DISTRIBUTION OF THE BAT FAMILY MORMOOPIDAE IN HONDURAS

DISTRIBUCIÓN DE LA FAMILIA MORMOOPIDAE EN HONDURAS

David Josué Mejía-Quintanilla[1,2,3]| Jonathan Hernández[3]| Hermes Vega[4]| Leonel Marineros[2]|Manuel Spinolla-Parallada[1]| Bernal Rodríguez[5]| Fiona Reid[6]| Mónica Farrera[1,7,8]| Arnulfo Medina[9]| Alberto Mejía-Paniagua[10] | Fausto Elvir-Valle[1]

[1] Instituto de Conservación y Manejo de Vida Silvestre (ICOMVIS), Universidad Nacional, Heredia, Costa Rica.

[2]Fundación en Ciencias para el Estudio y Conservación de la Biodiversidad (INCEBIO), Tegucigalpa, Honduras.

[3]Programa de Conservación de los Murciélagos en Honduras (PCMH), Tegucigalpa, Honduras

[4]Mancomunidades del Parque Nacional Celaque (MAPANCE), Gracias, Lempira.

[5]Escuela de Biología, Universidad de Costa Rica, San José, Costa Rica.

[6] Mammalogy Department, Royal Ontario Museum, Toronto, Canada.

[7]Instituto de Ecología, Universidad Nacional Autónoma de México, Ciudad de México, México.

[8]Animal Karma AC, Cuernavaca, México

[9]Asociación Mastozoológica de Nicaragua (AMAN), Managua, Nicaragua.

[10]Instituto Latino Americano de Ciências da Vida e da Naturaleza, Universidade Federal da Integração Latino-Americana, Foz do Iguaçu, Paraná, Brasil.

Abstract

Honduras is the second country in central America along with Panamá with the greatest bat diversity, and the insectivorous bats are the most diverse in the Chiroptera order. The family Mormoopidae has the largest number of records in Honduras and these bats are important as pest control in crops where they are present. To understand the importance of the Mormoopidae family in Honduras, we need to know where it is distributed. A species distribution model is a tool that provides information on the distribution of the species, based on presences records and climate variables. We collected information from free access databases like GBIF, reports, and paper publication to obtain presence data in Honduras. To run the models, we used Maxent in dismo package. Our results show a similar distribution for all species of Mormoopidae family, the principal causes that limited the distribution of the

Relevancia

Este estudio destaca la importancia de conocer la distribución de las especies de murciélagos mormoópidos en Honduras para protegerlas y conservarlas, en este caso, a través del uso de modelos de distribución potencial.

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Autor de correspondencia: David Mejía, davidmejia93@hotmail.es

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species are ecosystem type and altitude; some species tolerated evergreen forest and others prefer dry forest, in terms of elevation, in some species is limited from lowland to 1500 m.a.s.l., like *Mormoops megalophylla, Pteronotus psilotis*, and *Pteronotus gymnonotus*, and others can inhabit above 2800 m.a.s.l., like *Pteronotus fulvus*, and *Pteronotus mesoamericanus*. We need to obtain more records of species like *M. megalophylla, P. psilotis*, and *P. gymnonotus*. More surveys in the eastern part of Honduras are necessary where there are many information gaps, this would help us to have more robust models and a better understanding of the distribution of these species.

Palabras clave: biogeography, *Mormoops*, *Pteronotus*, species distribution model, suitability habitat.

RESUMEN

Honduras es el segundo país de Centroamérica junto a Panamá con la mayor diversidad de murciélagos, y los murciélagos insectívoros son los más diversos dentro del orden Chiroptera. La familia Mormoopidae es la que presenta una mayor cantidad de registros en Honduras y estos murciélagos son importantes por su rol como controladores de plagas en los cultivos donde están presentes. Para entender la importancia de los mormóopidos en Honduras debemos saber dónde están distribuidos. Los modelos de distribución de especies son una herramienta importante que provee información acerca de la distribución de especies basados en datos de presencia y variables climáticas. En este estudio recolectamos información de bases de datos de libre acceso como GBIF, reportes y publicaciones para obtener datos de presencia en Honduras. Para correr los modelos usamos Maxent dentro del paquete dismo. Nuestros resultados muestran una distribución similar para todas las especies de familia Mormoopidae, las principales causas de limitación en la distribución fueron los tipos de ecosistemas y la altitud; algunas especies toleran los bosques siempre verdes y otros prefieren los bosques secos, en cuanto a la elevación, algunas especies están limitadas desde tierras bajas hasta los 1500 m.s.n.m., como *Mormoops megalophylla*, *Pteronotus psilotis* y *Pteronotus gymnonotus*, y otras pueden habitar arriba de los 2800 m.s.n.m. como *Pteronotus fulvus* y *Pteronotus mesoamericanus*. Necesitamos obtener más registros de especies como *M. megalophylla, P. psilotis* y *P. gymnonotus*. Es necesario realizar más muestreos en el este de Honduras donde existen vacíos de información, para así tener modelos más robustos y mejorar el entendimiento de estas especies.

Palabras clave: biogeografía, hábitat idóneo, modelos de distribución de especies, *Mormoops*, *Pteronotus.*

INTRODUCTION

Honduras and Panama, together, are considered the second countries in Central America with the greatest bat diversity, since for both countries has been reported 113 species (Garbino *et al.*, 2022; Turcios-Casco *et al.*, 2020). The research about bats in Honduras is poorly (Mora, 2016), but some research has been done, from which we can mention Godwin (1942), Marineros and Martínez (1998), Portillo (2007), and the most current by Turcios-Casco *et al.*, (2020). In general, the distribution of bats is poorly known in the country. Reid (2009) made a regional distribution of bats in Central America, but for a more detailed scale, the maps are not accurate enough.

The Species Distribution Models (SDM) are a tool that may allow us to know the distribution of a species based on climate, land cover, and other variables that affect its distribution patterns. This tool can be used to plan conservation programs or find a new population of rare species (Kumar and Stohlgren, 2009), although they must be applied critically and cautiously (Loiselle *et al.*, 2002), because sometimes there is no data of true absence (Pearce and Boyce, 2006). To model the distribution of the species we required information about the presence of the species and environmental conditions available in the area (Elith and Leathwick, 2009; Mackenzie and Royle, 2005). SDM are used to address questions about the conservation biology of the species, ecology, and evolution (Guisan and Thuiller, 2005). Also, it allows us to know about the potential response of a species in a climate change scenario (Pearson and Dowson, 2003; Randin *et al.*, 2009). Some variables that affect the distribution patterns cannot be measured by the scale of the study, for example, the dispersal capabilities of the species, its body size, evolutionary age, etc. (Procheş, 2005), because we do not have this information and it's very hard to determine for every single population.

