BioOne COMPLETE

# Hiding in a Cool Climatic Niche in the Tropics? An Assessment of the Ecological Biogeography of Hairy Long-Nosed Armadillos (Dasypus pilosus)

Authors: Feng, Xiao, Castro, Mariela C., McBee, Karen, and Papeş, Monica

Source: Tropical Conservation Science, 10(1)

Published By: SAGE Publishing

URL: https://doi.org/10.1177/1940082917697249

BioOne Complete (complete.BioOne.org) is a full-text database of 200 subscribed and open-access titles in the biological, ecological, and environmental sciences published by nonprofit societies, associations, museums, institutions, and presses.

Your use of this PDF, the BioOne Complete website, and all posted and associated content indicates your acceptance of BioOne's Terms of Use, available at www.bioone.org/terms-of-use.

Usage of BioOne Complete content is strictly limited to personal, educational, and non - commercial use. Commercial inquiries or rights and permissions requests should be directed to the individual publisher as copyright holder.

BioOne sees sustainable scholarly publishing as an inherently collaborative enterprise connecting authors, nonprofit publishers, academic institutions, research libraries, and research funders in the common goal of maximizing access to critical research.

Downloaded From: https://bioone.org/journals/Tropical-Conservation-Science on 28 Mar 2024
Terms of Use: https://bioone.org/terms-of-use

*Research Article*

# Hiding in a Cool Climatic Niche in the Tropics? An Assessment of the Ecological Biogeography of Hairy Long-Nosed Armadillos (*Dasypus pilosus*)

Tropical Conservation Science
Volume 10: 1–13
© The Author(s) 2017
Reprints and permissions:
sagepub.com/journalsPermissions.nav
DOI: 10.1177/1940082917697249
journals.sagepub.com/home/trc
SAGE

**Xiao Feng[1], Mariela C. Castro[2], Karen McBee[1], and Monica Papeş[1,3]**

**Abstract**

The hairy long-nosed armadillo (*Dasypus pilosus*) is endemic to the Andes in Peru and rarely studied, thus more investigations are needed. To gain a better understanding of this species' distribution and to facilitate future surveys and conservation management, we compiled available information on specimens of *D. pilosus*, provided an ecological biogeography perspective of these specimens, and estimated suitable areas for *D. pilosus* using ecological niche modeling. We compiled 25 specimen records from six departments in Peru and extracted the climatic and elevation conditions for records with coordinates. We concluded that *D. pilosus* may occupy relatively high elevation sites, hiding in a relatively cool climatic niche at tropical latitude. We suggested possible upper and lower temperature limits for *D. pilosus* and lower precipitation limit for the genus *Dasypus*. The ecological niche model estimated that about half of the International Union for Conservation of Nature (IUCN) range map was not suitable for *D. pilosus* and predicted additional suitable areas outside the IUCN range map in Amazonas and Cajamarca departments, Peru. We recommend that future field surveys or conservation management efforts prioritize regions associated with suitable areas predicted by our model and with species' available records (e.g., Río Abiseo).

**Keywords**

Andes, *Dasypus bellus*, *Dasypus kappleri*, *Dasypus novemcinctus*, ecological niche modeling, Maxent

The hairy long-nosed armadillo is a poorly studied species that is endemic to Peruvian Andes (Castro et al., 2015; Superina & Abba, 2014; Superina, Pagnutti, & Abba, 2014; Wetzel, 1985). The species' generic affinity has been debated (Castro et al., 2015; Gibb et al., 2016) and here we adopted the nomenclature more frequently used in the literature so far, which is *Dasypus* (*Cryptophractus*) *pilosus*. *Dasypus pilosus* has long reddish tan to reddish gray hair concealing the carapace, which makes it unique among *Dasypus* species (Castro et al., 2015; Wetzel & Mondolfi, 1979). The species is known to occur on the high, moist eastern slopes of the Andes in cloud forest and subparamo habitats (Wetzel, 1982; Wetzel, Gardner, Redford, & Eisenberg, 2007). Xenarthrans are generally understudied (Superina & Loughry, 2015), but information on *D. pilosus* in particular is scarce: according to Castro et al. (2015), only 18 publications (including book chapters) from 1856 to 2007, most focused on taxonomy and morphology, or even more conservative estimates of one publication according to Loughry, Superina, McDonough, and Abba (2015) and three according to Superina, Pagnutti, and Abba (2014). The ecology, population status, threats, and even the geographic distribution of *D. pilosus* are largely unknown. The International Union for Conservation of Nature (IUCN) has changed the status

[1]Department of Integrative Biology, Oklahoma State University Stillwater, OK, USA
[2]Laboratório de Paleontologia de Ribeirão Preto, FFCLRP, Universidade de São Paulo, Brazil
[3]Department of Ecology and Evolutionary Biology, University of Tennessee, Knoxville, TN, USA

Received 23 January 2017; Accepted 26 January 2017

**Corresponding Author:**
Xiao Feng, Department of Integrative Biology, Oklahoma State University, 501 LSW, Stillwater, OK 74078, USA.
Email: xiao.feng@okstate.edu

Creative Commons Non Commercial CC BY-NC: This article is distributed under the terms of the Creative Commons Attribution-NonCommercial 3.0 License (http://www.creativecommons.org/licenses/by-nc/3.0/) which permits non-commercial use, reproduction and distribution of the work without further permission provided the original work is attributed as specified on the SAGE and Open Access pages (https://us.sagepub.com/en-us/nam/open-access-at-sage).

Downloaded From: https://bioone.org/journals/Tropical-Conservation-Science on 28 Mar 2024
Terms of Use: https://bioone.org/terms-of-use

of the species from vulnerable to data deficient (Superina & Abba, 2014), and Superina et al. (2014) recommended prioritization of investigations on *D. pilosus* among armadillo species.

In lieu of new data collections, museum specimens are a good resource to study a species' distribution. With the recent and rapid digitization of museum specimens and establishment of electronic databases, specimen information is becoming easily accessible through the Internet (e.g., http://vertnet.org/). Castro et al. (2015) compiled a comprehensive list of specimens available and provided a detailed analysis of morphology and phylogeny for *D. pilosus*; however, the important perspective of ecological biogeography has been overlooked. Generally speaking, ecological biogeography attempts to explain biodiversity and distribution patterns in relation to ecological factors (Lomolino, Riddle, Whittaker, & Brown, 2010). One major focus of ecological biogeography is the study of species' geographic distributions and ecological (abiotic) niches (Hutchinson, 1957; Soberón, 2007). Besides the digitized museum specimens, ecological biogeography also greatly relies on geographic information systems (GIS), especially the digitalized maps of various environmental conditions (e.g., climate and elevation). With location data (latitude and longitude) of specimens, one can directly detect the associated environmental requirements. Ecological niche modeling (ENM), or species distribution modeling, is used frequently in ecological biogeography (Peterson et al., 2011). ENM uses species' occurrence data and environmental layers to estimate potential distributions, which are frequently used for conservation purposes (Bond, Thomson, & Reich, 2014; Feng, Lin, Qiao, & Ji, 2015; Fois, Fenu, Cuena Lombraña, Cogoni, & Bacchetta, 2015; Loiselle et al., 2003; Menon, Choudhury, Khan, & Peterson, 2010).

In this study, we aimed to gain a better understanding of the distribution of *D. pilosus* based on previously collected museum specimens and methods in ecological biogeography. Specifically, we aimed to investigate three questions. First, how many specimens of *D. pilosus* have been collected thus far? Second, what ecological information is associated with the collected specimens and does this information match the current literature? Third, where should future surveys focus in order to find this species? Three objectives stemmed from the proposed questions: (a) compiling available information of *D. pilosus* specimens; (b) interpreting the information of specimens from the perspective of ecological biogeography and comparing our interpretation with current understanding of the species' ecology; and (c) assessing the potential distribution of *D. pilosus* within its range based on known occurrences and relevant environmental variables to formulate priorities for future surveys or conservation management.

