POTENTIAL DISTRIBUTION OF TWO INSECTS WITH GASTRONOMIC VALUE IN MEXICO †

[DISTRIBUCIÓN POTENCIAL DE DOS INSECTOS CON VALOR GASTRONÓMICO EN MÉXICO]

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SUMMARY

Background. Insects constitute the largest group on the planet, with around a million cataloged species. Some species have nutritional value for human beings, being used in various dishes of Mexican cuisine. Estimate the potential distribution of edible insects is required to enhance conservation and harvest practices. **Objective**. To identify the potential areas of occurrence of two insects of gastronomic value: escamoles (*Liometopum apiculatum* Mayr) and chapulines (*Sphenarium purpurascens* Charpentier). **Methodology.** Databases were compiled with the geographical coordinates of the two species and 19 bioclimatic variables were downloaded from Worldclim. Subsequently, the potential geographic distribution was estimated by using a novel technique based on dimensionality reduction analysis. Several indices were calculated to evaluate the model performance. **Results**. The results indicated that the distribution of escamoles in Mexico shows a significant concentration in the central area of the country, as well as in some northern and southern states. The potential distribution of chapulines is restricted to central and southern Mexico. **Implications.** The results reveal that distribution of the species covers most of the regions where they are consumed as food, and other areas that may help in conservation and extraction. Chapulines are more at risk than escamoles due to their reduced habitat. **Conclusion.** The potential distributions differ between species, *L. apiculatum* has a wide distribution in the northern and center of the country, reaching 20% of the total coverage of Mexico; while *S. purpurascens* has a more limited distribution, of only 6%.
Key words: UMAP; ecological niche; entomophagy; habitat; edible insects; gastronomy

RESUMEN

Antecedentes. Los insectos constituyen el grupo más grande del planeta, con alrededor de un millón de especies catalogadas. Algunas especies tienen valor nutricional para los seres humanos y se utilizan en diversos platillos de la cocina mexicana. Estimar la distribución potencial de los insectos comestibles es necesario para mejorar las prácticas de conservación y recolección. **Objetivo.** Identificar las áreas potenciales de ocurrencia de dos insectos de valor gastronómico: escamoles (*Liometopum apiculatum* Mayr) y chapulines (*Sphenarium purpurascens* Charpentier). **Metodología.** Se compilaron bases de datos con las coordenadas geográficas de las dos especies y se descargaron 19 variables bioclimáticas de Worldclim. Posteriormente, se estimó la distribución geográfica potencial utilizando una técnica novedosa basada en el análisis de reducción de dimensionalidad. Se calcularon varios índices para evaluar el rendimiento del modelo. **Resultados.** Los resultados indicaron que la distribución de los escamoles en México muestra una concentración significativa en el área central del país, así como en algunos estados del norte y del sur. La distribución potencial de los chapulines está restringida al centro y sur de México. **Implicaciones.** Los resultados revelan que la distribución de las especies cubre la mayor parte de las regiones donde se consumen como alimento, así como otras áreas que pueden ayudar en la conservación y extracción. Los chapulines están en mayor riesgo que los escamoles debido a su hábitat reducido. **Conclusión.** Las distribuciones potenciales difieren entre las especies; *L.*

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apiculatum tiene una amplia distribución en el norte y centro del país, alcanzando el 20% de la cobertura total de México, mientras que *S. purpurascens* tiene una distribución más limitada, de solo el 6%.
Palabras clave: UMAP; nicho ecológico; entomofagia; hábitat; insectos comestibles; gastronomía.

INTRODUCTION

Insects represent the largest animal group on the planet, with around one million catalogued species (Schnack, 2005). In their relationship with humans, they can be considered harmful or beneficial. Insects are pests when causing damage to crops or domestic animals or by carrying and transmitting pathogens, thus acting as disease vectors, but they can also provide benefits when participating in key ecological actions, for example, in the pollination process. They also have an important role as biological control agents by regulating pest populations, as well as for their nutritional value or for their aesthetic appeal (Gómez, 2006).

Entomophagy is the practice of using insects as a food source for the diet of humans, for example, the consumption of some bees, beetles, and locusts, among others. This practice can become a viable alternative to address the issue of food security in the world. In addition, they may be considered an attractive option because insects are used as exotic ingredients, due to their flavor or novel sensations for adventurous palates. In Mexico, they are used in a diverse menu of dishes (Palacios-Vargas and Navarrete-Heredia, 2003; Viesca González and Romero Contreras, 2009).

Among the edible insects that are listed in the gastronomy of Mexico, escamoles are among the most important. Escamoles are larvae and pupae of ants of the species *Liometopum apiculatum* Mayr (Formicidae: Hymenoptera). They are used to prepare different dishes in tourist regions of central Mexico and have an increasingly high market value (Lara-Juárez *et al*., 2015). Likewise, the chapulines *Sphenarium purpurascens* Charpentier (Pyrgomorphidae: Orthoptera) are highly appreciated in cultures of Oaxaca where they are used in various dishes in the region or as snacks. Though chapulines have been ingested since prehispanic times; currently, they are highly valued in different markets in the country due to the novelty of their taste and the sense of exoticism they represent in gastronomy (Vázquez *et al.*, 2016; Hernández-Ramírez *et al.*, 2020).