About the sample size, Wisz *et al.*, (2008) mention that unfortunately for many taxa and regions there is little information, so it is essential to quantify the sensitivity of the models to sample size. In general, as the sample size decreases, the accuracy of the model decreases and the variability increases, but the *Maxent* model is less sensitive to small sample sizes, thus, has good predictive power across different sample sizes, which could provide us with exploratory modeling. We must keep in mind that many species have few records, and the interpretation of the models must take this into account. Also, species with few records can provide us information on the distribution of rare species, and the researcher should check for the presence of those species in locations where they have not yet been recorded (Hanberry *et al.*, 2012).

Bat diversity is related to factors like weather and water availability, then, climate models can predict very well the presence of bat species (Cooper-Bohannon *et al.*, 2016; McCain, 2007). With the help of SDM, we can determine the bats' preferences of habitat and indicate which species are endangered (Goodman *et al.*, 2005). Insectivorous bats play the role of regulators of the insect populations, from the human perspective, they provide control of pest and disease-causing species service (Boyle *et al.*, 2011). Mormoopid bats are considered rapid and agile flyers, they use these skills to hunt prey in the air. They are considered insectivorous (Reid, 2009), but Rolfe *et al.*, (2011;2014) found that some species of *Pteronotus* from Puerto Rico can eat arthropods like spiders. The species of this family prefer to sleep in large and humid caves (Reid, 2009; Rezsutek and Cameron, 1993), some species like *P. psilotis* and *P. fulvus* can inhabit mines (de la Torre and Medellin, 2010). Among insectivorous bats, the Mormoopidae family has relatively many records in Honduras, but not all information has been processed (Mejía-Quintanilla, 2017). This family in the country is composed by two genera and five species: *Mormoops megalophylla*, and in the *Pteronotus* genera; *P. fulvus, P. mesoamericanus, P. psilotis*, and *P. gymnonotus* (Turcios-Casco *et al.*, 2020).

It is worth mentioning that Arias-Aguilar and Ramos-Pereira 2022 mention that it is suggested that the occurrence of *P. fulvus* and *P. davyi* is sympatric in Costa Rica, but there is a lack of data to know the distribution of *P. davyi* in the rest of Central America. For the purposes of this research, we will take into account what has been published by Pavan and Marroig (2016; 2017) where we only consider *P. fulvus* for Honduras, but will be attentive to changes in the distribution of *P. davyi,* because according to Pavan *et al.*, (2021), this species has a disjunctive distribution in Central America reaching as far northwest as Nicaragua, which opens the possibility that it is present on the Pacific slope of Honduras and El Salvador. In this study, we set out to determine the distribution of the species of the family Mormoopidae in Honduras.

METHODS

This research focused in Honduras, this country is located in a latitude between 13°N and 16°N, and has 112,492 km^2 of territorial extension (Agulla-Menoni, 2007). It is a very mountainous country with an irregular topography (Mejía-Quintanilla, 2017). The principal land use is the forest with an extension of 65,983 km^2, and the anthropic land use (crops, cities, hamlets, and others) has an extension of 46,509 km^2 (ICF, 2018). Portillo (2007) reported 9 life zones according to Holdridge classification, in 1985 Wilson and Meyer proposed the montane rain forest but it has never been considered as part of this classification system.

We revised the museum database in the GBIF platform for the presence record search using the following search terms: species of interest, Honduras, only records with valid coordinates, museum platform records and research-grade *iNaturalist* records (GBIF.org, 2022). We revise all the databases of the *Bat Conservation Program* in Honduras, records provided by the authors of this paper, projects reports (free access), and published papers.

To make the SDM, we used the statistical package dismo in R, with the *Maxent* function (Hijmans *et al.*, 2020). We used 19 bioclimatic variables available in Wordclim.org (Table 1). We combined the presence records of the five species with the bioclimatic variables in order to make the prediction and generate the SDM. The configuration used to run the model by species was: 80% of the included records for training and 20% for testing the model, and a background of

Table 1. Bioclimatic variables (WorldClim)

BIO1 = Annual Mean Temperature
BIO2 = Mean Diurnal Range (Mean of monthly (max temp - min temp))
BIO3 = Isothermality (BIO2/BIO7) (×100)
BIO4 = Temperature Seasonality (standard deviation ×100)
BIO5 = Max Temperature of Warmest Month
BIO6 = Min Temperature of Coldest Month
BIO7 = Temperature Annual Range (BIO5-BIO6)
BIO8 = Mean Temperature of Wettest Quarter
BIO9 = Mean Temperature of Driest Quarter
BIO10 = Mean Temperature of Warmest Quarter
BIO11 = Mean Temperature of Coldest Quarter
BIO12 = Annual Precipitation
BIO13 = Precipitation of Wettest Month
BIO14 = Precipitation of Driest Month
BIO15 = Precipitation Seasonality (Coefficient of Variation)
BIO16 = Precipitation of Wettest Quarter
BIO17 = Precipitation of Driest Quarter
BIO18 = Precipitation of Warmest Quarter
BIO19 = Precipitation of Coldest Quarter

This scheme follows that of ANUCLIM, except that for temperature seasonality the standard deviation was used because a coefficient of variation does not make sense with temperatures between -1 and 1).

10000 random replications (Ferraz *et al.*, 2012). Model performance was assessed by o mission and predicted area for species and area under the curve (AUC) value based on the sensitivity (omission rate) versus specificity (fractional predicted area) of the response between occurrence data and predictors, incorporating probability as a null model (Calabrese *et al.*, 2014; Pearson, 2007; Torres *et al.*, 2012).

To finish, based on the SDM and those variables that most contributed to the model, literature about the regional distribution for each species, and taking account of expert criteria about distribution of the species in local scale, we proposed a current distribution for each species in Honduras. To obtain the ecosystems in which the species are distributed, the distribution of bats was overlapped with the 2018 forest cover maps (ICF, 2018).

Results

We obtained records for all Mormoopidae species in Honduras. For *M. megalophylla* we obtained 21 records, *P. fulvus* obtained 64 records, *P. gymnonotus* obtained 22 records, *P. mesoamericanus* obtained 73 records and *P. psilotis* obtained 22 records.

1.1. *Mormoops megalophylla*

To assess the model, we used 17 training data to fit the model and 5 records to test data. The omission curve shows that the prediction is acceptable since the data is near to omission on training samples. The AUC was 0.876, this indicates the model has a good prediction and it is better than a null model. Variables that most contributed to the prediction of the distribution were isothermality with a value of 40.4%, annual precipitation with a value of 11.7%, the temperature seasonality with a value of 11.5% and, precipitation of warmest quarter with a value of 10.6%.