## Method

### Compiling Species Presence Data

We searched for information of museum specimens and observations through online databases (VertNet, http://vertnet.org/, Retrieved April 1, 2016; GBIF, http://www.gbif.org/, Retrieved September 3, 2016; iNaturalist, http://www.inaturalist.org/, accessed September 3, 2016). We also acquired information on specimens from the primary literature (Castro et al., 2015; Gardner, 2007; Wetzel, 1982, 1985; Wetzel & Mondolfi, 1979). The databases and literature overlapped in documenting several specimens; but when conflicting information occurred or when obvious doubts were raised (e.g., locality description), we used the following decreasing order of authority: literature, museum databases, external experts' opinions, and our own judgments. Our searches of databases and the literature yielded only museum specimen records. We georeferenced records with adequate locality descriptions using GeoNames WMS Viewer (http://geonames.nga.mil/namesviewer/default.asp), Google Maps, or local park maps. When available, we recorded the following information: museum, specimen ID, year collected, country, Peruvian administrative Levels 1–3 (department, province, and district), locality of collection site, latitude, longitude, elevation, and other information such as specimen preparation type and sex. Some records did not have information of administrative units of Peru or had such information but without specifying the level. Therefore, we located the administrative units or protected areas based on specimen coordinates and maps of administrative units of Peru (Retrieved from http://www.diva-gis.org/data on July 1, 2016) and protected areas (International Union for Conservation of Nature and United Nations Environment Programme's World Conservation Monitoring Centre, 2016).

### Overlaying Specimens With Environmental Layers

We compiled a list of 25 unique specimens, 21 of which had geographic coordinates (Table 1). Aiming to gain a better understanding of the species' environmental requirements, we overlaid the georeferenced specimens with three environmental layers: annual mean temperature, annual precipitation, and elevation, retrieved from worldclim.org (Hijmans, Cameron, Parra, Jones, & Jarvis, 2005) at the resolution of 2.5 arc min. We expected the three variables to represent the general, basic information of *D. pilosus* biogeography.

### Ecological Niche Modeling

To estimate the species' potential distribution, we built an ecological niche model in Maxent algorithm (Phillips, Dudík, & Schapire, 2004) using the georeferenced

Downloaded From: https://bioone.org/journals/Tropical-Conservation-Science on 28 Mar 2024
Terms of Use: https://bioone.org/terms-of-use

Downloaded From: https://bioone.org/journals/Tropical-Conservation-Science on 28 Mar 2024
Terms of Use: https://bioone.org/terms-of-use

**Table 1.** Compiled Information of Hairy Long-Nosed Armadillo (*Dasypus pilosus*) Specimens.

| msID | Specimen ID | Year | Source | Country | Department | Province | District or protected area | Locality | Preparations | Sex | Elevation from tag | Extracted elevation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | NHM-27.11.1.235 | n/a | Castro et al. (2015); Wetzel and Mondolfi (1979) | Peru | Junín | Tarma | Acobamba | Acobamba, Junín | Skin | n/a | 2,440 m | 3,553 m |
| 2 | NHM-94.10.1.13 | n/a | Castro et al. (2015); Wetzel and Mondolfi (1979) | Peru | Junín | Jauja | Monobamba | Maraynoic, Junin | Skin and Skull | n/a | n/a | 3,492 m |
| 3 | MSB-49990 | 1980 | VertNet retrieved April 2016 | Peru | Huánuco | Huánuco | Chinchao | 6 km NE Acomayo, 9300 feet | Skin | Female | 2835 m | 2,996 m |
| 4 | LSU-14352 | 1968 | VertNet retrieved April 2016; Castro et al. (2015) | Peru | Huánuco | Huánuco | Chinchao | E slope Cordillera Carpish, Carretera Central, Huánuco | Skin | n/a | n/a | 2,509 m |
| 5 | LSU-14353 | 1968 | VertNet retrieved April 2016, Castro et al. (2015); Wetzel and Mondolfi (1979) | Peru | Huánuco | Huánuco | Chinchao | E slope Cordillera Carpish, Carretera Central, Huánuco | Skin | n/a | n/a | 2,509 m |
| 6 | LSU-19240 | 1974 | VertNet retrieved April 2016; Castro et al. (2015) | Peru | Huánuco | Huánuco | Chinchao | Bosque Taprag above Acomayo, Huánuco | Skin and skull | Female | n/a | 2,509 m |
| 7 | LSU-19241 | 1974 | VertNet retrieved 2016 April, Castro et al. (2015) | Peru | Huánuco | Huánuco | Chinchao | Bosque Taprag above Acomayo, Huánuco | Skin and skull | n/a | n/a | 2,509 m |
| 8 | LSU-19242 | 1974 | VertNet retrieved April 2016; Castro et al. (2015) | Peru | Huánuco | Huánuco | Chinchao | Bosque Taprag above Acomayo, Huánuco | Skin | n/a | n/a | 2,509 m |
| 9 | LSU-19243 | 1974 | VertNet retrieved April 2016; Castro et al. (2015) | Peru | Huánuco | Huánuco | Chinchao | Bosque Zapatagocha above Acomayo, Huánuco | Skin and skull | n/a | n/a | 2,509 m |
| 10 | LSU-21888 | 1978 | VertNet retrieved April 2016; Castro et al. (2015); Wetzel (1982) | Peru | Amazonas | Bagua | Aramango (Cordillera Colán or Chayu Naín) | Cordillera Colán, NE La Peca, Amazonas, Peru | Skin and partial skeleton | Male | 3,201 m | 2,831 m |
| 11 | LSU-18435 | 1973 | VertNet retrieved April 2016; Castro et al. (2015) | Peru | Huánuco | Huánuco | Chinchao | Bosque Zapatagocha, Huánuco, Peru | Skin | n/a | n/a | 2,509 m |
| 12[a] | NMW-222 | 1833 | Castro et al. 2015; Wetzel and Mondolfi (1979) | Peru | n/a | n/a | n/a | Unknown locality; bought in 1833 from an animal dealer in London | Mounted skin | n/a | n/a | n/a |
| 13[a] | IRSNB-291536/319 | 1846 | Castro et al. (2015); Wetzel and Mondolfi (1979) | Peru | La Libertad | Santiago de Chuco | Santiago de Chuco | Unknown locality. Suggested as Santiago, Piura, Peru by Fechkop and Yepes (1949) | Mounted skin without tail | n/a | n/a | n/a |

(continued)

Downloaded From: https://bioone.org/journals/Tropical-Conservation-Science on 28 Mar 2024
Terms of Use: https://bioone.org/terms-of-use

**Table 1.** Continued

| msID | Specimen ID | Year | Source | Country | Department | Province | District or protected area | Locality | Preparations | Sex | Elevation from tag | Extracted elevation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 14 | MUSM-CT1312 | 2013 | Castro et al. (2015) | Peru | Amazonas | Luya | Tingo (Huiquilla) | Yurac Rume | Skin | n/a | n/a | 2,846 m |
| 15 | MUSM-ING633 | 1999–2009[b] | Castro et al. (2015) | Peru | San Martín | Mariscal Cáceres | Huicungo | Concesión para la Conservación Alto Huayabamba | Skin | n/a | n/a | 3,121 m |
| 16 | MUSM-2056 | 1974 | Castro et al. (2015); Wetzel and Mondolfi (1979) | Peru | Huánuco | Huánuco | Chinchao | Zapatogocha, Acomayo | Skull and skin | Male | 3,000 m | 2,509 m |
| 17 | MUSM-7499 | n/a | Castro et al. 2015 | Peru | San Martín | Mariscal Cáceres | Huicungo (Río Abiseo) | Parque Nacional Río Abiseo | Skin | n/a | n/a | 2,264 m |
| 18[a] | MUSM-7500 | n/a | Castro et al. (2015) | n/a | n/a | n/a | n/a | Unknown locality | Skull | n/a | n/a | n/a |
| 19 | MUSM-7501 | 1989 | Castro et al. (2015) | Peru | San Martín | Mariscal Cáceres | Huicungo (Río Abiseo) | La Playa, ca 28 km NE Pataz, Las Papayas, vegetación ribereña | Skull and skin | Male | n/a | 2,627 m |
| 20 | MUSM-7502 | n/a | Castro et al. (2015) | Peru | San Martín | Mariscal Cáceres | Huicungo (Río Abiseo) | Parque Nacional Río Abiseo | Skull and skin | Female | n/a | 2,264 m |
| 21 | MUSM-7503 | 1990 | Castro et al. (2015) | Peru | San Martín | Mariscal Cáceres | Huicungo | NE Pataz, Las Papayas | Skull and skin | Male | n/a | 2,468 m |
| 22 | MUSM-7504 | 1989 | Castro et al. (2015) | Peru | San Martín | Mariscal Cáceres | Huicungo (Río Abiseo) | Río Colorado, Bosque en zona inundable, entre el mirador y la playa | Skull and skin | Female | 2,950 m | 3,486,m |
| 23 | MUSM-7505 | 1989 | Castro et al. (2015) | Peru | San Martín | Mariscal Cáceres | Huicungo (Río Abiseo) | Río Colorado, entre el mirador y la playa, ca 28 km NE Pataz | Skull and skin | Female | 2,930 m | 3,486 m |
| 24 | MUSM-24214 | n/a | Castro et al. (2015) | Peru | Pasco | Oxapampa | Huancabamba (Yanachaga-Chemillén) | Santa Barbara | Disarticulated carapace | n/a | 3,400 m | 2,539 m |
| 25[a] | MUSM-26/27 | n/a | Castro et al. (2015); Wetzel (1985) | n/a | n/a | n/a | n/a | "Guayaquil," no nation | Mounted skin | n/a | n/a | n/a |

