia y Desarrollo Amazonico: Estudio Integrado En La Zona de Iquitos, Peru. University of Turku Press, Turku, Finland*, 35–57.

Matsubayashi, H., Lagan, P., Majalap, N., Tangah, J., Sukor, J. R. Abd., & Kitayama, K. (2007). Importance of natural licks for the mammals in Bornean inland tropical rain forests. *Ecological Research*, *22*(5), 742–748. https://doi.org/10.1007/s11284-006-0313-4

Matsuda, I., & Izawa, K. (2008). Predation of wild spider monkeys at La Macarena, Colombia. *Primates*, *49*(1), 65–68.

Mere Roncal, C., Middendorf, E., Forsyth, A., Cáceres, A., Blake, J. G., Almeyda Zambrano, A. M., & Broadbent, E. N. (2019). Assemblage structure and dynamics of terrestrial birds in the southwest Amazon: A camera-trap case study. *Journal of Field Ornithology*, *90*(3), 203–214.

Moe, S. R. (1993). Mineral content and wildlife use of soil licks in southwestern Nepal. *Canadian Journal of Zoology*, *71*(5), 933–936.

Panichev, A. M., Golokhvast, K. S., Gulkov, A. N., & Chekryzhov, I. Y. (2013). Geophagy in animals and geology of kudurs (mineral licks): A review of Russian publications. *Environmental Geochemistry and Health*, *35*(1), 133–152.

Peres, C. A. (2000). Effects of subsistence hunting on vertebrate community structure in Amazonian forests. *Conservation Biology*, *14*(1), 240–253. https://doi.org/10.1046/j.1523-1739.2000.98485.x

R Core Team (2019). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Tobler, M. W. 2015. Camera base version 1.7. 1.7 ed.: San Diego Zoo Global.

Tobler, M. W., Carrillo-Percastegui, S. E., Pitman, R. L., Mares, R., & Powell, G. (2008). An evaluation of camera traps for inventorying large- and medium-sized terrestrial rainforest mammals. *Animal Conservation*, *11*(3), 169–178. https://doi.org/10.1111/j.1469-1795.2008.00169.x

Tobler, M. W., Carrillo-Percastegui, S. E., & Powell, G. (2009). Habitat use, activity patterns and use of mineral licks by five species of ungulate in south-eastern Peru. *Journal of Tropical Ecology*, *25*(3), 261–270.

Tobler, M. W. (2008). *The ecology of the lowland tapir in Madre de Dios, Peru: Using new technologies to study large rainforest mammals*. Texas A&M University.

Voigt, C. C., Capps, K. A., Dechmann, D. K., Michener, R. H., & Kunz, T. H. (2008). Nutrition or detoxification: Why bats visit mineral licks of the Amazonian rainforest. *PloS One*, *3*(4), e2011.

Young, J. C., & Gilmore, M. P. (2013). The spatial politics of affect and emotion in participatory GIS. *Annals of the Association of American Geographers*, *103*(4), 808–823.

Young, J. C., & Gilmore, M. P. (2014). Subaltern empowerment in the Geoweb: Tensions between publicity and privacy. *Antipode*, *46*(2), 574–591.

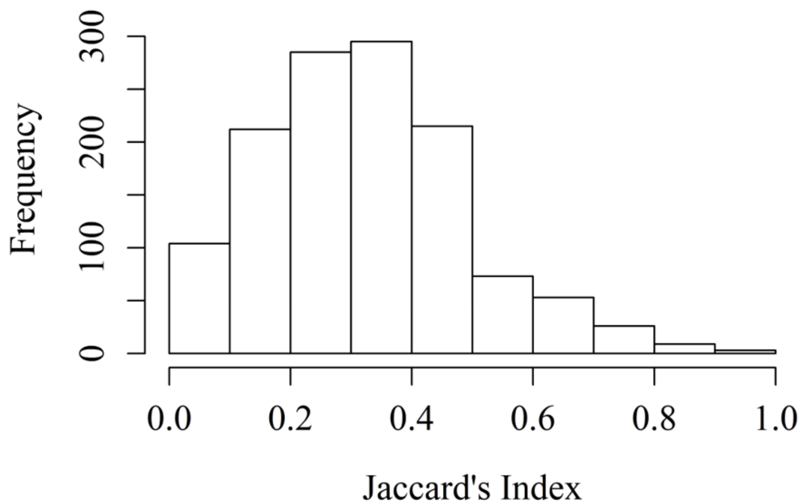
Young, J., & Gilmore, M. (2017). Participatory uses of geospatial technologies to leverage multiple knowledge systems within development contexts: A case study from the Peruvian Amazon. *World Development*, *93*, 389–401.

