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## Correspondence

# A new distribution record and updated conservation assessment of the endangered Marañón poison frog, *Excidobates mysteriosus* (Amphibia: Dendrobatidae)

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*Excidobates mysteriosus* (Myers, 1982) is a species of poison frog (family Dendrobatidae) endemic to Northern Peru and one of the more enigmatic species of the family. It was described in 1982 from a single specimen originally collected in 1929 (Myers 1982). This species remained undocumented in life until R. Schulte (1990) rediscovered it from near the type locality of Santa Rosa de La Yunga, Cajamarca department, Peru. Although *E. mysteriosus* was initially suggested to belong to the *Oophaga histrionica* group based on its color pattern, large size (SVL 26–29 mm), and osteology, later molecular phylogenetic work placed it in the genus *Excidobates* (Twomey & Brown 2008). The species is easily recognizable due to its distinctive white "polka-dot" pattern (Fig. 1A) and has become an emblematic species of Peru's exceptionally diverse but threatened amphibian fauna (Jarvis et al. 2015). Here, we report a population of *E. mysteriosus* from a new locality and provide an updated model of suitable habitat to reevaluate this species' conservation status.

In the roughly 20 years following its rediscovery, *E. mysteriosus* was known only from a handful of sites within 5 km of the type locality. All these sites occur in areas of heavy anthropogenic disturbance (personal observations). These sites generally fall into two habitat categories: rock walls and forest (Monsalve-Pasapera 2011). In rock-wall habitat, frogs live and breed in large lithophytic bromeliads (e.g., *Tillandsia* cf. *ecarinata*) growing on the rock faces (Fig. 1B). All known rock-wall habitats lack forest cover and thus seem to be relatively immune to anthropogenic disturbance. In forest habitats, frogs use both terrestrial and epiphytic bromeliads (Figs 1C, 1D). In contrast with rock-wall habitats, low-slope areas that are deforested do not contain bromeliads nor frogs. Therefore, *E. mysteriosus* seems to require forest cover except in areas where slope is steep enough to support lithophytic bromeliads. Given its restricted range and the fact that much of its habitat is fragmentary and degraded, *E. mysteriosus* is currently listed as Endangered on the IUCN Red List of Threatened Species (IUCN 2019). However, Twomey & Brown (2008) identified additional suitable habitat for this species using an environmental niche model (ENM), mainly localized around the peripheral slopes of the Huancabamba depression (i.e., the dry valleys near the confluence of the Utcumbamba, Chinchipe, and Marañón rivers), raising the possibility that this species occurs more widely.

During field work in the vicinity of Pedro Ruiz, Amazonas, in 2010, one of us (MF) found a population of *E. mysteriosus* occurring ~90 km SE from the type locality. We visited this site again in 2011 and a single voucher (CORBIDI 10481) was collected and deposited in the herpetological collection of Centro de Ornitologia y Biodiversidad (CORBIDI), in Lima, Peru. Notably, this record occurs in an area predicted to be suitable habitat in the previous ENM (Twomey & Brown 2008), raising the possibility that the previous model was accurate and that *E. mysteriosus* occupies, at the very least, a corridor of suitable habitat between the type locality and the new locality (Fig. 2E).

In an effort to improve previous habitat models for *E. mysteriosus,* we used climate, forest, and topographic data and the new locality to model suitable habitat for this species. Our overall approach was to classify each of the data types to a binary suitable/unsuitable habitat layer, with the final model being a combination of all the binary layers. We determined the thresholds for binary classification using data at each occurrence record. However, in all cases we tended towards a less conservative estimate (i.e., favoring habitat overprediction) so as not to overly restrict the final model. To determine a suitable climatic niche for *E. mysteriosus,* we ran an ENM with Maxent 3.4.1 (Phillips et al. 2017), under the following conditions: features = linear, quadratic, product, threshold, hinge; regularization multiplier = 1.0, lq to lqp threshold = 10, linear to lq threshold = 10; other parameters were set to default values. Background sampling included 10,000 points within the area of the climate raster. For climate data we used the WORLDCLIM version 1.4 dataset for current conditions (30 seconds resolution, tiles 23, 24, 33, and 34) (Hijmans et al. 2005). Fourteen presence points (all obtained from our own field work) were used to build the model; due to concerns about illegal collection for the pet trade (Brown et al. 2011), these points are withheld but are available on request. The resulting model was converted to a binary raster layer at a threshold of > 0.8 probability of occurrence. This threshold was justified in that it included all occurrence records as well as additional habitat in the region, but did not include areas of clearly unsuitable habitat such as the low-elevation arid scrub surrounding Bagua Grande