*Note.* The column "msID" corresponds to the specimen ID plotted in Figures 1 and 3. "n/a" means data not available or not applicable. The detailed coordinates are not shown for the purpose of protecting the species. NHM = The Natural History Museum, London, United Kingdom; MSB = Mammal Collection, Museum of Southwestern Biology, University of New Mexico, Albuquerque, USA; LSU = Louisiana State University, Museum of Zoology, Baton Rouge, USA; NMW = Naturhistorisches Museum Wien, Vienna, Austria; IRSNB = Institut Royal des Sciences Naturelles de Belgique, Brussels, Belgium; MUSM = Museo de Historia Natural, Universidad Nacional Mayor de San Marcos, Lima, Peru.

[a]Coordinate not available or not applicable.

[b]Exact collection year unknown.

specimen records and a set of environmental variables (19 bioclimatic variables; Hijmans et al., 2005) at the resolution of 2.5 arc min. Maxent calculates the probability of presence by minimizing the relative entropy between the probability densities of occurrences and the training background in the environmental space (Elith et al., 2006, 2011). Maxent is also known for its robust performance with few occurrences (Phillips & Dudik, 2008), which fits the situation of this study.

To avoid the issue of sampling bias, we only kept one record per pixel, thus the records retained (12 of the 21) were spatially unique. To consider the dispersal ability in our model (Soberón & Peterson, 2005), we restricted the training area to a two-decimal degree (approximately 220 km at equator) buffer around all spatially unique records, within which we selected 10,000 background points as pseudo-absences for model training. To avoid the influence of predictor collinearity and potential model overfitting, we eliminated bioclimatic variables based on their contributions to the full model and the correlation matrix, following Feng, Anacleto, and Papeş (2016). First, we built a Maxent model with all spatially unique presences (12) and all bioclimatic variables (19) using linear and quadratic features and default regularization value, according to an empirical study (Phillips & Dudik, 2008). Then, we eliminated highly correlated ($|r| \geq .7$) variables while retaining those with high contribution and removing those with no contribution to the accuracy gain of the first Maxent model. This procedure led to selection of three bioclimatic variables (BIO6, minimum temperature of the coldest month; BIO15, precipitation seasonality; BIO16, precipitation of the wettest quarter), which were used to train the final model.

To evaluate the performance of the model obtained with the three selected environmental variables, we split the occurrences into four sets with the "checkerboard2" method (Muscarella et al., 2014) and used alternatively three sets as training and the fourth one as testing. The advantage of "checkerboard2" over random split is that the former can lessen the influence of spatial autocorrelation and thus leads to more robust evaluation index (Muscarella et al., 2014). We calculated two evaluation indices: partial area under the receiver operating characteristic curve (pAUC; Peterson, Papeş, & Soberon, 2008) at the threshold of 5% training omission rate (5% of training presences predicted as absences) and true skill statistic (TSS; Allouche, Tsoar, & Kadmon, 2006) at the threshold of 0% training omission rate. Compared with the traditional AUC, the pAUC evaluates the model performance at high sensitivity levels (percentage of correctly predicted presences), in our case from 0.95 to 1, thus it is more appropriate for ENM that usually adopts threshold approaches (Peterson et al., 2008); a value of $\text{pAUC} > 1$ indicates model performance better than random. The TSS considers both sensitivity (percentage of correctly predicted presence) and specificity (percentage of correctly predicted absence) and its value ranges from $-1$ to 1, while a value $> 0$ indicates that the model performs better than random (Allouche et al., 2006).

We projected the model to the extent of area surrounding the IUCN range map of *D. pilosus*. We thresholded the raw prediction of continuous suitability values to binary format (suitable vs. unsuitable) based on the minimum training threshold (0% training omission rate), which identifies suitable areas at least as good as known occurrences (Pearson, Raxworthy, Nakamura, & Peterson, 2007). To identify possible limiting factors of *D. pilosus* distribution, we ran the multivariate environmental similarity surface analysis (MESS; Elith, Kearney, & Phillips, 2010) within the predicted absence or unsuitable area using the three climatic variables involved in ENM training (BIO6, BIO15, and BIO16) and specimens' coordinates as the reference group. This procedure identifies the most different environmental conditions that exceeded the conditions associated with specimens' coordinates in the area predicted unsuitable.

### *Relating Distribution Information With Protected Areas*

To provide information for possible future field surveys and conservation management, we overlaid the specimens' coordinates and area predicted suitable with the map of protected areas (IUCN and UNEP-WCMC, 2016) in Peru. We calculated the frequency of specimens and the size of areas predicted suitable associated with each protected area.

## Results

We compiled a data set with 25 records of *D. pilosus* specimens (Table 1 and Figure 1). The oldest specimen dates to 1833 (NMW-222). In the latter half of the 20th century, *D. pilosus* was repeatedly collected in the Andes in Peru and the newest specimen was collected in 2013 from Yurac Rume (Huiquilla private conservation area, Tingo district, Luya province, Amazonas department, Peru). The specimens generally occurred in five protected areas and seven surrounding districts (Level-3 administrative unit) in six departments (Level-1 administrative unit).

The tags of five specimens had the elevation of the collection sites, ranging from 2,440 to 3,400 m (Table 1). The elevation derived from specimens with geographic coordinates ranged from 2,264 to 3,553 m (Table 1). The geographic coordinates of the specimens were

Downloaded From: https://bioone.org/journals/Tropical-Conservation-Science on 28 Mar 2024
Terms of Use: https://bioone.org/terms-of-use