Species distribution model (Figure 1) for *M. megalophylla* shows that the most likely to find this species are the lowlands of both slopes. In the honduran Moskitia this species has low probability to be found, but the south of this region has habitat suitability. Valle de Sula and Valle de Aguán are sites with a high probability of presence for this species. In the middle and west of Honduras, the dry lowland and pine forest have a high probability of presence. Some areas up to 1500 m.a.s.l. in west Honduras like Parque Nacional Celaque and the high mountains of Ocotepeque have a high probability presence for this species. In south Honduras, Choluteca and Valle departments are sites with a high probability of presence in the dry forest, mainly in the mangrove in coastal areas and in some cloudy forest of San Marco de Colón.

Based on the SDM, *M. megalophylla* is distributed in all Honduras (Figure 2), in elevations between 0 to 2800 m.a.s.l. in Parque Nacional Celaque. It is widely distributed in the Olancho department and the west of Honduras (Ocotepeque, Copan, and Santa Bárbara departments). The main forests where it is distributed are dry lowland and very dry forest, pine and pine-oak forest, some evergreen forest in the caribbean slope, and some cloudy forest in the west of Honduras.

1.2. *Pteronotus fulvus*

The model for *P. fulvus* was fitted with 49 training data and 15 data were used as test data. The omission curve shows that the model has a very good prediction, and the AUC value was 0.848, this indicates the model is better than a null model and the SDM predicts very well the distribution of the species. Variables that most contributed to the prediction were precipitation seasonality with a value of 24.2%, maximum temperature of warmest month with a value of 12.99%, temperature seasonality with a value of 11.9% and, mean diurnal range with a value of 10.9%.

The model for *P. fulvus* predicts that pine forest, cloud forest, and mixed forest are suitable for the presence of this species (Figure 3). The probability for its presence is low in the evergreen forest. *P. fulvus* prefers to inhabit above the 500 m.a.s.l. but we can find it from lowland to 2000 m.a.s.l. The principal distribution area is middle-west Honduras. There is absence in

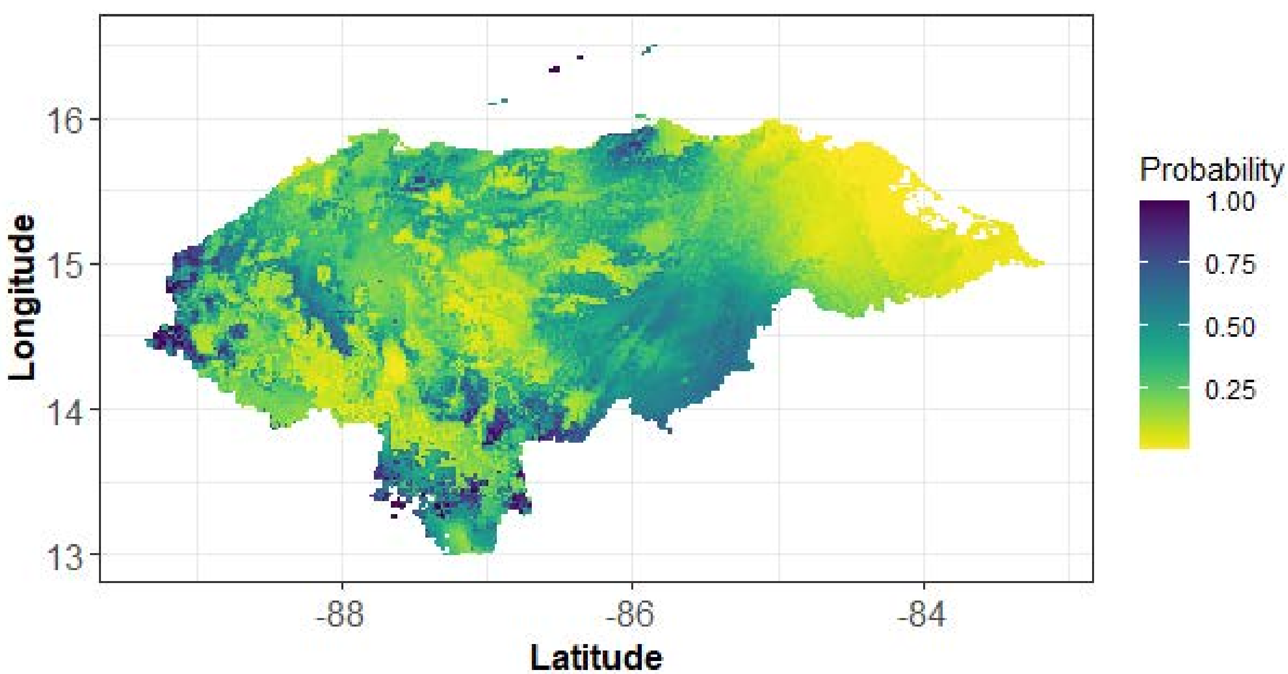

Figure 1. *Mormoops megalophylla* species distribution model to Honduras, Central America.

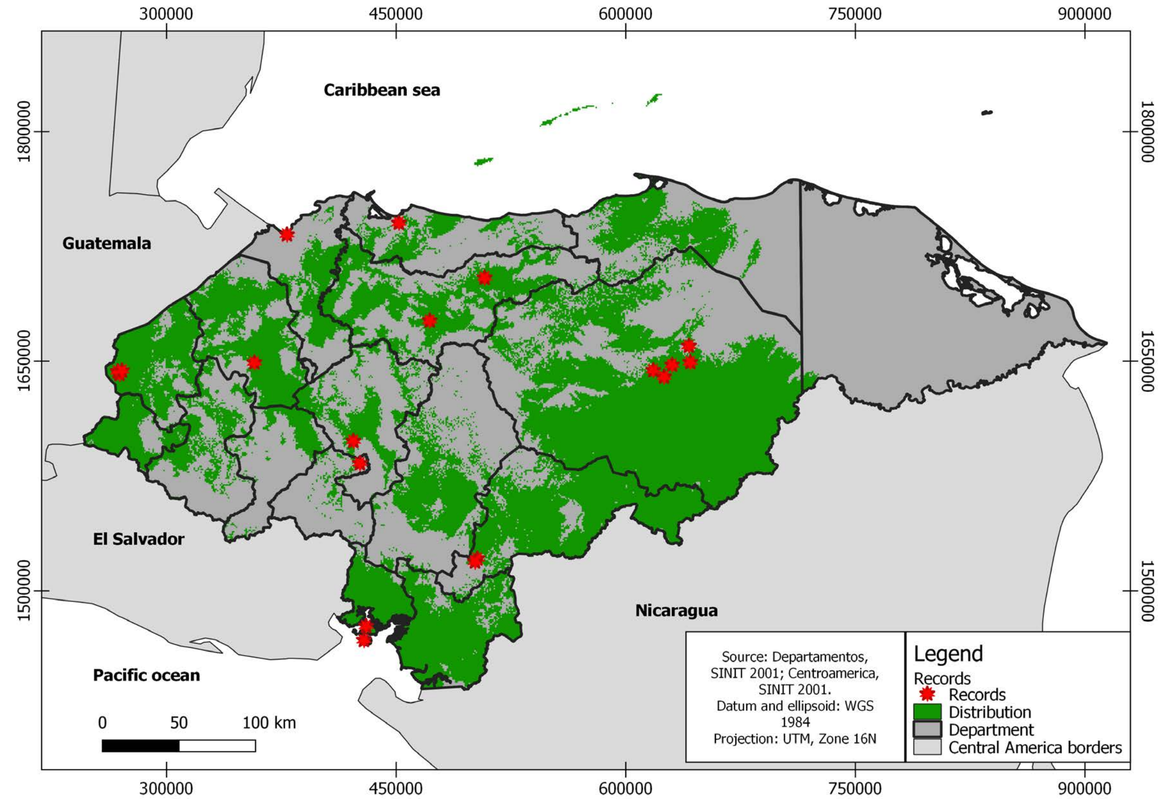

Figure 2. Proposal of the current distribution of *Mormoops megalophylla* to Honduras based on 30% of presence probability of the Species Distribution Model.