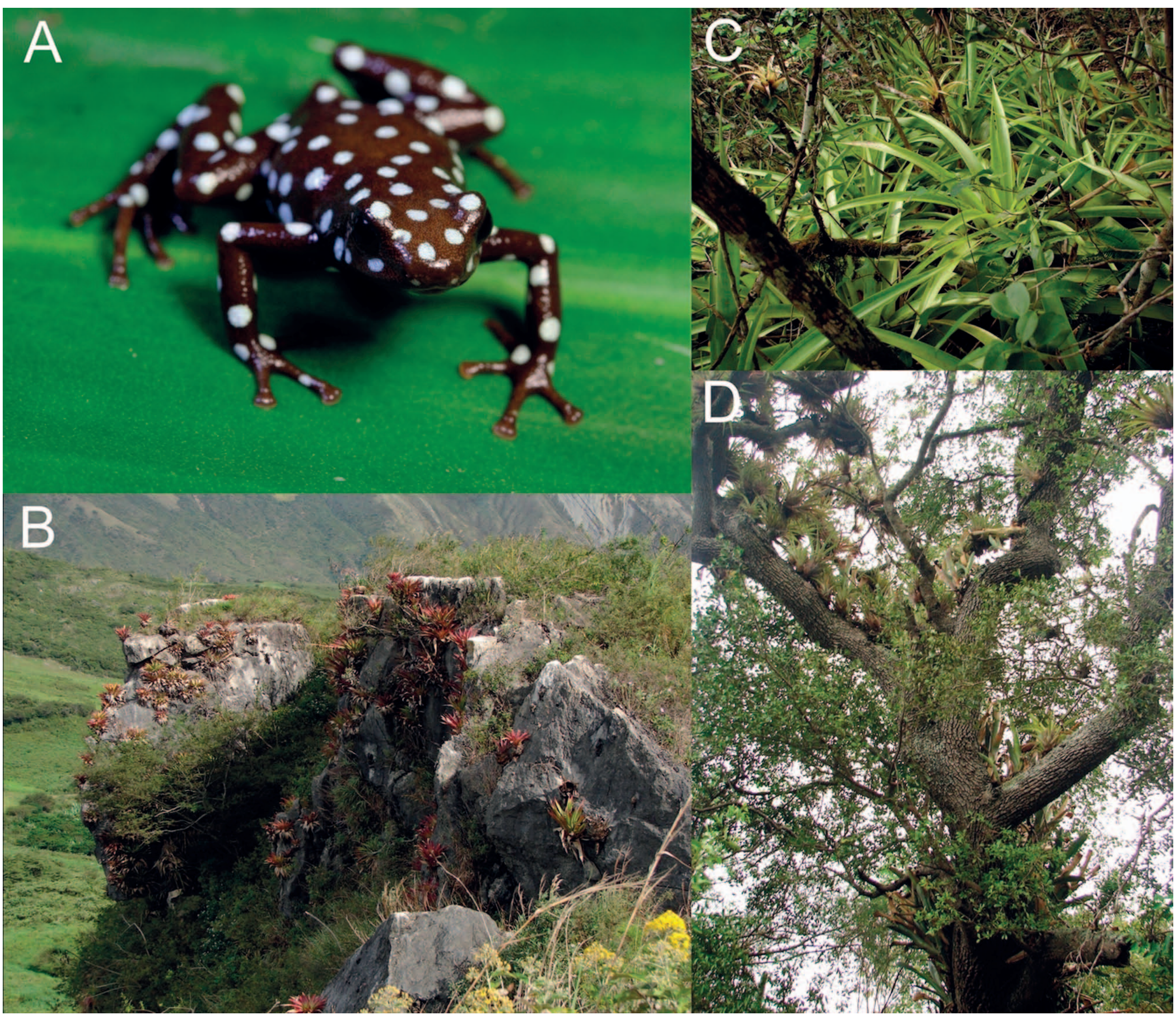


Figure 1. *Excidobates mysteriosus* and habitat types: (A) *E. mysteriosus* from the new locality, adult male, CORBIDI 10481. (B) Rock-wall habitat near the type locality, Santa Rosa de la Yunga, Cajamarca, Peru. Note abundant lithophytic bromeliads growing on rocks and lack of forest cover. (C) Forest habitat with terrestrial bromeliads near the type locality. (D) Forest habitat with epiphytic bromeliads near the type locality.