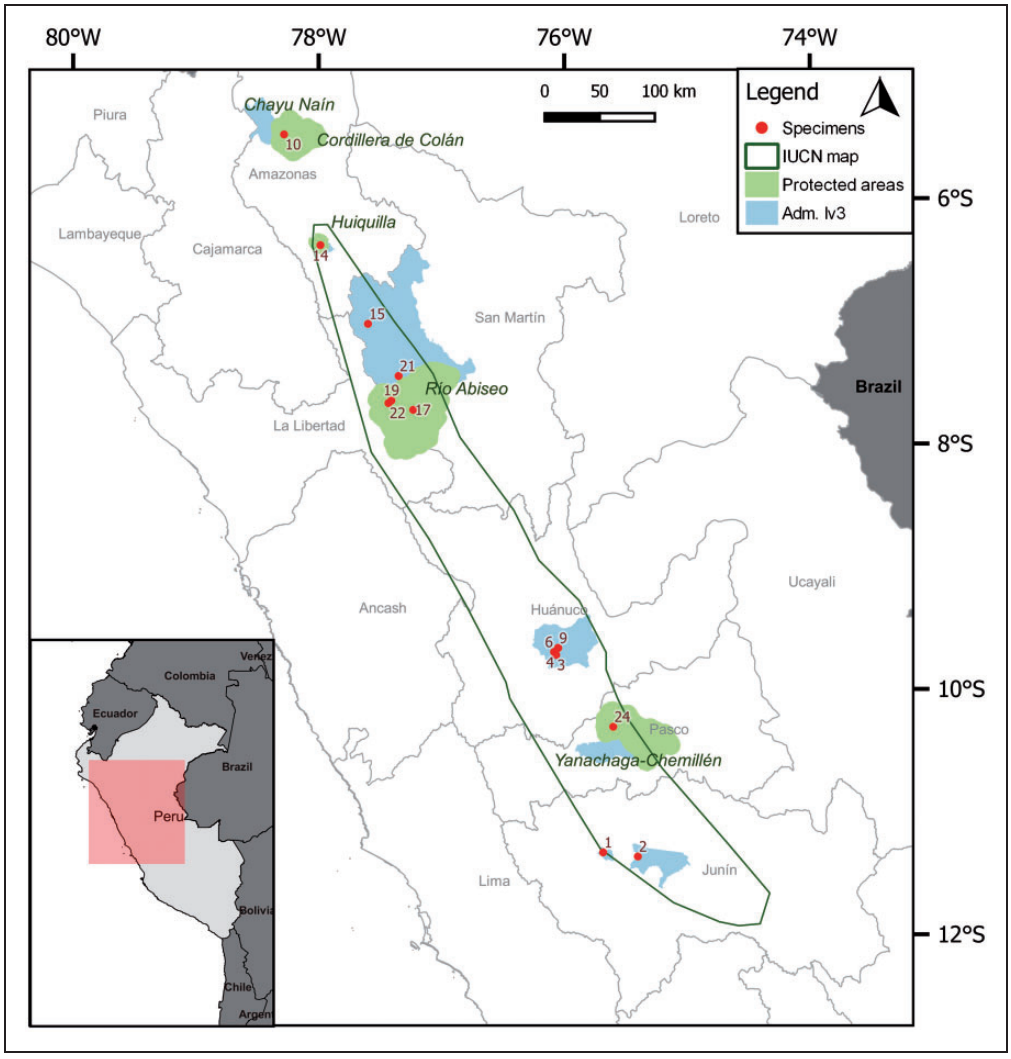



**Figure 1.** An overview of the distribution of *Dasypus pilosus*. The red circles represent the geographic coordinates of specimens. Numbers correspond to specimens listed in Table 1. The green open polygon represents the International Union for Conservation of Nature range map. The green-shaded polygons represent protected areas (names also in green) with specimen records. The blue-shaded polygons represent Level-3 administrative units (district) with specimen records.

representative of temperate climate, with annual mean temperature (BIO1 variable) of 8.9–16.7°C and annual precipitation (BIO12 variable) of 623–1,253 mm. Compared with annual mean temperature and annual precipitation of surrounding background (two decimal degrees buffer area), the known locations for this species appear to represent a narrow two-dimensional environmental space (Figure 2). We also mapped the differences in two climatic dimensions between the specimens and the projected area to illustrate possible regional climatic limits for this species (Figure 3).

The performance of Maxent model was better than random, according to pAUC of $1.85 \pm 0.01$ (mean $\pm$ *SD*) and TSS of $0.20 \pm 0.01$. The predicted potential distribution had a northwest to southeast extent along the Andes (Figure 4(a)). Within the IUCN range map, only 49% was predicted suitable for *D. pilosus*. Outside the IUCN range map, a considerable portion of Department of Cajamarca was predicted as suitable but was disconnected from the main potentially suitable area by a narrow gap of low elevation. Based on the MESS analysis, the majority of the unsuitable area exceeded the range of temperature of the coldest month (BIO6) associated with specimens' geographic coordinates (Figure 4(b)).

Among the protected areas in Peru, 33 were predicted partly or completely suitable for *D. pilosus* (Figure 4(a) and Table A1). Of the 33 protected areas, 5 had at least one *D. pilosus* record, while Río Abiseo had the most (5; Table A1).

Downloaded From: https://bioone.org/journals/Tropical-Conservation-Science on 28 Mar 2024
Terms of Use: https://bioone.org/terms-of-use

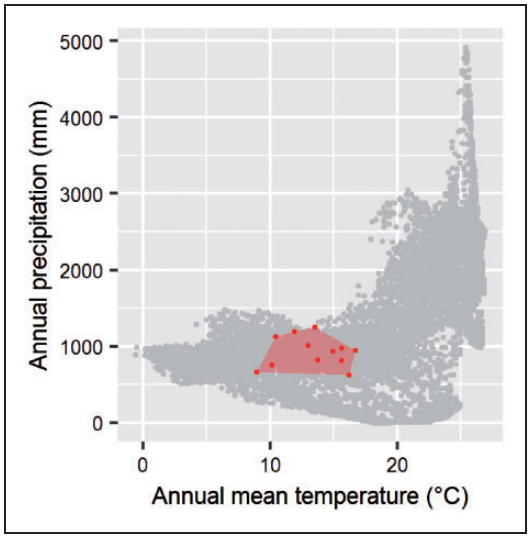



**Figure 2.** Illustration of climatic requirements for *Dasypus pilosus* in two-dimensional environmental space. The red points represent the climatic conditions associated with the geographic coordinates of specimens. The gray points represent climatic conditions associated with the pixels surrounding specimens in two decimal degree buffers. The red polygon is the convex hull of the specimens, illustrating the possible boundary of the precipitation and temperature requirements of *D. pilosus*.

## Discussion

We compiled information for only 25 specimens of *D. pilosus*; however, this is the most comprehensive catalog of collected specimens of *D. pilosus*. The IUCN status of *D. pilosus* is "data deficient" (Superina & Abba, 2014), but we presume that *D. pilosus* is not extinct given the recent specimen collected in 2013 (MUSM-CT1312) and the observation record in 2009 (Abba & Superina, 2010). The species may be rare or have a low abundance, but considering the longtime span of the collecting history (from 1833 to 2013, 181 years), the small number of specimens (25) indicates that limited effort has been invested in studying *D. pilosus*. Thus, our work provides more support for the proposal of Superina et al. (2014) to prioritize *D. pilosus* in scientific studies, and we hope our work will promote more investigations of *D. pilosus*.

Compiling locality information broadened our understanding of the distribution of *D. pilosus*. The species has been found in the Peruvian departments of San Martín, La Libertad, Huánuco, and Junín, but uncertainty was associated with the 2009 observation in Huiquilla, Amazonas (A. M. Abba, personal communication, November 14, 2016; Abba & Superina, 2010; but see Wetzel, 1982). However, we found that two specimens of *D. pilosus* (LSU-21888 and MUSM-CT1312) have been collected from department of Amazonas, and LSU-21888 was collected well beyond the IUCN range map (Superina & Abba, 2014; Figure 1). In addition to these records, a considerable portion of southern Amazonas was predicted suitable by our Maxent model, supporting the possibility of *D. pilosus* presence in Amazonas. Besides locations in previously reported departments in the literature (Abba & Superina, 2010; Wetzel, 1982, 1985; Wetzel & Mondolfi, 1979), we also found a specimen (MUSM-24214) collected from Santa Barbara, a mountain in the department of Pasco. Based on the new distribution information for *D. pilosus*, we suggest a revision of the IUCN range map.

By associating climate variables to geographic coordinates of specimens, we gained a deeper understanding of environmental requirements for *D. pilosus*. Elevation recorded on the specimen labels ranged from 2,440 to 3,400 m and the values extracted with the geographic coordinates of specimens ranged from 2,264 to 3,553 m. The two sources of elevation are not identical because the extracted values represent the average elevation of surrounding pixels while the elevation recorded on specimen labels may represent the elevation of the collection site, though not well documented. However, the elevation ranges of the two sources generally described similar patterns. The compiled elevation information generally matched the description of the upper elevation limit for *D. pilosus* distribution (3,000–3,200 m; Abba & Superina, 2010; Wetzel, 1982) but not the lower elevation (500 m; Abba & Superina, 2010). Furthermore, low elevation is generally associated with warmer climatic conditions, thus the species' distribution at lower elevation contradicts our finding of temperature requirements for *D. pilosus*. Thus, we note that revisions of current assumptions of the elevation range for *D. pilosus* are needed.