The escamoles are considered a unique delicacy in Mexican gastronomy, with a long culinary tradition in various regions of the country. Its delicate flavor and texture have gained recognition both at national and international levels, attracting the attention of chefs and lovers of *haute* cuisine (Lara-Juárez *et al.*, 2015). This species stands out for its versatility in the kitchen and can be prepared in various ways such as tacos, omelettes, soups and stews. Its high gastronomic value has contributed to its conservation and promotion as a gourmet product, which in turn has generated interest in its sustainable management to guarantee its long-term availability (Tovar *et al.*, 2021; Barrios-Morales *et al.*, 2022). These insects have been reported mainly in arid regions of the northern and central states of Mexico (Lara-Juárez *et al*., 2015). Understanding how escamoles are distributed is crucial to implement effective protection measures that guarantee their long-term survival, for example, to identify priority areas for conservation and plan sustainable management strategies that promote their responsibly use and thus help in its conservation (Hipolito-Cruz *et al.*, 2020; Tovar *et al.*, 2021).

As for the chapulines, these insects are rich in proteins and essential nutrients, which makes them a valuable food resource for local communities. In addition, the chapulines play an important role in ecosystems and agro-ecosystems by being food for various species of birds, mammals and reptiles, thus contributing to maintaining the natural balance. Chapulines are an important component in the traditional diet of various indigenous peoples in Mexico and other regions of Latin America. Its consumption not only provides nutrients such as proteins and minerals, but also represents a fundamental part of the cultural and gastronomic identity of these communities. The collection and preparation of chapulines follows ancestral techniques transmitted from generation to generation, which demonstrates its relevance in the culinary and cultural heritage of the region. Furthermore, the chapulines trade, both locally and internationally, contributes to the economy of rural communities and the preservation of ancestral traditions (Leyva-Trinidad *et al.*, 2020; Coronado *et al.*, 2024). This species has a distribution in Morelos, Oaxaca and Guerrero (Ramos-Elorduy, 2006). Therefore, its conservation not only guarantees the availability of traditional and culturally significant food, but also promotes biological diversity and the stability of ecosystems (Ramos-Elorduy, 2006; Makkar *et al.*, 2014). Due to their consumption in different areas of the country, the conservation of chapulines is crucial for food security and protection of biodiversity in the producing and consuming regions of this species.

On the other hand, distribution models represent a technique to estimate the potential habitat of a species in areas that have not been previously investigated (Hernández *et al.*, 2008). Some conservation strategies often use models to guide studies on species distribution (Bourg *et al.*, 2005) and to identify areas of highest conservation priority (Wilson *et al.*, 2005). This approach requires the selection of environmental variables related to each location occupied by the species and to the target area. The purpose is to obtain more precise estimates of the distribution range of the species of interest and define the climatic parameters that characterize them (Phillips *et al.*, 2006). There are different methods used to infer the potential distributions of species and considered valuable tools in the field of biogeography (Phillips and Dudik, 2008). Distribution modeling has become an important tool for analyzing and predicting the distribution of species (Elith *et al.*, 2011).

There are several techniques for modeling species distribution, among the most used is MaxEnt, which applies the principle of maximum entropy to delineate the distribution of species. Recently, Lopez-Collado *et al.* (2024) proposed a new method to estimate species distribution based on a dimensionality reduction technique, UMAP (Uniform Manifold Approximation and Projection). The basis of this method is that, in the reduced dimension, the latent distance between the points of the species and the environment reflects the similarity in the original bioclimatic variables. Comparison of this method with MaxEnt indicated that it has a similar performance.

In Mexico, although some species of insects do not have the relevance as other more widely known species, they have biological, gastronomic, economic or cultural value. In the case of insects with gastronomic importance, escamoles and chapulines comprise some representative species of the culinary diversity based on insects and are important in different regions of this country. For this reason, it is crucial to know their potential distribution, which can help to suggest preservation areas and to propose better management practices of these species. Therefore, the objective was to determine the potential areas of occurrence of the species *L. apiculatum* and *S. purpurascens* based on their bioclimatic features.

MATERIALS AND METHODS

Figure 1 represents the workflow of the operations carried out to estimate the distribution of the target species. Basically, four phases are distinguished: selection of bioclimatic variables (Figure 1A), calculation of proximity probabilities (S) between the environmental and the species points (Figure 1B), calculation of performance indices (Figure 1C) and, finally, the estimated geographical distributions of the target species are presented in the form of maps (Figure 1D). These steps are described in more detail below.

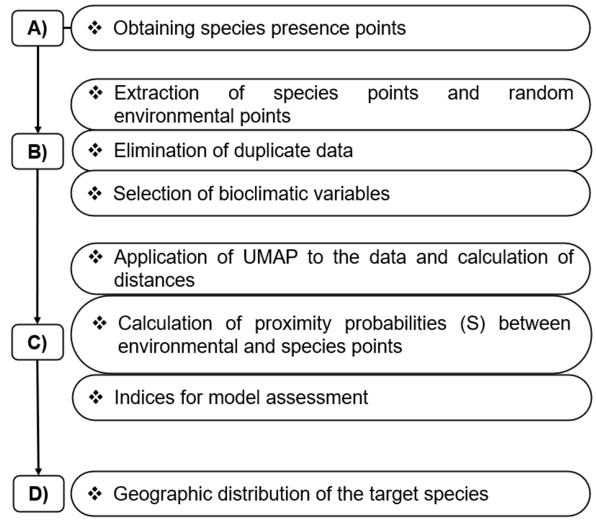

Figure 1. Flow diagram of the activities to carry out the distribution analysis of two edible insect species in Mexico with the UMAP method.