Gracias a Dios department, and in the surroundings of the río Segovia and laguna de Karataska, which corresponds to pine savannah, the probability is very low (less than 25%).

Based on the map distribution proposed for *P. fulvus*, we determine this species is widely distributed throughout Honduras except in Gracias a Dios department, because this site does not have the bioclimatic conditions to be inhabited by *P. fulvus* (Figure 4). The distribution for this species includes the dry and very dry forest of Honduras, evergreen forest in the caribbean coast, the island system of Honduras, pine forest, and some high forest on both slopes. The altitudinal range goes from 0 to 2800 m.a.s.l.

1.3. *Pteronotus gymnonotus*

The SDM was fitted with 17 presence data as training data and 5 as test data. The omission curve shows that the model has a good prediction, and the AUC value was 0.827, this model has a good prediction and is better than a null model. The SDM predicts the species has a high probability of presence in dry forests, some evergreen forest in the caribbean coast, and pine forests (Figure 5). The pine savanna ecosystem (eastern Honduras), cloudy forest, and some mixed forest have a low probability for *P. gymnonotus* inhabiting, based on bioclimatic conditions. The variables that most contributed to the prediction of the distribution were precipitation of driest moth with a value of 33.6%, precipitation of wettest quarter with a value of 21.5%, temperature seasonality with a value of 18.6% and isothermality with a value of 13.3%.

We propose that currently *P. gymnonotus* is widely distributed in Honduras, except in Gracias a Dios department. Its distribution extends from lowland to 1500 m.a.s.l. The main ecosystems where dwell are dry forests and evergreen forests on both slopes (Figure 6). This species can inhabit the pine savanna in the Moskitia.

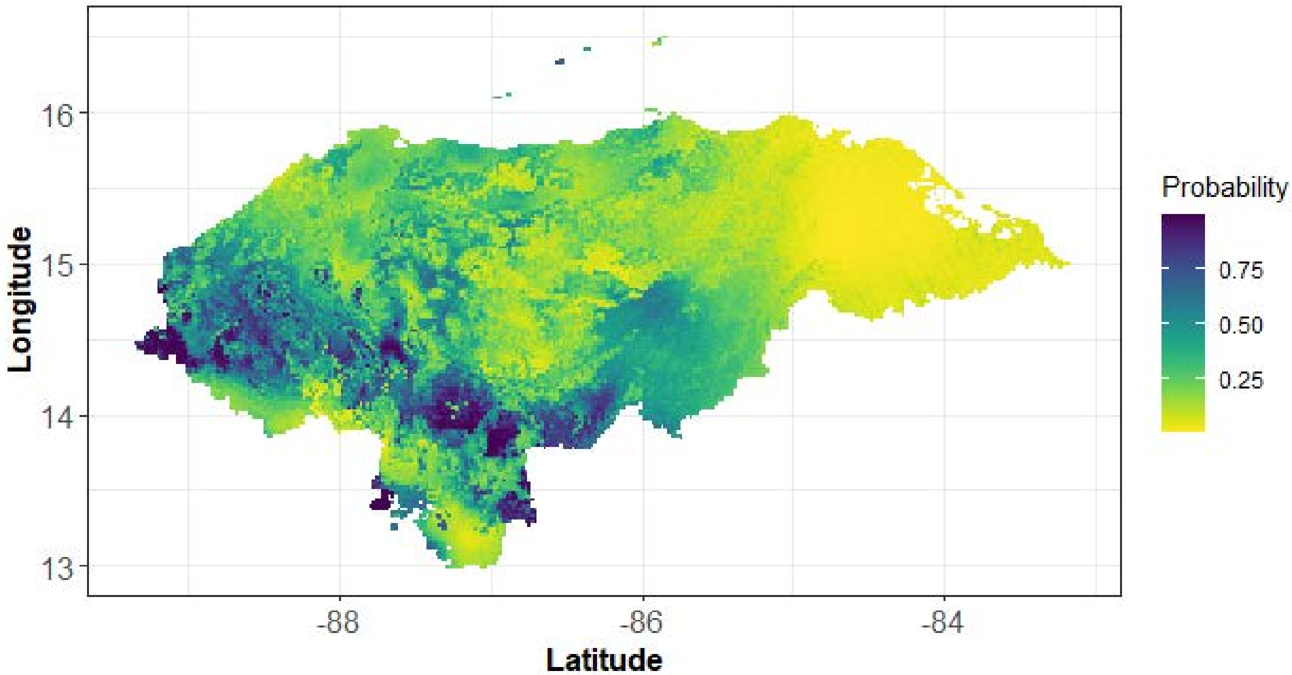

Figure 3. *Pteronotus fulvus* species distribution model to Honduras, Central America.