The derived temperature requirements of the species, based on the specimen geographic coordinates, showed an intermediate climate profile within the surrounding area (Figures 2 and 3(a)). The areas predicted unsuitable were most different from georeferenced localities for *D. pilosus* in terms of coldest temperature (Figure 4(b)). The range of temperature values associated with the specimens corresponded to a narrow geographic area, thus we propose that *D. pilosus* is restricted to (or selecting) a temperate to relatively cool niche in the Neotropics. The elongated shape of the *D. pilosus* distribution could be explained by the upper and lower thermal limits of the species. The distribution of Dasypodidae taxa is directly affected by their physiological characteristics (i.e., low body temperature, low basal metabolism, and high thermal conductance; McNab, 1980). A limitation on distribution related to temperature seems likely for *D. pilosus*, similar to the limitation of the distribution of *D. novemcinctus* by cold temperature in the northern portion of its range (Feng & Papeş, 2015; Taulman & Robbins, 2014). The dense fur of *D. pilosus* may extend

Downloaded From: https://bioone.org/journals/Tropical-Conservation-Science on 28 Mar 2024
Terms of Use: https://bioone.org/terms-of-use

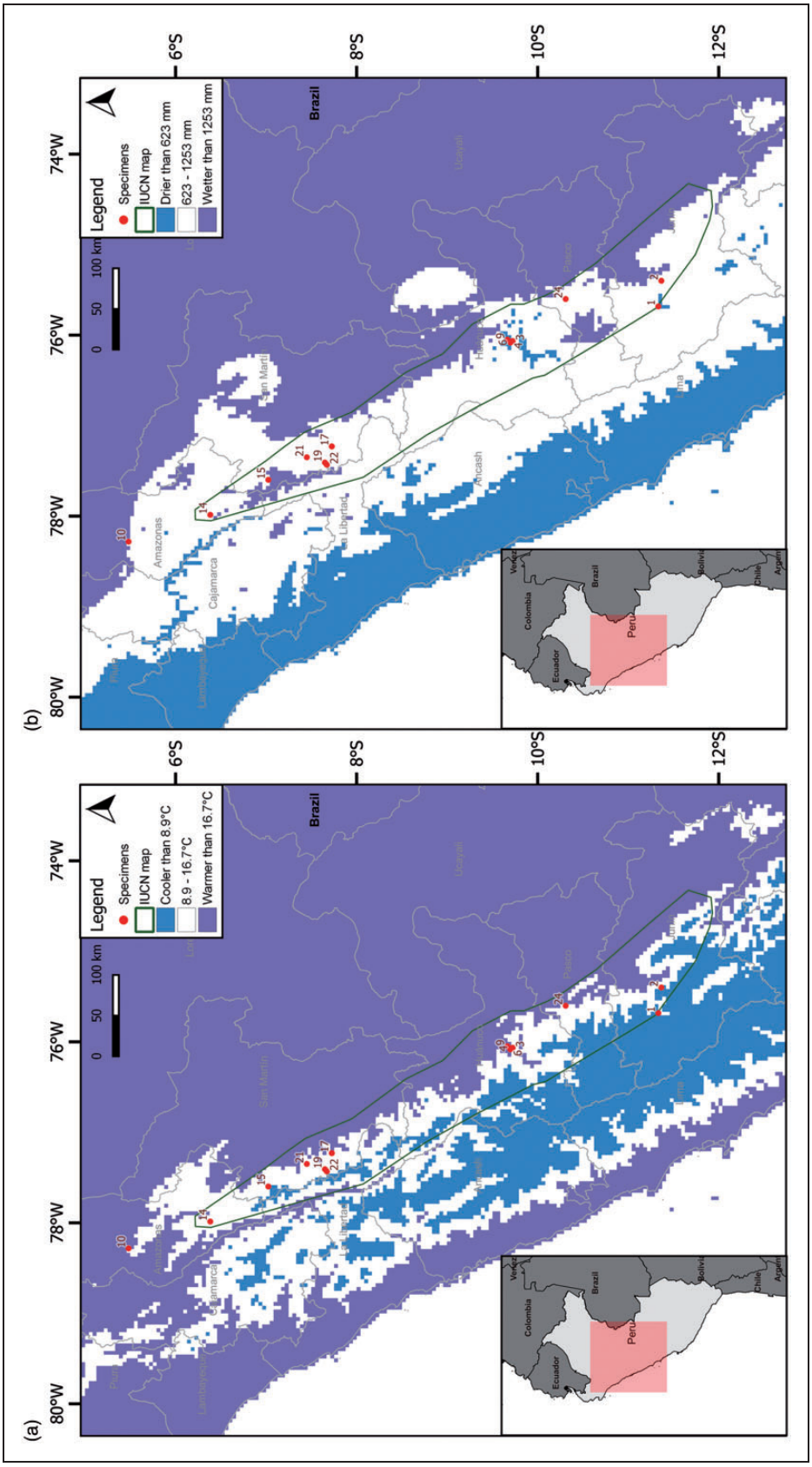



**Figure 3.** Illustration of climatic requirements for *Dasypus pilosus* in geographic space. The red circles represent the geographic coordinates of specimens. The green polygon represents the International Union for Conservation of Nature range map. In the white area, the annual mean temperature (Panel a) or annual precipitation (Panel b) are within the limit of conditions associated with the specimens. In the blue area, the annual mean temperature (Panel a) or annual precipitation (Panel b) are lower than those associated with the specimens. In the purple area, the conditions are higher than those associated with the specimens.

Downloaded From: https://bioone.org/journals/Tropical-Conservation-Science on 28 Mar 2024
Terms of Use: https://bioone.org/terms-of-use