Obtaining the occurrence points of the species

The species information was obtained from gbif.org. A database of the geographical coordinates was created with the presence points of *L. apiculatum* (GBIF.org, 2024a) and *S. purpurascens* (GBIF.org, 2024b) reported for Mexico. The data were subsequently processed to eliminate duplicate and incomplete records.

Bioclimatic database

A total of 19 bioclimatic variables were used (Table 1) with a spatial resolution of 2.5 arc minutes and were obtained from the WorldClim database (Fick and Hijmans, 2017). With the species locations their bioclimatic values were extracted, as well as 10,000 environmental random points for Mexico (background points). These records were verified so that they did not have repeated values. Subsequently, a principal coordinate analysis (PCoA) was carried out with the Hellinger index to observe the groupings of the bioclimatic variables in 2D. A network was also built with the infomap algorithm, grouping the variables by similarity (Rosvall *et al.,* 2009). The analysis used the values of bioclimatic variables, standardized between 0 and 1, associated with the presence records. Both the PCoA and the similarity network were used to select one variable from each group (Rodríguez-Aguilar *et al*., 2023).

Potential distribution modeling based on occurrence records

With the presence records of the two species and the environmental random points of Mexico, the potential distribution was modeled through dimensionality reduction analysis with UMAP (McInnes *et al.*, 2018; Lopez-Collado *et al.*, 2024). This method reduces the dimensions of the bioclimatic variables of both the species and the environmental points. Later, it calculates the latent euclidean distances to the nearest neighbor for species-species and environment-species; the distribution of distances allows establishing a probabilistic value of proximity S, of the environmental points to those of the species, with the closest points being those that have the greatest similarity in the original bioclimatic space (Lopez-Collado *et al.*, 2024). The distribution was estimated using UMAP with the configuration of its hyperparameters defined by the following values: minimum distance of 0.005, setting the number of neighbors to 15 and the number of dimensions set to k= 2. Analyzes were applied with double cross-validation to partitioned training and test data.

Table 1. Bioclimatic variables used for species distribution modeling.

Code	Bioclimatic variables
BIO1	Average Annual Temperature (°C)
BIO2	Average daytime range (max temp - min temp)
BIO3	Isothermality (bio02/bio07) (×100)
BIO4	Temperature seasonality (standard deviation ×100)
BIO5	Maximum temperature of the warmest month (°C)
BIO6	Minimum temperature of the coldest month (°C)
BIO7	Annual Temperature Range (bio05-bio06)
BIO8	Average temperature of the wettest quarter (°C)
BIO9	Average temperature of the driest quarter (°C)
BIO10	Average temperature of the warmest quarter (°C)
BIO11	Average temperature of the coldest quarter (°C)
BIO12	Annual Precipitation (mm)
BIO13	Precipitation of the wettest month (mm)
BIO14	Precipitation of the Driest Month (mm)
BIO15	Seasonality of Precipitation (coefficient of variation, %)
BIO16	Precipitation of the wettest quarter (mm)
BIO17	Precipitation of the Driest Quarter (mm)
BIO18	Precipitation of the warmest quarter (mm)
BIO19	Coldest Quarter Precipitation (mm)

Evaluation of distribution models

To evaluate the models built with UMAP, several indices were calculated, including the area under the curve (AUC), the Kappa, Boyce, TSS indices and a cut-off threshold (Lopez-Collado *et al.*, 2024; Cohen, 1960; Valavi *et al.,* 2022). The calculations were performed with the R v4.4 language (R Core Team, 2024). The performance indices were calculated with the ModEval library (Barbosa *et al.*, 2013). In addition, the mutual information coefficient between the latent distance and the bioclimatic variables was calculated, to estimate their relative importance on the distribution model (Kraskov *et al.*, 2024; Lopez-Collado *et al.*, 2024).

Geographic distribution of bioclimatic similarity between species and their environment

Once the values of probability S were computed for each background point, we select those in the proximity of the species points by applying a cut-off threshold that maximizes the sum of sensitivity and specificity (Liu *et al.*, 2013). The selected points represent the potential species distribution. The maps were made with QGis (QGIS.org, 2024).

RESULTS AND DISCUSSION

Selection of bioclimatic variables

After downloading and cleaning the georeferenced data, preprocessing was performed to select variables that were not correlated. Principal coordinate analysis and clustering generated several groups, depending on the species. Of the 19 bioclimatic variables, one was chosen for each group; the selected variables are found in Table 2 for the two species. The variables BIO01 and BIO12 correspond to the annual average of temperature and precipitation, respectively, while the other variables correspond to seasonal values (hot and cold quarters), and periods of drought and rain. This helps us link the biological phases of the species.

Table 2. Target insect species, and selected bioclimatic variables for distribution modeling[1]

Common and scientific names of edible insects	Bioclimatic variables selected for the respective species
Escamoles (*Liometopum apiculatum)*	BIO01, BIO02, BIO04, BIO12, BIO14, BIO15. BIO18, BIO19
Chapulines (*Sphenarium purpurascens)*	BIO01, BIO03, BIO04, BIO12, BIO14, BIO15

[1]Bioclimatic variables were detailed in table 1.