FIGURE LEGENDS

Figure 1. Histogram of Jaccard's indices comparing community similarity of medium- and large-bodied mammals and birds among 52 mineral licks in the Sucusari River basin in the Peruvian Amazon.

Figure 2. Basis splines calculated from optimal generalized dissimilarity model assessing dissimilarities of communities of mammals and birds recorded at 52 mineral licks in the Sucusari River Basin in the northeastern Peruvian Amazon, in order of effect size. Partial ecological distances on the y-axis represent community dissimilarity and are scaled to show effect size. A spline slope of zero indicates that the parameter did not have an effect on community dissimilarity at that level.

355 **Figures**



356

357 Figure 1.

358

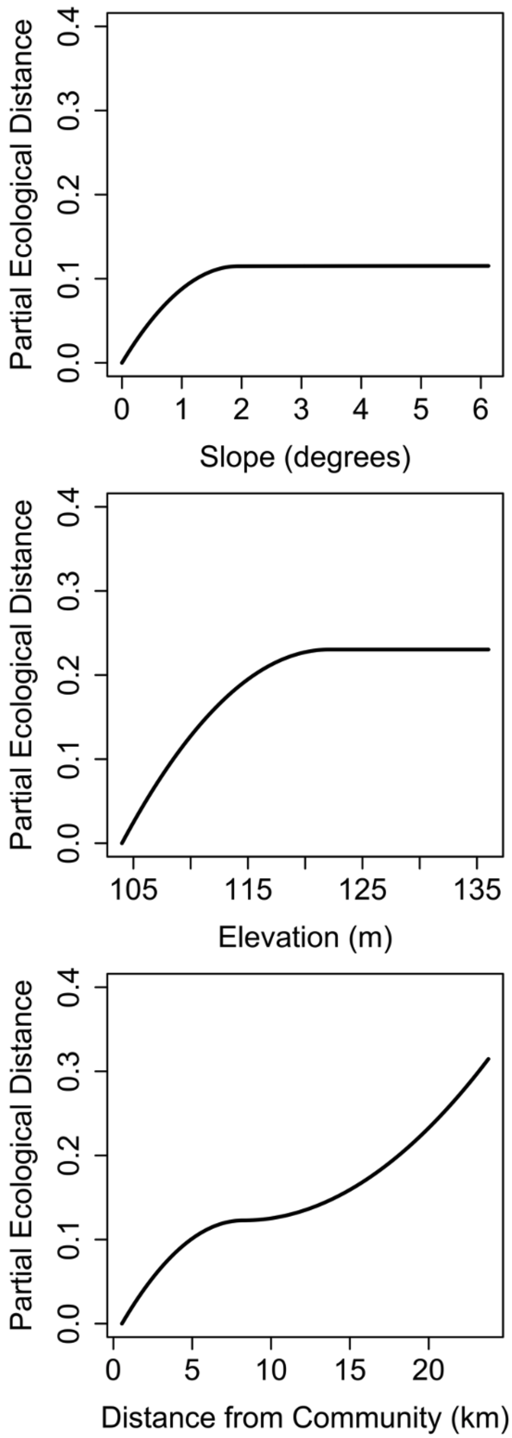

Partial Ecological Distance
0.0
0.1
0.2
0.3
0.4
0 1 2 3 4 5 6
Slope (degrees)
Partial Ecological Distance
0.0
0.1
0.2
0.3
0.4
50 100 150 200 250
Camera Nights
Partial Ecological Distance
0.0
0.1
0.2
0.3
0.4
105 115 125 135
Elevation (m)
Partial Ecological Distance
0.0
0.1
0.2
0.3
0.4
0 50 100 150
Lick Size (sq. m)
Partial Ecological Distance
0.0
0.1
0.2
0.3
0.4
0 5 10 15 20
Distance from Community (km)

Figure 2.