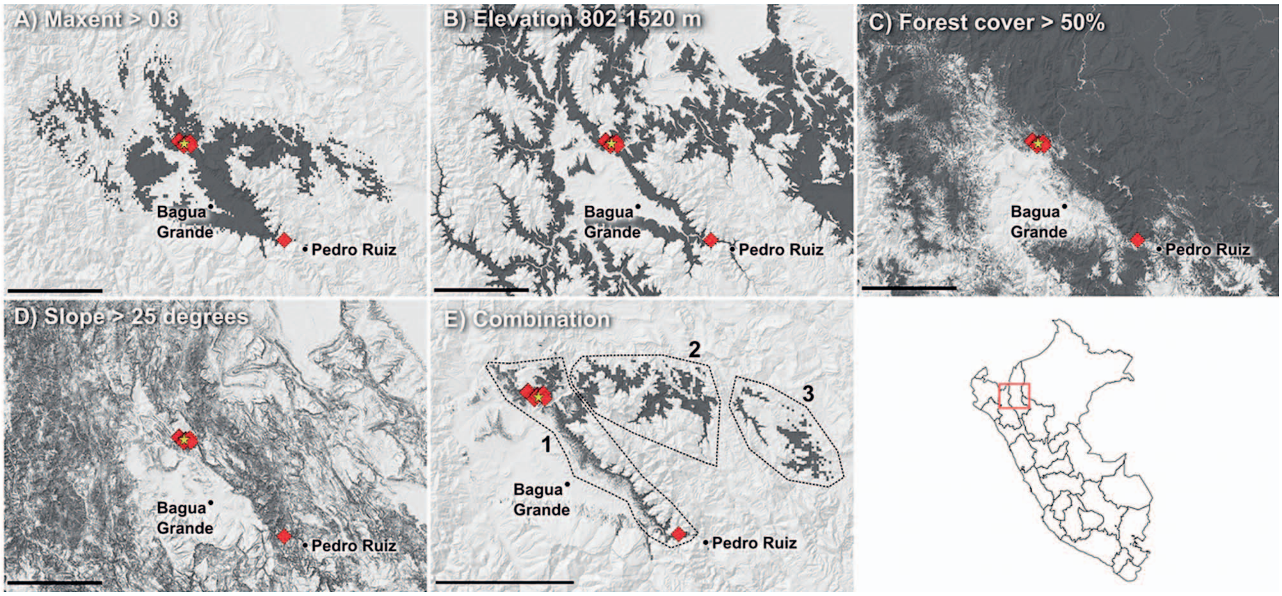


Figure 2. Binary data layers for *Excidobates mysteriosus* habitat modeling. In panels A–E, suitable habitat shown in dark grey. (A) Suitable climate modeled with Maxent (prediction probability > 80%), (B) Suitable elevation (elevation 802–1520 m above sea level), (C) Suitable forest cover (forest cover > 50%), (D) Suitable slope (slope > 25°), (E) Combination of suitable climate, elevation, and habitat type. Polygons represent the three general areas discussed in the text: (1) Main "corridor" throughout which *E. mysteriosus* is highly likely to be distributed; expanded detail shown in Figure 3; (2) Northern versant of the Cordillera de Colan, occurrence status unknown; (3) Alto Mayo, occurrence status doubtful. We note that area 1 (main corridor) was drawn to approximate a minimum convex polygon surrounding the known localities and that there is no geographical barrier between areas 1 and 2. Black scale bar in each panel = 50 km; red polygons indicate occurrence records; yellow star indicates the type locality.

(Fig. 2A). As the ENM predicted habitats far outside the apparent elevational range of *E. mysteriosus,* we refined this prediction by determining the observed elevational range of *E. mysteriosus* and excluding habitats well outside this range. To do this, we used the Japan Aerospace Exploration Agency (JAXA) ALOS digital surface model (DSM) to extract elevation data from the occurrence records, resulting in an observed elevational range of 902–1420 m above sea level. We used a 100 m +/- buffer around this range to define a suitable elevation window for this species of 802–1520 m (Fig. 2B). We identified forest habitat using the Global Forest Change dataset (Hansen et al. 2013); habitat was deemed suitable if a grid cell indicated > 50% forest cover, which corresponds to the lower values of forest cover seen in the known forest sites (Fig. 2C). To identify potential rock-wall habitats, we calculated a slope raster from the DSM and defined potentially suitable rock-wall habitats as slope of > 25° (Fig. 2D). The final model was calculated from areas of suitable climate and elevation, where either percent forest cover or slope was also suitable (i.e., deforested, high-slope habitats would be included) (Fig. 2E). All GIS work was done in QGIS version 3.2 (QGIS Development Team, 2019).