Analysis of dimension reduction and similarity between species and their environment

Dimensionality reduction with UMAP shows that the points corresponding to the species (red boxes) were in different groups as can be observed in Figure 2 for *L. apiculatum* (Figure 2A) and *S. purpurascens* (Figure 2B). On the other hand, the environmental points (background) were dispersed along the axis space also in different groups. The environmental points closer to the species points have a greater similarity with the values of the species in the original bioclimatic space and therefore have a higher probability S (colored points in Figure 2A and 2B) (López-Collado *et al*., 2024). For both species, similar patterns were obtained, that is, environmental records close to those of the species, indicating similarity and the rest of the points in distant groups.

On the other hand, distant background points are dissimilar to species, these are presented as grey points in Figure 2. Also, the relationship between the latent distance of species and the probability of being close to a point is presented in Figure 3, the dashed line represents the cut-off threshold that limits the bioclimatic similarity between species and background points. In Figure 3, the x-axis represents the nearest neighbor distance between background points, while the vertical axis shows the corresponding probability for both *L. apiculatum* (Figure 3A) and *S. purpurascens* (Figure 3B). The dashed line is the cut-off threshold, which sets the limit of the distribution model, this threshold maximizes the sum of sensitivity and specificity (Liu *et al*., 2013).

The estimated threshold was 0.12 for *L. apiculatum*, while for *S. purpurascens* was 0.14. These values indicate that *L. apiculatum* has a higher probability of inhabiting areas with more diverse conditions, as its lower threshold suggests that it can establish in areas with lower environmental suitability. In contrast, *S. purpurascens* requires more specific conditions to thrive, which is reflected in its slightly higher threshold, indicating a more restricted potential distribution to areas with higher suitability.

Geographic distribution of bioclimatic similarity between the environment and the target species

The geographic representation of the environment-species similarity analysis with UMAP is presented in Figure 4A for escamoles (*L. apiculatum*, red boxes) and the presence points in Figure 4B. In both species, the background points (colored circles) with high probability are closest to the species points (red boxes) and, therefore, also present a high similarity in the bioclimatic space (Figure 4A). This in turn is reflected in the geographic space (Figure 4A) in the regions with bioclimatic similarity. The regions of environmental similarity are located mainly in the central area of

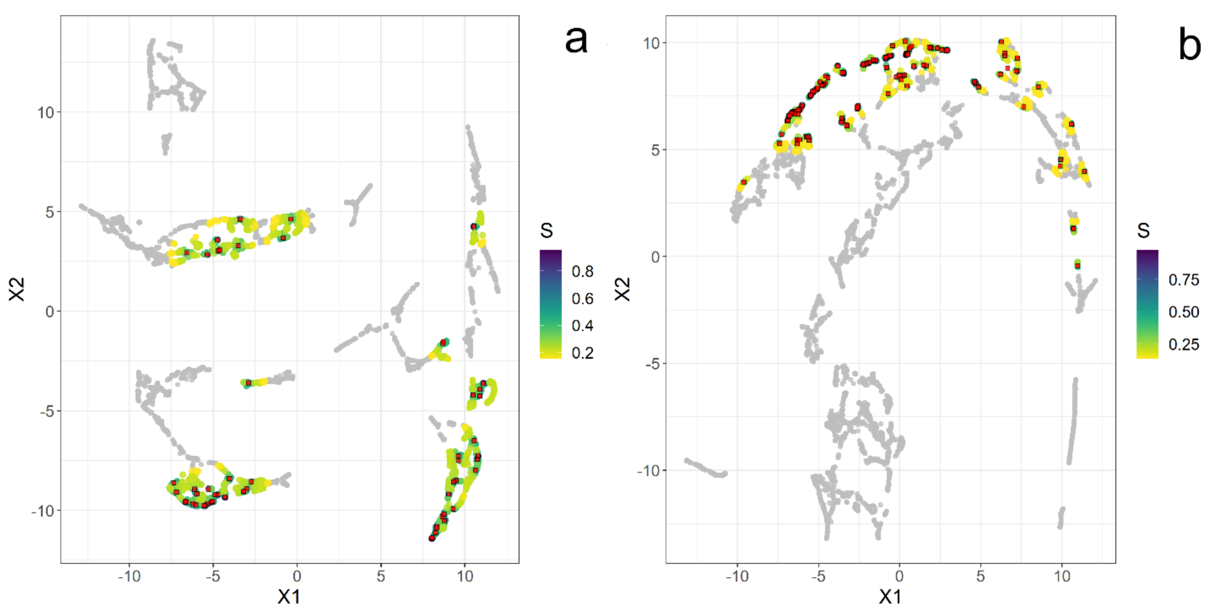

Figure 2. Dimensionality reduction of the environmental bioclimatic variables (background) and of the species presence points. The red squares are records of the species and the circles are environmental values (background) for Mexico. The color scale represents the probability of being near a point of the species. The gray points in the background are below the cut-off threshold of 0.12 for escamoles (*L. apiculatum*) and 0.14 for chapulines (*S. purpurascens*). A) *L. apiculatum*. B) *S. purpurascens*.