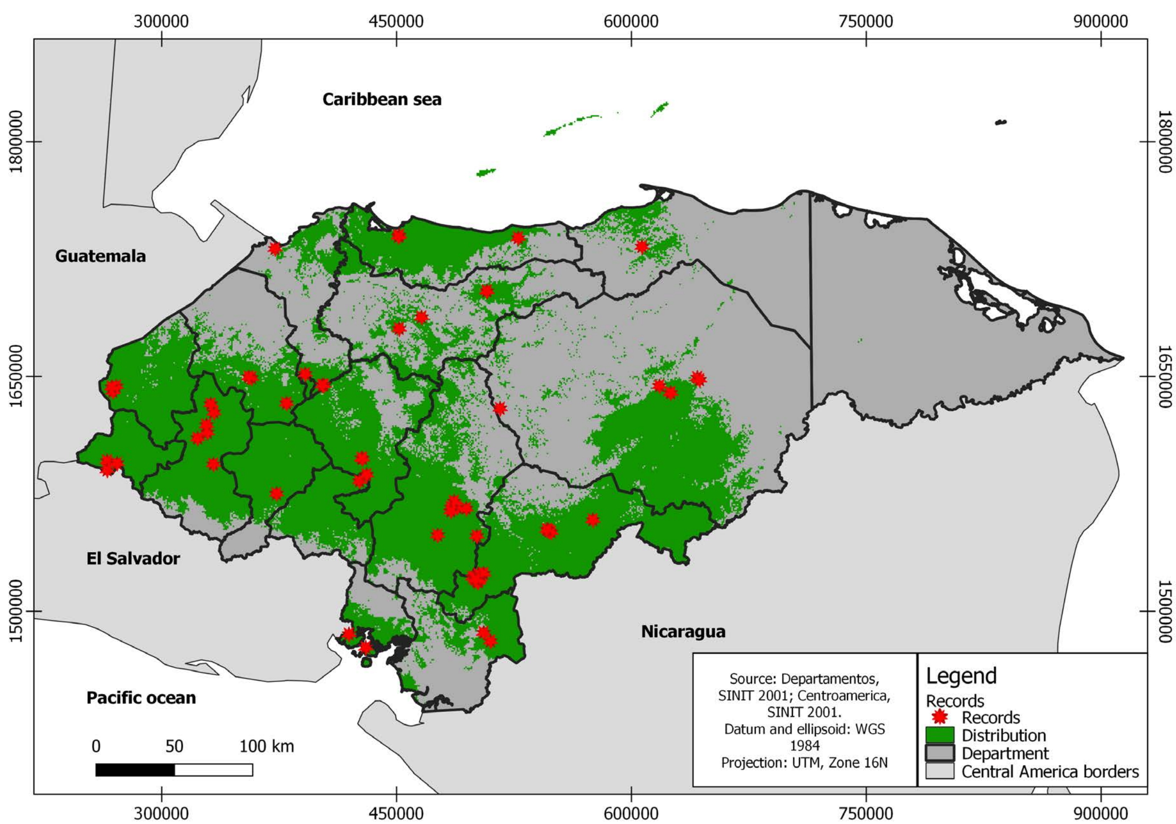

Figure 4. Proposal to the distribution of *Pteronotus fulvus* to Honduras based on 30% of presence probability of the Species Distribution Model.

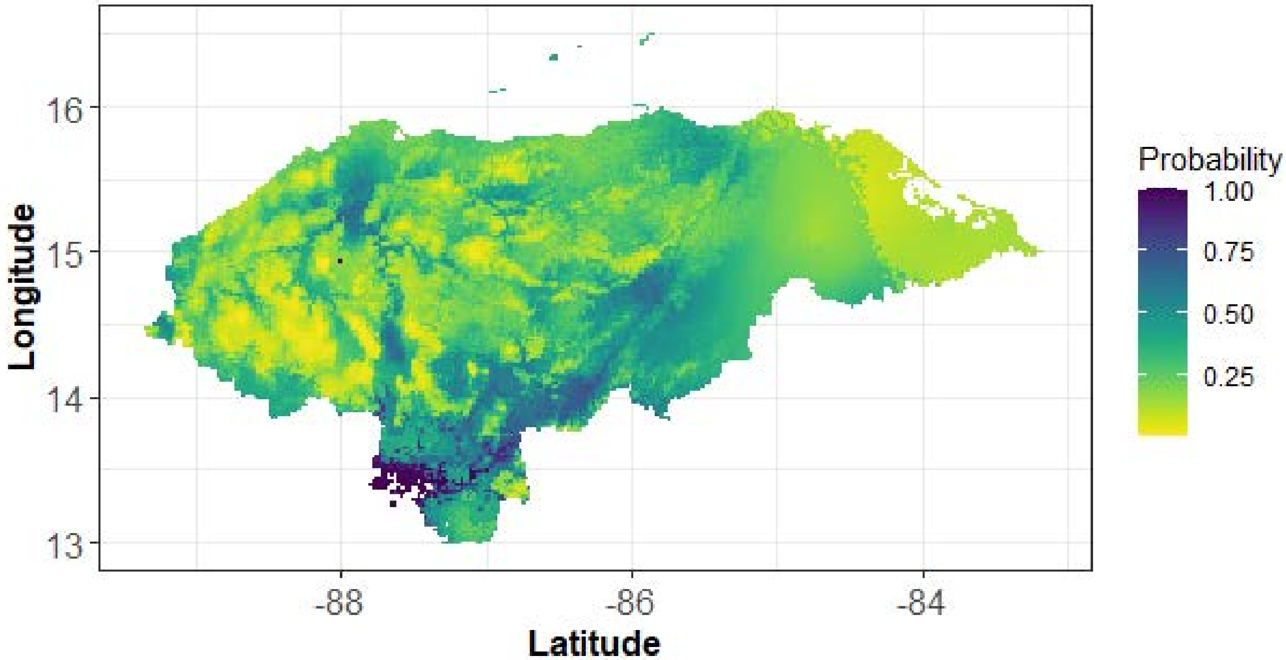

Figure 5. *Pteronotus gymnonotus* species distribution model to Honduras, Central America.

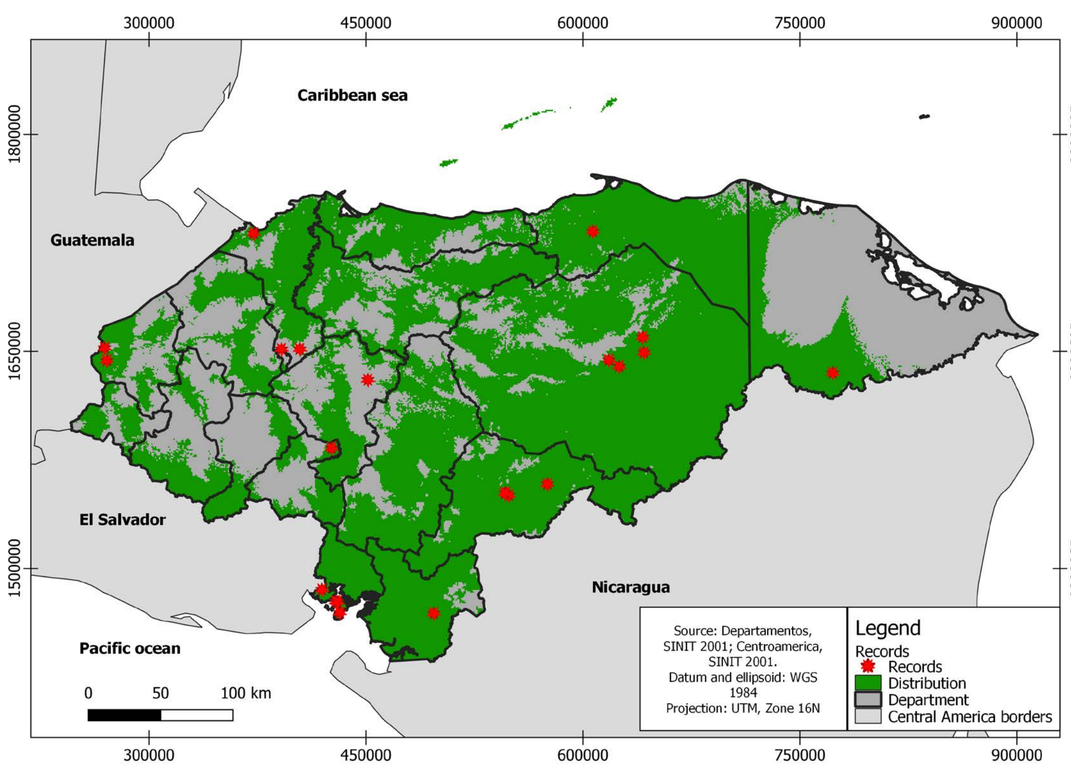

Figure 6. Proposal to the distribution of *Pteronotus gymnonotus* to Honduras based on 30% of presence probability in the Species Distribution Model.