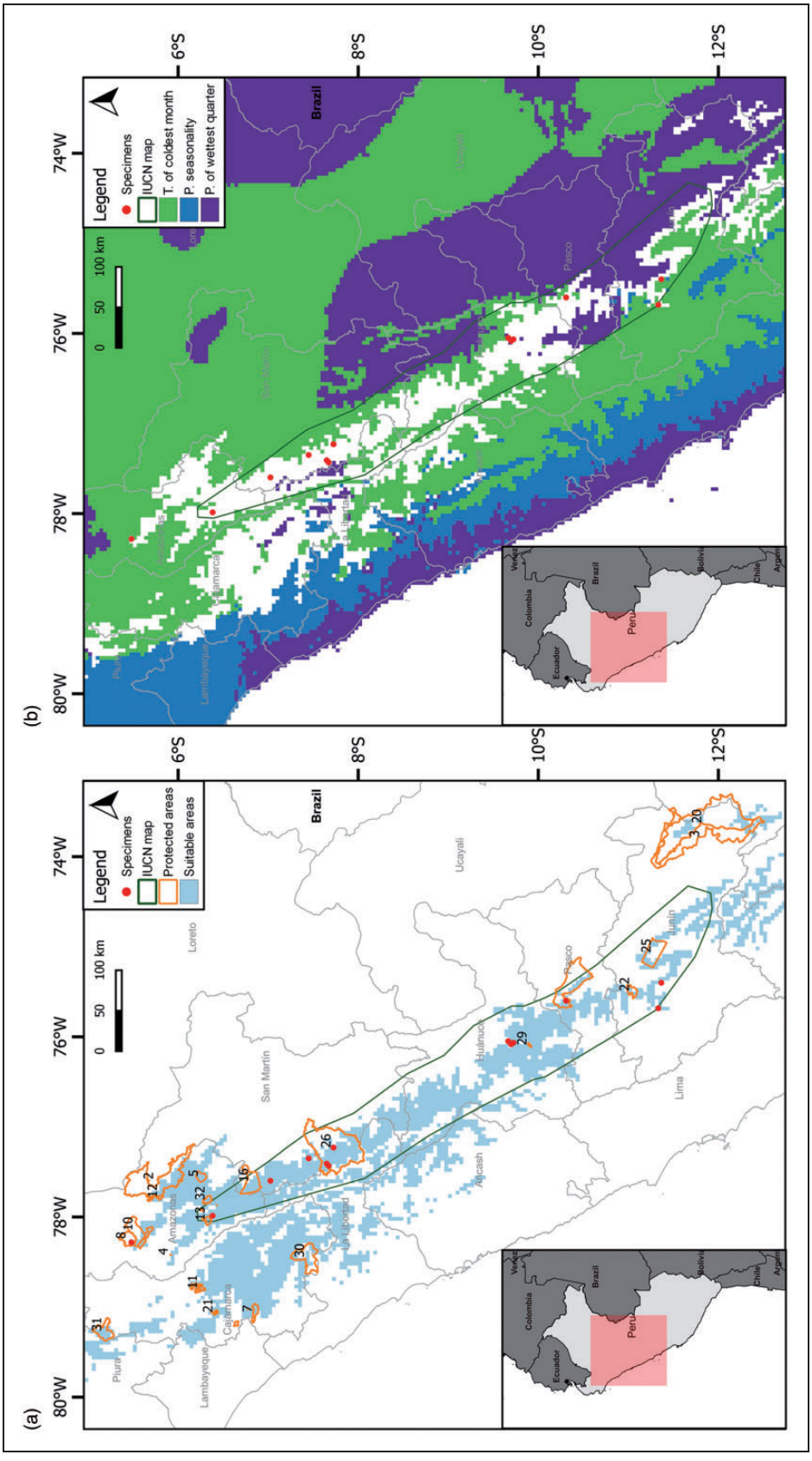



**Figure 4.** The suitable area for *Dasypus pilosus*, estimated with ecological niche modeling and climatic dissimilarity analysis. The red circles represent the geographic coordinates of specimens. The green polygon represents the International Union for Conservation of Nature range map. In Panel a, the area predicted suitable by the ecological niche model is represented by the blue color, whereas the orange polygons, with numeral labels (Table A1), represent protected areas either completely or partly suitable for *D. pilosus*. The multivariate environmental similarity surface analysis calculates the climatic similarity between target localities (area predicted unsuitable) and a group of reference points (coordinates of specimens) based on the three variables used in ecological niche modeling training (i.e., BIO6, minimum temperature of the coldest month; BIO15, precipitation seasonality; BIO16, precipitation of the wettest quarter). The most dissimilar variable of each target locality is shown in Panel b.

Downloaded From: https://bioone.org/journals/Tropical-Conservation-Science on 28 Mar 2024
Terms of Use: https://bioone.org/terms-of-use

its cold temperature tolerance; however, this tolerance is probably still narrow in light of the South American origin of armadillos (Leigh, O'Dea, & Vermeij, 2014), making the species more likely to be warm adapted than cold adapted (Superina & Loughry, 2012). Krmpotic et al. (2015) found less adipose tissue in the osteoderms of Dasypodinae than in those of Euphractinae, which may contribute to the high thermal conductance of Dasypodinae and therefore limited cold tolerance. In contrast, McNab (1980) explained the necessity of high thermal conductance to prevent overheating of armadillos in burrows. Therefore, the dense fur may pose an upper thermal limit on *D. pilosus* by hindering heat dissipation, given that the species' distribution appears to be restricted to a temperate regime, excluding the surrounding tropical climatic conditions.

The precipitation requirements derived from specimens used in the current study showed a plausible minimum limit (623 mm; Figures 2 and 3(b)). A minimum moisture limit was proposed for *D. novemcinctus* (380 mm [Taulman & Robbins, 1996, 2014] or 500 mm [Humphrey, 1974]) as necessary for maintaining a vegetative litter layer with prey items. The same rule seems to fit *D. pilosus* as well, given the species' suspected dietary requirements of ants and termites (Castro et al., 2015). Interestingly, two other *Dasypus* species (*D. kappleri* and the extinct *D. bellus*) have been shown to follow the precipitation limit of 500 mm (Feng, Anacleto, & Papeş, 2016). This suggests the possibility that, along with temperature, the distribution of *Dasypus* taxa is limited by low precipitation which in turn limits prey availability, given the shared adaptation to mymecophagy/insectivory among the species of *Dasypus* (Wetzel et al., 2007).

The predicted distribution of *D. pilosus* did not match the IUCN range map (Figure 1). A considerable portion (51%) of the IUCN range map was predicted as unsuitable, probably because of temperature regimes that are either too cold or too hot (Figures 2–4). Additional suitable areas were predicted outside the expert range map. The potential distribution presented here was based on a limited number of specimens of *D. pilosus*; however, all known specimens were included in the model and we considered the model prediction preliminary but valid. Previous methodological studies have found that Maxent algorithm is robust to low number of presences (from 5 to 25; Hernandez, Graham, Master, & Albert, 2006; Pearson et al., 2007; Wisz et al., 2008), and with the same number of presences, Maxent model is accurate for narrowly distributed species (Hernandez et al., 2006; van Proosdij, Sosef, Wieringa, & Raes, 2016). Additionally, applications of ENM have successfully guided field surveys in discovering rare species, and in several cases, these were based on low number of presences (3 presences of a mammal species in Jackson and Robertson, 2011; 8 presences of a plant species in Fois, Fenu, Cuena Lombraña, Cogoni, and Bacchetta, 2015; and 14 presences of a tree species in Menon et al., 2010). The Maxent model in our study was based on 12 presences (representing 21 specimen records), a sample size within the range of those that have led to useful models. Also, *D. pilosus* has a relatively narrow distribution (Abba & Superina, 2010; Wetzel et al., 2007) and the 12 presences were spread latitudinally throughout the IUCN range map (Figure 1). The theoretical and practical experiences from previous studies suggest that our prediction could guide future field surveys in a meaningful way (Fois et al., 2015; Hernandez et al., 2006; Jackson & Robertson, 2011; Menon et al., 2010; van Proosdij et al., 2016). Based on the geographic information we assessed, we suggest that future surveys or conservation management for *D. pilosus* should give priority to areas predicted suitable within existing protected areas (Table A1), especially those that have records of specimens (e.g., Río Abiseo). However, after more information is collected, we expect that an updated model could provide a refined potential distribution and guide field survey more efficiently.

Given the reality that the ecology of *D. pilosus* is unknown, it is worth emphasizing descriptions associated with two specimens. First, MUSM-7504 was a female with four embryos, suggesting that this species might exhibit polyembryony with identical quadruplets, like *D. novemcinctus* (McBee & Baker, 1982). Second, MSB-49990 was a juvenile caught on a ridge top, in a hole with three other individuals, indicating that *D. pilosus* may inhabit high elevations and build burrows, like other *Dasypus* armadillos (Sawyer, Brinkman, Walker, Covington, & Stienstraw, 2012; Trovati, 2015). Also, since MSB-49990 was a juvenile sharing the burrow with three other individuals, it is possible that they were from the same litter. Because *Dasypus* taxa generally show monozygotic polyembryony (Wetzel, 1982), and they generally do not share burrows except as young litter mates (McBee & Baker, 1982; McDonough & Loughry, 2008; Vizcaíno & Loughry, 2008), the two specimens provide evidence for reproduction through polyembryony with identical quadruplets in *D. pilosus* as well.

## Implications for Conservation

The IUCN status of *D. pilosus* has been changed from vulnerable to data deficient (Superina & Abba, 2014), thus we suspect that there is little or no specific conservation effort on *D. pilosus*, probably because of the lack of knowledge for this species. Therefore, we argue that a first step for conservation of *D. pilosus* is to learn more about it. Our study improves the current state of knowledge of *D. pilosus* from three perspectives. First, we synthesized the most comprehensive *D. pilosus* specimen data set to date, and we expect this will facilitate future

Downloaded From: https://bioone.org/journals/Tropical-Conservation-Science on 28 Mar 2024
Terms of Use: https://bioone.org/terms-of-use

studies of *D. pilosus*. Second, we analyzed elevation and climatic requirements of *D. pilosus* and proposed that the narrow temperature tolerance of *D. pilosus* is the reason for its restricted distribution. Third, we provided maps of known locations of specimens and predicted potential distribution, together with protected areas in its range. The maps may facilitate future field surveys and conservation efforts. Our study exemplifies the potential of ecological biogeography tools (e.g., GIS and ENM) for use in gaining knowledge of species' distribution and ecology, especially for endangered or lesser studied species.

## Acknowledgments

The authors thank J. E. Serrano-Villavicencio for his help with georeferencing specimens. We also would like to thank the curators who allowed the study and provided helpful information of specimens under their care: G. Lenglet (IRSNB), J. Dunnum (MSB), F. Zachos (NMW), V. Pacheco (MUSM), and J. Esselstyn (LSU). The suggestions of three anonymous reviewers improved the clarity and focus of the manuscript.

## Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

## Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This research has been partially supported by FAPESP (Proc. 2014/23815-2 to MCC).

## References

Abba, A. M., & Superina, M (2010). The 2009/2010 armadillo red list assessment. *Edentata*, *11*, 135–184.

Allouche, O., Tsoar, A., & Kadmon, R (2006). Assessing the accuracy of species distribution models: Prevalence, kappa and the true skill statistic (TSS). *Journal of Applied Ecology*, *43*, 1223–1232.

Bond, N. R., Thomson, J. R., & Reich, P (2014). Incorporating climate change in conservation planning for freshwater fishes. *Diversity and Distributions*, *20*, 931–942.

Castro, M. C., Ciancio, M. R., Pacheco, V., Salas-Gismondi, R. M., Bostelmann, J. E., & Carlini, A. A (2015). Reassessment of the hairy long-nosed armadillo ''*Dasypus*'' *pilosus* (Xenarthra, Dasypodidae) and revalidation of the genus *Cryptophractus* Fitzinger, 1856. *Zootaxa*, *3947*, 30–48.

Elith, J., Graham, C. H., Anderson, R. P., Dudik, M., Ferrier, S., Guisan, A., . . . Zimmermann, N. E (2006). Novel methods improve prediction of species' distributions from occurrence data. *Ecography*, *29*, 129–151.

Elith, J., Kearney, M., & Phillips, S (2010). The art of modelling range-shifting species. *Methods in Ecology and Evolution*, *1*, 330–342.

Elith, J., Phillips, S. J., Hastie, T., Dudík, M., Chee, Y. E., & Yates, C. J (2011). A statistical explanation of MaxEnt for ecologists. *Diversity and Distributions*, *17*, 43–57.

Feng, X., Anacleto, T. C. S., & Papeş, M. (2016). Climatic similarity of extant and extinct *Dasypus* armadillos. *Journal of Mammalian Evolution.* doi 10.1007/s10914-016-9336-y.

Feng, X., Lin, C., Qiao, H., & Ji, L (2015). Assessment of climatically suitable area for *Syrmaticus reevesii* under climate change. *Endangered Species Research*, *28*, 19–31.

Feng, X., & Papeş M (2015). Ecological niche modelling confirms potential north-east range expansion of the nine-banded armadillo (*Dasypus novemcinctus*) in the USA. *Journal of Biogeography*, *42*, 803–807.

Fois, M., Fenu, G., Cuena Lombraña, A., Cogoni, D., & Bacchetta, G. (2015). A practical method to speed up the discovery of unknown populations using species distribution models. *Journal for Nature Conservation*, *24*, 42–48.

Frechkop, S., & Yepes, J. (1949). Étude systématique et zoogéographique des dasypodidés conservés a l'Institut. *Bulletin de l'Institut Royal des Sciences Naturelles de Belgique*, *25*, 1–56.

Gardner, A. L (2007). *Mammals of South America, Volume 1. Marsupials, Xenarthrans, Shrews, and Bats*. Chicago, IL: University of Chicago Press.

Gibb, G. C., Condamine, F. L., Kuch, M., Enk, J., Moraes-Barros, N., Superina, M., . . . Delsuc, F. (2016). Shotgun mitogenomics provides a reference phylogenetic framework and timescale for living Xenarthrans. *Molecular Biology and Evolution*, *33*, 621–642.

Hernandez, P. A., Graham, C. H., Master, L. L., & Albert, D. L. (2006). The effect of sample size and species characteristics on performance of different species distribution modeling methods. *Ecography*, *29*, 773–785.

Hijmans, R. J., Cameron, S. E., Parra, J. L., Jones, P. G., & Jarvis, A. (2005). Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology*, *25*, 1965–1978.

Humphrey, S. R (1974). Zoogeography of the nine-banded armadillo (*Dasypus novemcinctus*) in the United States. *Bioscience*, *24*, 457–462.

Hutchinson, G. E (1957). Concluding remarks. *Cold Spring Harbor Symposia on Quantitative Biology*, *22*, 415–427.

International Union for Conservation of Nature and United Nations Environment Programme's World Conservation Monitoring Centre. (2016). *The World Database on Protected Areas (WDPA)*. Retrieved from http://www.protectedplanet.net.

Jackson, C. R., & Robertson, M. P (2011). Predicting the potential distribution of an endangered cryptic subterranean mammal from few occurrence records. *Journal for Nature Conservation*, *19*, 87–94.

Krmpotic, C. M., Ciancio, M. R., Carlini, A. A., Castro, M. C., Scarano, A. C., & Barbeito, C. G (2015). Comparative histology and ontogenetic change in the carapace of armadillos (Mammalia: Dasypodidae). *Zoomorphology*, *134*, 601–616.

Leigh, E. G., O'Dea, A., & Vermeij, G. J (2014). Historical biogeography of the Isthmus of Panama. *Biological Reviews*, *89*, 148–172.

Loiselle, B. A., Howell, C. A., Graham, C. H., Goerck, J. M., Brooks, T., Smith, K. G., & Williams, P. H (2003). Avoiding pitfalls of using species distribution models in conservation planning. *Conservation Biology*, *17*, 1591–1600.

Lomolino, M. V., Riddle, B. R., Whittaker, R. J., & Brown, J. H. (2010). *Biogeography* (4th ed.). Sunderland, MA: Sinauer Associates.

Downloaded From: https://bioone.org/journals/Tropical-Conservation-Science on 28 Mar 2024
Terms of Use: https://bioone.org/terms-of-use

Loughry, W. J., Superina, M., McDonough, C. M., & Abba, A. M (2015). Research on armadillos: A review and prospectus. *Journal of Mammalogy*, *96*, 635–644.

McBee, K., & Baker, R. J (1982). *Dasypus novemcinctus*. *Mammalian Species*, *162*, 1–9.

McDonough, C. M., & Loughry, W. J. (2008). Behavioral ecology of armadillos. In: S. F. Vizcaíno, & W. J. Loughry (Eds.). *The biology of the Xenarthra* (pp. 281–293). Gainesville, FL: University Press of Florida.

McNab, B. K (1980). Energetics and the limits to a temperate distribution in armadillos. *Journal of Mammalogy*, *61*, 606–627.

Menon, S., Choudhury, B. I., Khan, M. L., & Peterson, A. T (2010). Ecological niche modeling and local knowledge predict new populations of *Gymnocladus assamicus* a critically endangered tree species. *Endangered Species Research*, *11*, 175–181.

Muscarella, R., Galante, P. J., Soley-Guardia, M., Boria, R. A., Kass, J. M., Uriarte, M., & Anderson, R. P (2014). ENMeval: An R package for conducting spatially independent evaluations and estimating optimal model complexity for Maxent ecological niche models. *Methods in Ecology and Evolution*, *5*, 1198–1205.

Pearson, R. G., Raxworthy, C. J., Nakamura, M., & Peterson, A. T (2007). Predicting species distributions from small numbers of occurrence records: A test case using cryptic geckos in Madagascar. *Journal of Biogeography*, *34*, 102–117.

Peterson, A. T., Papeş M., & Soberon, J (2008). Rethinking receiver operating characteristic analysis applications in ecological niche modeling. *Ecological Modelling*, *213*, 63–72.

Peterson, A. T., Soberón, J., Pearson, R. G., Anderson, R. P., Martínez-Meyer, E., Nakamura, M., . . . Araújo, M. B. (2011). *Ecological niches and geographic distributions*. Princeton, NJ: Princeton University Press.

Phillips, S. J., & Dudik, M (2008). Modeling of species distributions with Maxent: New extensions and a comprehensive evaluation. *Ecography*, *31*, 161–175.

Phillips, S. J., Dudík, M., & Schapire, R. E. (2004). *A maximum entropy approach to species distribution modeling*. Paper presented at the Proceedings of the Twenty-First International Conference on Machine Learning, Banff, Alberta, Canada.