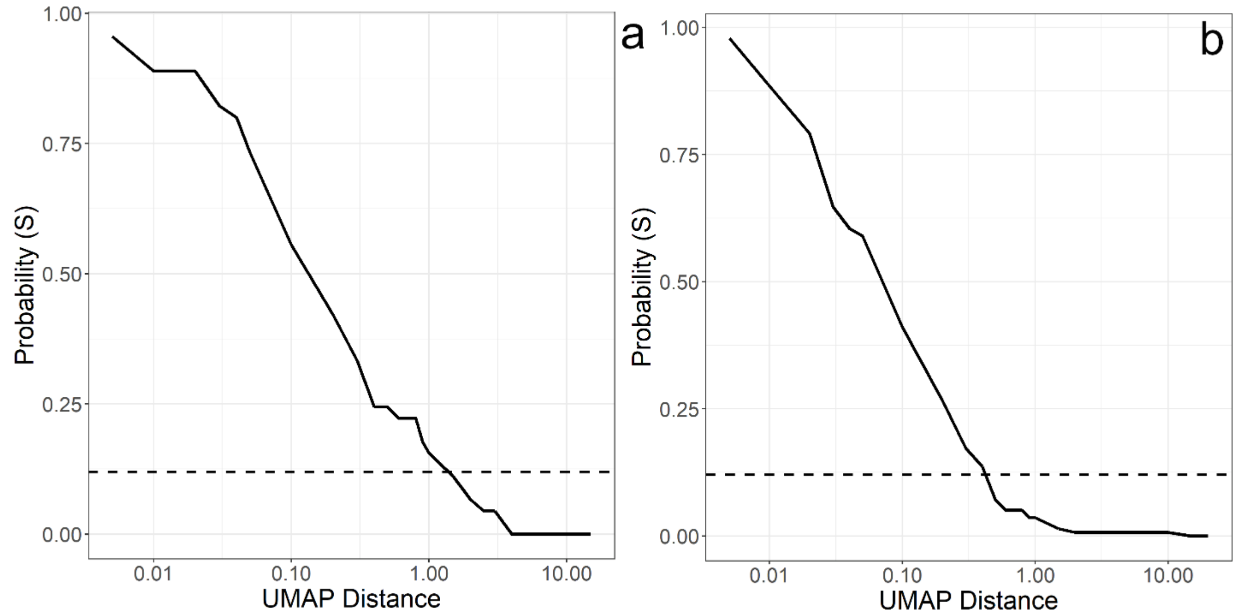

Figure 3. Relationship between UMAP distance and probability of being near a presence point. Dashed line is the cut-off threshold. A) Escamoles (*L. apiculatum*). B) Chapulines (*S. purpurascens*).

Mexico, Aguascalientes, San Luis Potosí, Guanajuato, Querétaro, Hidalgo, State of Mexico, Mexico City, Morelos, Tlaxcala and Puebla. Likewise, in the states of Chihuahua, Coahuila, Durango, Baja California Sur and Zacatecas in the northern part of the country, while for the southern part of Mexico they correspond to some areas of the states of Guerrero, Campeche, Chiapas, Oaxaca and Veracruz. The distribution in the previously mentioned regions correspond to those already reported but are larger than the region where they are used as food (gray areas in Figure 4A) (Lara-Juárez *et al*., 2015). Regarding the potential distribution with favorable environmental conditions, the potential coverage above the cut-off threshold occupies approximately 20% of the national coverage. The points where there is a greater probability of distribution for *L. apiculatum* are those with altitudes ranging from 1,000 masl (Del Toro *et al*., 2009), the average annual rainfall is 707 mm and the average annual temperature is 18.9 ºC, close to those reported by Velasco Corona *et al*., (2007). The distribution agrees with the states where escamoles are reported, that is, the states of Chihuahua, Durango, Michoacán, Colima, Hidalgo, State of Mexico, Federal District and Puebla (Del Toro *et al*., 2009; Alatorre-Bracamontes and Vázquez-Bolaños, 2010).

On the other hand, the observed distribution and potential of the UMAP model of grasshoppers (*S. purpurascens*) is presented in Figure 5. The potential distribution covers areas of the center and south of the country (Figure 5A), the states of Oaxaca, Guerrero, Michoacán, Jalisco, Puebla, Tlaxcala, Hidalgo, Mexico City and the State of Mexico have the greatest distribution in their territory, while the states of Veracruz, Morelos, Chiapas and Tabasco also have some potential areas, in addition to some areas of Nuevo León and Durango (the areas closest to the center of the country). The total percentage corresponding to the potential distribution is 6% of the total for the country.

S. purpurascens seems to be more sensitive to thermal fluctuations throughout the year, which could influence its behavior, phenology and distribution. In places that have an average annual rainfall of 1,000-2,000 mm, an average annual temperature of 20 to 22 °C, and are located at an altitude of 1500 and not more than 2000 meters above sea level (Castellanos-Vargas and Cano-Santana, 2009). The distribution favors the consumption of grasshoppers in the gastronomy of the states of Oaxaca, Puebla, Tlaxcala and the State of Mexico, these being the ones that mainly consume this species (Ramos-Elorduy, 2006).