1.4. *Pteronotus mesoamericanus*

The SDM was fitted with 52 training data and 22 test data. The omission curve shows a good prediction because the omission on training data is very near to predicted omission, and the AUC value was 0.838, obtaining a good prediction of the distribution to *P. mesoamericanus* and this model is better than a null model.

The SDM predicts that *P. mesoamericanus* may be present from lowland to 2000 m.a.s.l. in both slopes. Middle Honduras and the pine savanna ecosystem aren't suitable habitats for this species. Based on this model, the species can be found in the lowland caribbean coast (Cortés, Atlántida, Colón, and Gracias a Dios departments), dry and pine forest in the west of Honduras, in dry forest and mangrove forest in Valle and Choluteca departments and the Olancho department (Figure 7). The variables that most contributed to the prediction of the distribution were isometry with a value of 41%, mean diurnal range with a value of 13.8% and, precipitation of wettest month with a value of 11.1%

For *P. mesoamericanus* we propose that it is widely distributed throughout Honduras, this species has been recorded in La Moskitia but just río Segovia and laguna de Karatasta complex present suitable habitat for this species, around evergreen forests (Figure 8). The middle of Honduras does not have the bioclimatic conditions that this species can inhabit. The principal ecosystem where this species is distributed is pine forest, pine-oak forest, dry forest, very dry forest, evergreen forest, and some mountain forests like the cloudy and mixed forest.

1.5. *Pteronotus psilotis*

To fit the SDM, 17 presence data were used as training data and 5 points as test data. The omission curve shows a good prediction of our model. The AUC value was 0.870 which indicates the model is very well fit and is better than a null model. The SDM predicts this species can be found from lowland up to 1300 m.a.s.l. and is widely distributed in Honduras but is absent in the pine savanna ecosystem. The main ecosystem that SDM predicts for the presence of this species are dry forests, pine forests, and pine-oak forests (Figure 9). The variables that most contributed to the prediction of the distribution were isothermality with a value of 48.6% and temperature seasonality with a value of 13.9%.

We proposed that *P. psilotis* is widely distributed in Honduras, the greatest area of its distribution range is found in Olancho, El Paraíso,

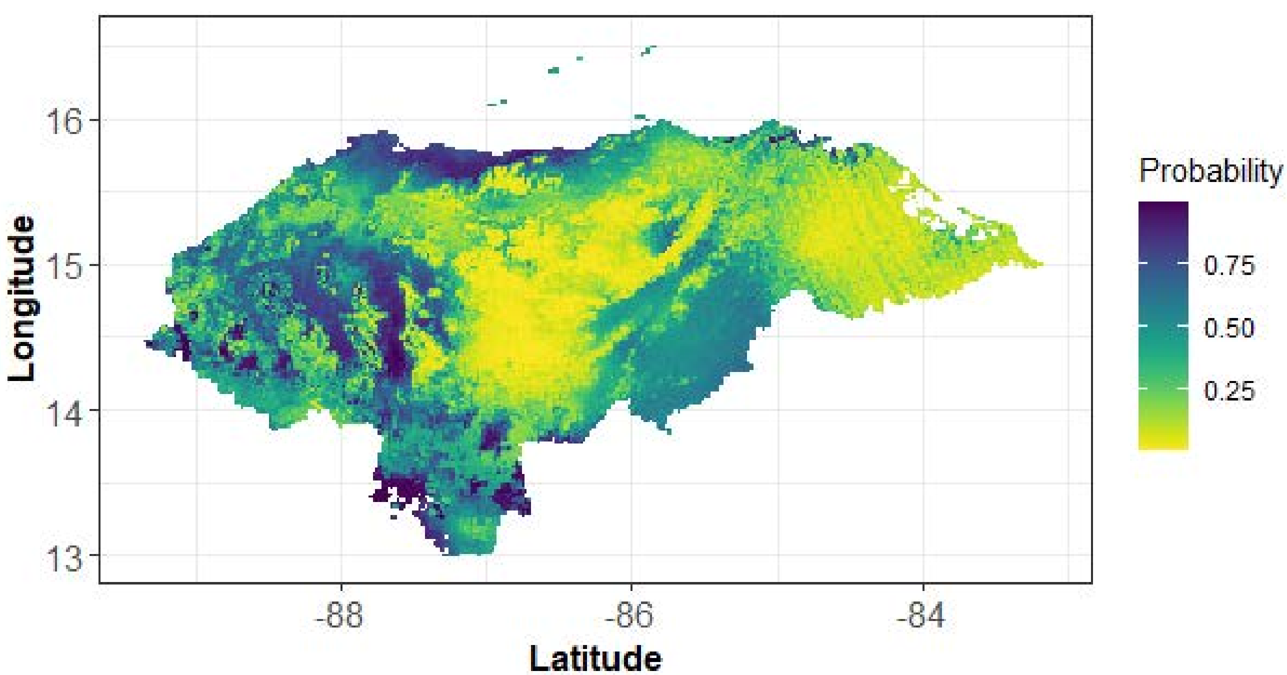

Figure 7. *Pteronotus mesoamericanus* species distribution model to Honduras, Central America.