Our results indicate that there is a continuous corridor of suitable habitat extending between the type locality and the new locality presented here (Fig. 2E, area 1). Given that the corridor has occurrence records at either end, it is highly likely that *E. mysteriosus* occurs (or occurred historically) throughout this range. Other areas of suitable habitat include the northern versant of the Cordillera de Colan (Fig. 2E, area 2) and the Alto Mayo (Fig. 2E, area 3). The Cordillera de Colan area has been poorly surveyed,

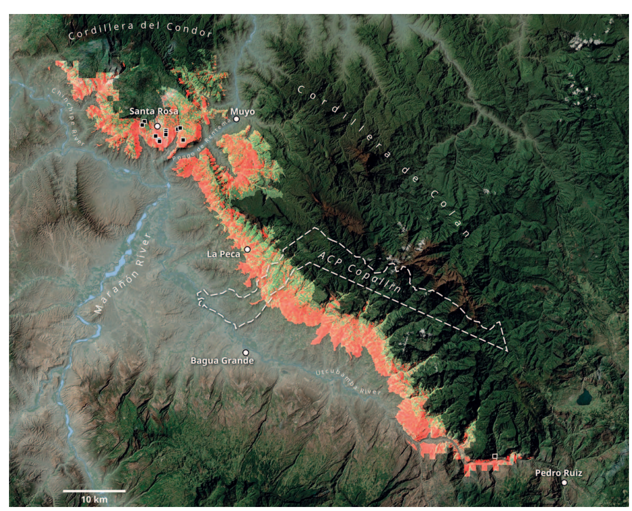


Figure 3. Deforestation of the habitat corridor of *Excidobates mysteriosus*. Suitable habitat is highlighted; areas within this with < 50% forest cover are highlighted in red. Dashed white polygon shows boundary of Área de Conservación Privada Copallin (ACP Copallin). This map shows roughly the same area depicted by the red box on the overview map in Figure 2.

and it is unknown if *E. mysteriosus* occurs here. This area has experienced no appreciable deforestation, being remote and inaccessible (i.e., no roads or navigable rivers exist in this area) and determining whether *E. mysteriosus* occurs here should be a conservation priority as it would represent a large area of undisturbed habitat. The Alto Mayo area has been relatively well surveyed and thus far no *E. mysteriosus* have been found in this area. Additional habitat southwest from the type locality as well as the slopes south of Bagua Grande were found to have a suitable climate and elevation (Fig. 2A), but lacked forest cover and/or suitable slope and are therefore unlikely to represent viable habitat.

Under the assumption that *E. mysteriosus* is restricted to the habitat corridor between the type locality and Pedro Ruiz (Fig. 2E, area 1; Fig. 3), we calculate the extent of occurrence to be 623 $km^2$. Of this, 268 $km^2$ (43%) has forest cover < 50% (Fig. 3, pink shaded area). Given that this corridor is characterized by forested areas interdigitated with deforested agricultural plots, which are clearly visible from satellite images, low forest cover in this area is unlikely to be natural and therefore represents deforestation. However, of this low forest cover habitat, a significant fraction (59 $km^2$, 22%) occurs in high-slope situations and thus may still represent viable habitat. Overall, tallying the forested habitats along with the potential rock-wall habitats (i.e., low forest cover, high slope) brings the total estimated extent of occurrence within the core habitat corridor to 414 $km^2$. This estimate is substantially less than the extent of occurrence currently listed by the IUCN (717 $km^2$), but would maintain the current classification of *E. mysteriosus* as Endangered (EN) B1ab(iii), satisfying the following criteria (version 3.1): extent of occurrence < 5,000 $km^2$, severely fragmented or known to exist at no more than five locations, and continuing decline in the extent and/or quality of habitat. In terms of habitat protection, a small fragment of the main habitat corridor occurs within the Área de Conservación Privada Copallin (ACP Copallin) (Fig. 3); this area should be surveyed for *E. mysteriosus* populations and, if present, may represent a focal point for conservation of this species. Overall, conservation priorities for *E. mysteriosus* include (1) additional surveys within the habitat corridor (e.g., near La Peca) to determine whether *E. mysteriosus* has a continuous distribution through this area and occurs within the ACP Copallin, (2) surveys along the north slope of the Cordillera de Colan to determine the presence/absence of *E. mysteriosus* in this region, and (3) expanding the extent of protected habitat along the main habitat corridor between the type locality and the Pedro Ruiz locality.

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