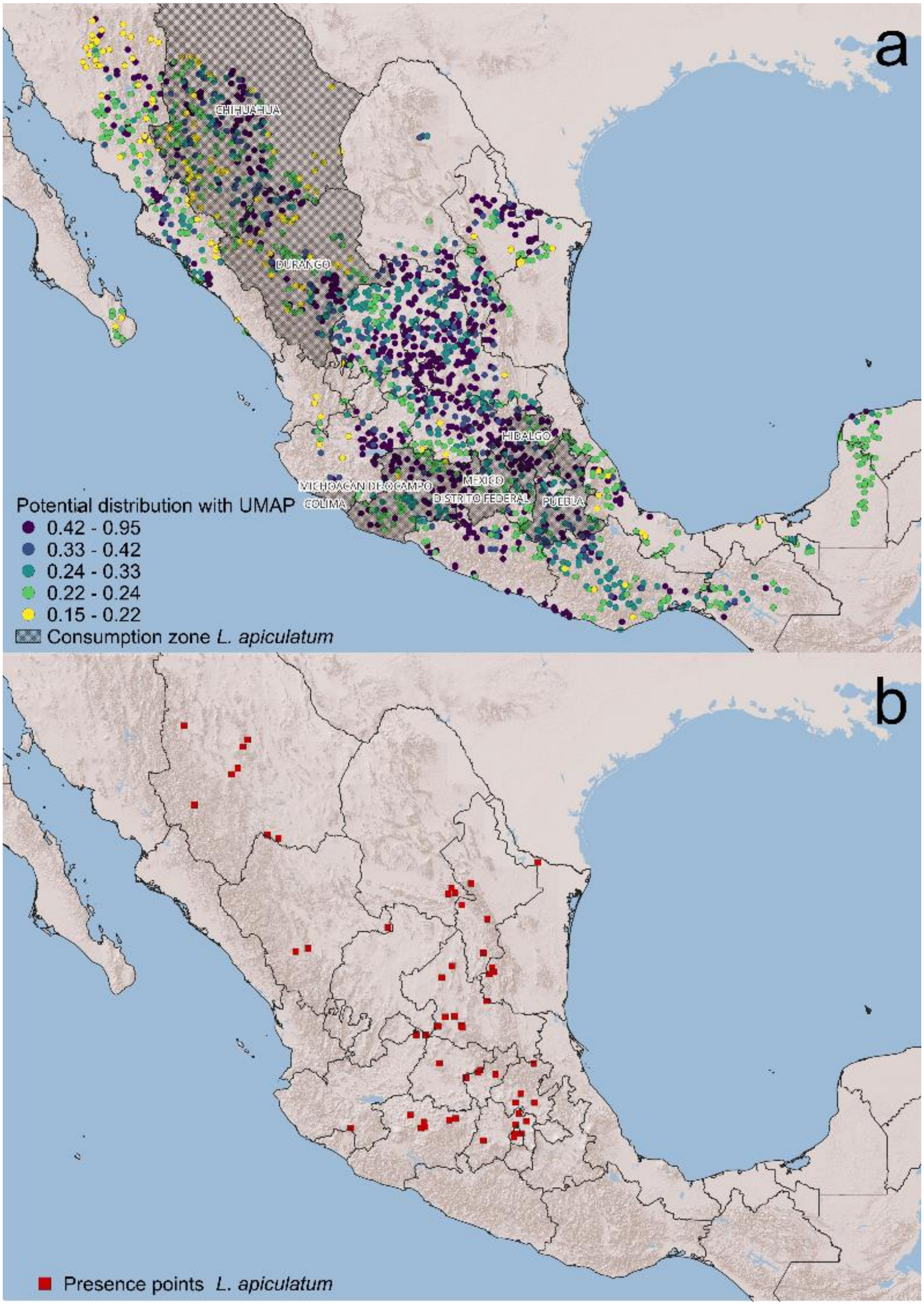

Figure 4. A) Probability Distribution (S) of background points close to presence records of escamoles (*L. apiculatum*) in the geographic dimension. B). Presence points of *L. apiculatum* (red boxes).