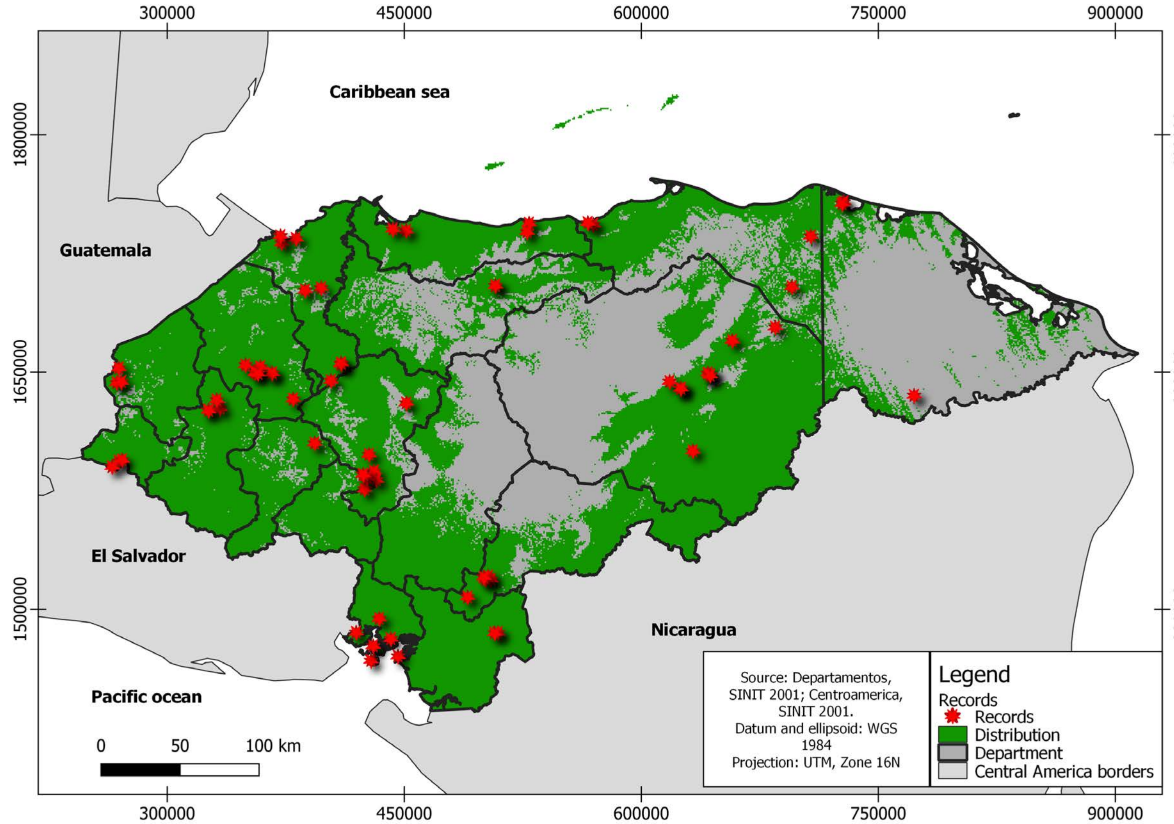

Figure 8. Proposal to the distribution of *Pteronotus mesoamericanus* to Honduras based on 20% of presence probability in the Species Distribution Model.

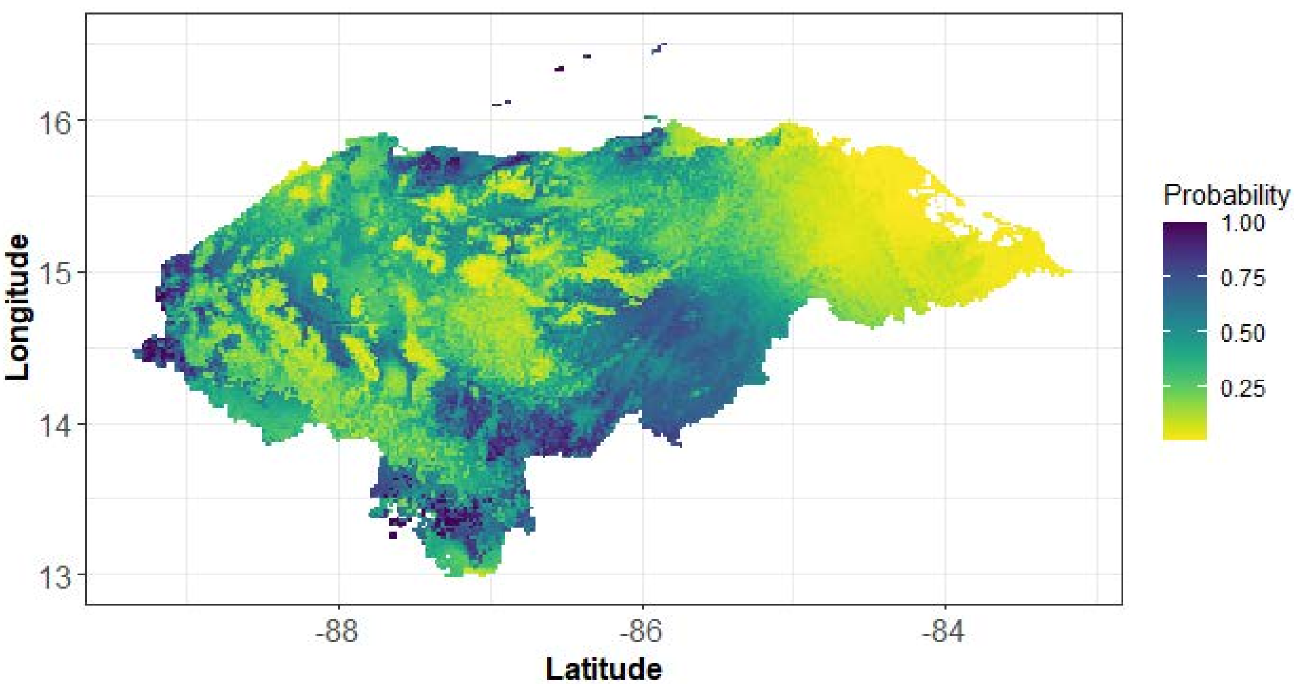

Figure 9. *Pteronotus psilotis* species distribution model to Honduras, Central America.