Sawyer, C. F., Brinkman, D. C., Walker, V. D., Covington, T. D., & Stienstraw, E. A (2012). The zoogeomorphic characteristics of burrows and burrowing by nine-banded armadillos (*Dasypus novemcinctus*). *Geomorphology*, *157–158*, 122–130.

Soberón, J., & Peterson, A. T (2005). Interpretation of models of fundamental ecological niches and species' distributional areas. *Biodiversity Informatics*, *2*, 1–10.

Soberón, J. M (2007). Grinnellian and Eltonian niches and geographic distributions of species. *Ecology Letters*, *10*, 1115–1123.

Superina, M., & Abba, A. M. (2014). *Dasypus pilosus*. The IUCN Red List of Threatened Species 2014: e.T6291A47441122. Retrieved from http://www.iucnredlist.org.

Superina, M., & Loughry, W. J (2012). Life on the half-shell: consequences of a carapace in the evolution of armadillos (Xenarthra: Cingulata). *Journal of Mammalian Evolution*, *19*, 217–224.

Superina, M., & Loughry, W. J (2015). Why do Xenarthrans matter? *Journal of Mammalogy*, *96*, 617–621.

Superina, M., Pagnutti, N., & Abba, A. M (2014). What do we know about armadillos? An analysis of four centuries of knowledge about a group of South American mammals, with emphasis on their conservation. *Mammal Review*, *44*, 69–80.

Taulman, J. F., & Robbins, L. W (1996). Recent range expansion and distributional limits of the nine-banded armadillo (*Dasypus novemcinctus*) in the United States. *Journal of Biogeography*, *23*, 635–648.

Taulman, J. F., & Robbins, L. W (2014). Range expansion and distributional limits of the nine-banded armadillo in the United States: An update of Taulman & Robbins (1996). *Journal of Biogeography*, *41*, 1626–1630.

Trovati, R. G (2015). Differentiation and characterization of burrows of two species of armadillos in the Brazilian Cerrado. *Revista Chilena de Historia Natural*, *88*, 19–19.

van Proosdij, A. S. J., Sosef, M. S. M., Wieringa, J. J., & Raes, N (2016). Minimum required number of specimen records to develop accurate species distribution models. *Ecography*, *39*, 542–552.

Vizcaíno, S. F., & Loughry, W. J. (2008). *The biology of the Xenarthra*. Gainesville, FL: University Press of Florida.

Wetzel, R. M. (1982). Systematics, distribution, ecology, and conservation of South American edentates. In: M. A. Mares, & H. H. Genoways (Eds.). *Mammalian biology in South America* (pp. 345–375). Pittsburgh, PA: Pymatuning Laboratory of Ecology, University of Pittsburgh.

Wetzel, R. M. (1985). Taxonmy and distribution of armadillos, Dasypodidae. In: G. G. Montgomery (ed.) *The evolution and ecology of armadillos, sloths, and Vermilinguas* (pp. 23–46). Washington, D.C.: Smithsonian Institution Press.

Wetzel, R. M., Gardner, A. L., Redford, K. H., & Eisenberg, J. F. (2007). Order Cingulata. In: A. L. Gardner (ed.) *Mammals of South America, Volume 1. Marsupials, Xenarthrans, Shrews, and Bats* (pp. 128–157). Chicago, IL: University of Chicago Press.

Wetzel, R. M., & Mondolfi, E. (1979). The subgenera and species of long-nosed armadillos, genus *Dasypus* L. In: J. F. Eisenberg (ed.) *Vertebrate Ecology in the Northern Neotropics* (pp. 43–63). Washington, D.C.: Smithsonian Institution Press.

Wisz, M. S., Hijmans, R. J., Li, J., Peterson, A. T., Graham, C. H., Guisan, A., & Group, N. P. S. D. W (2008). Effects of sample size on the performance of species distribution models. *Diversity and Distributions*, *14*, 763–773.

Downloaded From: https://bioone.org/journals/Tropical-Conservation-Science on 28 Mar 2024
Terms of Use: https://bioone.org/terms-of-use

# Appendix

**Table A1.** Summary of Protected Areas in Peru that are Potentially Suitable for *Dasypus pilosus*.

| mapID | WDPAID | Name | Type | Total area ($km^2$) | Percentage of suitable area | Number of specimens collected |
|---|---|---|---|---|---|---|
| 1 | 555555639 | Abra Patricia–Alto Nieva | Private conservation area | 14.16 | 33.33 | 0 |
| 2 | 20183 | Alto Mayo | Protection forest | 1,820.00 | 26.51 | 0 |
| 3 | 303318 | Ashaninka | Communal reserve | 1,844.68 | 6.90 | 0 |
| 4 | 555555691 | Berlin | Private conservation area | 0.59 | 50.00 | 0 |
| 5 | 555555684 | Bosque de Palmeras de la Comunidad Campesina Taulia Molinopampa | Private conservation area | 109.21 | 100.00 | 0 |
| 6 | 555555640 | Bosque Nublado | Private conservation area | 33.54 | 50.00 | 0 |
| 7 | 555544103 | Bosques Nublados de Udima Sector Centro | Wildlife refuge | 121.83 | 60.00 | 0 |
| 8 | 555544088 | Chayu Naín | Communal reserve | 235.98 | 15.38 | 1 |
| 9 | 555555664 | Copallín | Private conservation area | 115.49 | 100.00 | 0 |
| 10 | 20179 | Cordillera de Colán | National sanctuary | 392.16 | 22.22 | 1 |
| 11 | 261 | Cutervo | National park | 82.14 | 100.00 | 0 |
| 12 | 555555660 | Hierba Buena—Allpayacu | Private conservation area | 22.82 | 100.00 | 0 |
| 13 | 555555669 | Huaylla Belén—Colcamar | Private conservation area | 63.38 | 100.00 | 0 |
| 14 | 555555631 | Huiquilla | Private conservation area | 11.41 | 100.00 | 1 |
| 15 | 555555674 | Japu—Bosque Ukumari Llaqta | Private conservation area | 186.96 | 40.00 | 0 |
| 16 | 555555687 | Los Chilchos | Private conservation area | 460.00 | 66.67 | 0 |
| 17 | 257 | Manu | National park | 17,162.95 | 4.10 | 0 |
| 18 | 20186 | Megantoni | National sanctuary | 2,158.69 | 14.55 | 0 |
| 19 | 555555670 | Milpuj—La Heredad | Private conservation area | 0.17 | 100.00 | 0 |
| 20 | 303323 | Otishi | National park | 3,059.73 | 20.67 | 0 |
| 21 | 20184 | Pagaibamba | Protection forest | 20.78 | 100.00 | 0 |
| 22 | 30034 | Pampa Hermosa | National sanctuary | 115.44 | 66.67 | 0 |
| 23 | 68137 | Paracas | Ramsar Site, Wetland of International Importance | 3,350.00 | 28.74 | 0 |
| 24 | 555555672 | Pillco Grande—Bosque de Pumataki | Private conservation area | 2.72 | 50.00 | 0 |
| 25 | 20181 | Pui Pui | Protection forest | 600.00 | 55.56 | 0 |
| 26 | 7461 | Río Abiseo | National park | 2,745.20 | 54.33 | 5 |
| 27 | 555555634 | San Antonio | Private conservation area | 3.57 | 33.33 | 0 |
| 28 | 555555596 | San Fernando | National reserve | 1,547.16 | 44.44 | 0 |
| 29 | 555555663 | San Marcos | Private conservation area | 9.86 | 100.00 | 0 |
| 30 | 30060 | Sunchubamba | Hunting preserve | 597.35 | 46.43 | 0 |
| 31 | 20178 | Tabaconas Namballe | National sanctuary | 321.25 | 73.33 | 0 |
| 32 | 555555647 | Tilacancha | Private conservation area | 68.00 | 100.00 | 0 |
| 33 | 12213 | Yanachaga–Chemillén | National park | 1,220.00 | 29.63 | 1 |

*Note.* The list of protected areas was compiled from IUCN and UNEP-WCMC (2016). The column "WDPAID" represents the protected area original identifier from IUCN and UNEP-WCMC (2016). The column "mapID" corresponds to the ID plotted in Figure 4(a).

Downloaded From: https://bioone.org/journals/Tropical-Conservation-Science on 28 Mar 2024
Terms of Use: https://bioone.org/terms-of-use