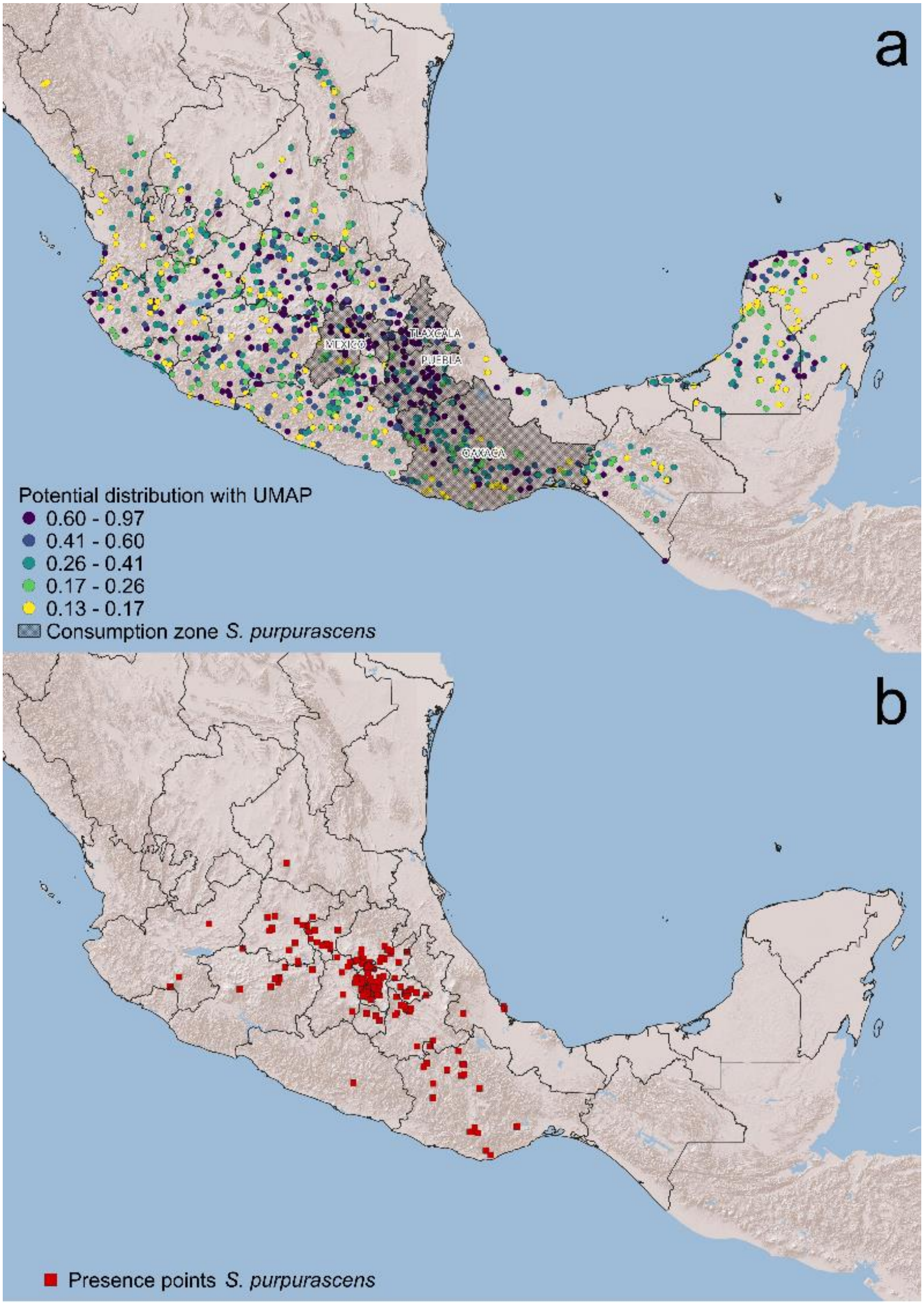

Figure 5. A) Distribution of background points close to presence records of chapulines (*S. purpurascens*) in the bioclimatic dimension. **B)**. Presence points of *S. purpurascens* (red boxes).

Evaluation of UMAP as a binary classifier

The performance indices obtained for the two edible species *L. apiculatum* and *S. purpurascens* as binary classifier are shown in Table 3. Regarding the AUC, *L. apiculatum* reached a value of 0.79, indicating a satisfactory performance. On the other hand, *S. purpurascens* obtained an AUC of 0.91, indicating a very high capacity of the model to distinguish between positive and negative classes. The Boyce indices were above 0.7 in both *L. apiculatum* and *S. purpurascens*, reflecting the ability to correctly identify the most suitable areas for each species. These results indicate a strong predictive capacity of the model in the classification of these species, with a good agreement between the observed classifications and those predicted by the model. On the other hand, the Kappa index for *L. apiculatum* was 0.52, while *S. purpurascens* had a value of 0.58, revealing a moderate agreement between the actual classifications and those predicted by the model. This coefficient, although moderate, suggests a reasonable capacity of the model to correctly classify instances of both species. Finally, the TSS was high for both species as well, indicating an excellent performance of the model in terms of its ability to correctly classify distribution areas, both in terms of true positives and true negatives, contributing to its overall predictive capacity (Allouche *et al.*, 2006).

Regarding the assessment of the variables in the reduced dimension as measured by the mutual information coefficient (López-Collado *et al*., 2024), for *L. apiculatum* the variables that had the greatest relationship with latent distance were BIO04 (Temperature seasonality, 0.29), BIO12 (Annual precipitation, 0.31), and BIO18 (Precipitation of the warmest quarter, 0.33), thus suggesting they influence the species distribution. Accordingly, this species is very sensitive to seasonal variations in temperature and precipitation conditions, particularly during the warmer months and throughout the year. For *S. purpurascens*, the most influential variables were BIO03 (Isothermality, 0.49), BIO04 (Temperature seasonality, 0.67), and BIO12 (Annual precipitation, 0.61). These results suggest that this species is strongly influenced by the relationship between daily and seasonal variation in temperature (isothermality), as well as by seasonal changes in temperature and the total amount of annual precipitation. The results indicate that bioclimatic variables related to precipitation and temperature are key in the distribution of these species, with differences in the relevance of each variable according to the adaptations and needs of each one.

Implication of the species distributions for management and conservation

Escamoles (*Liometopum apiculatum*)

Knowing the potential distribution of *L. apiculatum* in Mexico provides spatial information for the sustainable use of this species (Ramos-Elorduy and Pino, 2001). The wide distribution from the central to northern regions of the country suggests that rotational collection strategies can be implemented, and some unexploited regions can be included to promote consumption in tourist cities or locations. However, this should derive from previous field explorations to check for the presence of the target species. Other conservation management practices include promoting sustainable practices such as controlled pre-collection and nest protection, among others (Jiménez *et al*., 2021).