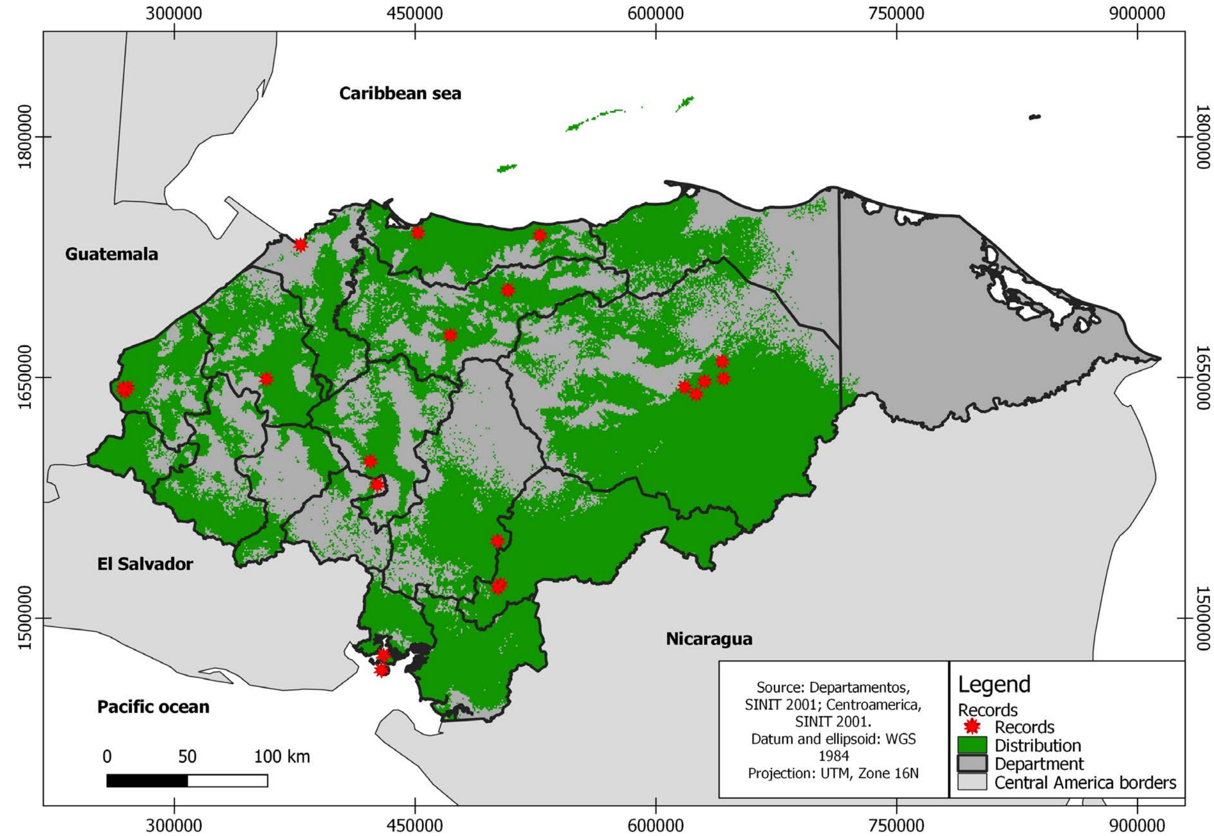

Figure 10. Proposal to the distribution of *Pteronotus psilotis* to Honduras based on 30% of presence probability in the Species Distribution Model.

Choluteca, and Valle departments (Figure 10). The main ecosystems where we can find this species are the dry forests, evergreen forests, pine forests, and pine-oak forests. It is less distributed in west Honduras, in mixed forests and cloudy forests.

Discussion and Conclusion

With respect to bioclimatic variables, isothermality and temperature seasonality were the variables that most contributed to prediction in four of the species studied. Isothermality explains how large the day-to-night temperatures oscillate relative to the summer-to-winter (annual) oscillations, and based on O'Donnell and Ignizio (2012) this is a useful predictor of species distribution. On the other hand, temperature seasonality is a measure of temperature change over the course of the year. Thus, we can say that fluctuations in temperature, either during the day and night or seasonally, are affecting the species of the Mormoopidae family. This could be related to insect activity; Wolbert *et al*., (2014) determined that higher temperature implies an increase in insect biomass, hence, elevating bat activity, but we need more evidence to corroborate this hypothesis for the Mormoopidae family.

We detected sites with low sampling rates like Intibucá, La Paz, Olancho, Colón, and Gracias a Dios departments; it is necessary to carry out more surveys to provide more accurate models for eastern Honduras. *M. megalophylla*, *P. gymnonotus*, and *P. psilotis* were the species with less record in Honduras according to the databases revised. These species are characterized to be rare (Reid, 2009). On the other hand, *P. fulvus* and *P. mesoamericanus* were the species with more records, they are usually more common (Medina-Fitoria, 2014; Reid 2009). The SDM predicts the distribution of these species in zones where the karstic soil is common, in these soils, the caves are very common, and this type of roost is preferred for these species (Mejía-Quintanilla, 2017).

Mormoops megalophylla has a wide presence in Honduras but its distribution is limited by altitude, pine forests and dry forests are some of the ecosystems where we can find it. This species has been recorded between 0 to 1500 m.a.s.l., but the probability to find it above 1500 m.a.s.l. is very high (specifically in the west of Honduras, in Lempira and Ocotepeque departments), indeed, there are records for *M. megalophylla* above 1500 m.a.s.l., for example, Retzutek and Cameron (1993) reported the species up to 3000. ma.s.l. and in Ecuador, Boada *et al.*, (2003) reported it up to 2700 m.a.s.l., but to corroborate the presence of *M. megalophylla* en those altitudes in Honduras we need to carry out more monitoring Absence in Gracias a Dios (honduran Moskitia region: evergreen forests and pine-savanna) agrees with the observation of Medina-Fitoria (2014), who says *M. megalophylla* is absent in nicaraguan Moskitia, however in this part of Honduras we found lack of surveys, despite in the Moskitia there are karstic systems and caves that would be suitable for the species, therefore is needed surveys to determine the true absence in this part of Honduras.

Pteronotus gymnonotus and *P. fulvus* in Honduras are in the dry forests and evergreen forests on both slopes, this coincides with the regional distribution description of Medina-Fitoria (2014) and Reid (2009) for Nicaragua. *P. gymnonotus* is present in evergreen forests, in contrast with *P. fulvus* who is uncommon in this habitat (Reid, 2009). In western Honduras *P. fulvus* and *P. gymnonotus* are distributed in a peculiar way; *P. fulvus* is present from lowland to 2800 m.a.s.l and *P. gymnonotus* is absent in the highland of Lempira, Ocotepeque, and Intibucá departments, but is necessary to corroborate this latitudinal differentiation through with more acoustic sampling in the highlands above 2000 m.a.s.l. However, this does not mean that both species can inhabit the same site, given that Hernandez (2015) recorded both species using the same roost, and Girón-Galvan (2002) in Costa Rica reported the same situation in Parque Nacional Barra Honda.

Pteronotus mesoamericanus and *P. psilotis* have a similar distribution in Honduras, but *P. mesoamericanus* has a widely distribution in the west, while *P. psilotis* has more habitat suitability in the east, without reach the very rainy forests in the Moskitia, Medina-Fitoria (2014) describes this distribution situation for both species, being *P. mesoamericanus* more adaptable to different forests types of the lowlands, while *P. psilotis* has more presence in dry forests. Reid (2009) mentions that *P. psilotis* is common in the south of Honduras, and our models provide a high probability for that region.

This information provides us knowledge about the preferred habitats to mormoopids species, we can affirm that the species that prefer dry forest or pine forest are very endangered because those habitats are the least represented in the national system of protected areas of Honduras (SINAPH, by its acronym in spanish; Mejía-Quintanilla, 2017). To address this, the honduran bat conservation program (PCMH) implements strategies to conserve the habitats and ecosystem services provided by bats, such as the declarations AICOM (Áreas Importantes para la Conservación de Murciélagos, in spanish) and SICOM (Sitios Importantes para la Conservación de Murciélagos).

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