Additionally, with a potential coverage of 20% of Mexico, which requires careful monitoring and conservation efforts to avoid overexploitation. Establishing community-based conservation programs to involve local populations in sustainable collection and the protection of *L. apiculatum* is essential. This approach helps ensure the continuous availability of escamoles and provides economic benefits to rural communities that depend on these insects as a source of income. By maintaining a balance between exploitation and conservation, the potential expansion of collection areas can be achieved without endangering the long-term survival of the species or its habitats (Hernández-Roldan *et al*., 2017; García-Sandoval *et al*., 2022).

The management of *L. apiculatum* should be based on implementing rotational collection strategies that allow natural population regeneration. Collection areas should be defined, and collectors should follow sustainable practices, such as controlled pre-collection, where the condition of the nests is monitored. Moreover, local authorities and involved communities must actively participate in supervising and regulating these practices to avoid overexploitation (García-Sandoval *et al*., 2022).

Table 3. Indices to evaluate the performance of UMAP as a binary classifier. AUC is the area under the curve, Boyce index, the Kappa coefficient and True Skill Statistics TSS.

Edible species	AUC	Boyce	Kappa	TSS
Escamoles (*Liometopum apiculatum*)	0.79	0.73	0.52	0.75
Chapulines (*Sphenarium purpurascens*)	0.91	0.85	0.58	0.85

Table 4. Mutual information coefficient (MIC) values of two edible species in Mexico for the bioclimatic variables (BIO) listed in table 2.

Edible species	BIO	MIC
Escamoles (*Liometopum apiculatum*)	BIO01	0.16
	BIO02	0.09
	BIO04	0.29
	BIO12	0.31
	BIO14	0.08
	BIO15	0.12
	BIO18	0.33
	BIO19	0.07
Chapulines (*Sphenarium purpurascens*)	BIO01	0.16
	BIO03	0.49
	BIO04	0.67
	BIO12	0.61
	BIO14	0.12
	BIO15	0.10

The utilization of *L. apiculatum* can extend to new unexploited areas, especially in tourist cities or regions with high potential for local gastronomy, for example, Zacatecas or San Luis Potosi, in the north-center regions. Promoting responsible consumption in these places would contribute to a controlled increase in demand, helping to distribute economic benefits among various communities. Additionally, utilization should be linked to marketing policies that promote responsible practices and ensure the sustainability of the resource (Dinwiddie *et al*., 2013; Lara-Juárez *et al*., 2015).

***Chapulines* (*Sphenarium purpurascens*)**

For the states that already have a deeply rooted tradition in the consumption of chapulines (*S. purpurascens*), it is important to strengthen sustainable management practices. In states such as Veracruz, Morelos, Chiapas, and Tabasco, it is crucial to begin evaluating the feasibility of using chapulines (Ramos-Elorduy, 2006). Other activities related to understand its potential distribution include conducting additional research studies to confirm the presence and population density, as well as training programs on sustainable harvesting methods. A holistic approach that combines research, education, hatchery development, and promotion, and appropriate policies can ensure that these insects remain a food source for future generations. In this way, not only is a gastronomic tradition preserved, but it also contributes to food security and environmental protection (Ramos-Elorduy *et al*., 2006; Ramos-Elorduy and Moreno, 2023).

With a more restricted coverage of only 6%, *S. purpurascens* is significantly more vulnerable to environmental changes and overexploitation. This highlights the need for a more focused and urgent conservation strategy. Furthermore, promoting awareness and education about the ecological role of chapulines is essential to ensure their long-term survival. Local communities can benefit from sustainable harvesting practices that minimize environmental impact while ensuring a constant supply of chapulines. Establishing community-led monitoring programs and integrating these insects into broader conservation frameworks will help mitigate the risks posed by environmental changes and overexploitation (Ramos-Elorduy *et al*., 2006; Ramos-Elorduy and Moreno, 2023).

The sustainable management of chapulines should be based on harvesting practices that respect the species' natural cycles. This includes implementing monitoring programs to evaluate population density and the health of ecosystems where they inhabit. In contrast to *L. apiculatum*, which has a wider distribution, *S. purpurascens* requires more targeted management efforts due to its limited potential coverage of only 6%. Communities should be trained in sustainable harvesting techniques and encouraged to participate in monitoring and protection efforts. This will help because most of the harvesting is done by hand. By making the process more technical, it will help grasshopper populations stay healthy for the future (Ramos-Elorduy *et al*., 2006; Hernández-Ramírez *et al*., 2020).

The utilization of *S. purpurascens* should focus on preserving the gastronomic tradition while implementing measures that allow for its sustainable use (Hernández-Ramírez *et al*., 2020). Due to the species' smaller coverage, developing hatcheries and controlled production programs will be critical for meeting demand without depleting wild populations. Moreover, responsible marketing should be promoted, supporting the creation of local markets that respect sustainability standards and providing communities with a steady source of income (Ramos-Elorduy *et al*., 2006). In both species, a long run strategy should be developing rearing techniques such that harvest and collection activities would be reduced and switch to more sustainable production methods. Our findings suggest that the incorporation of management actions, within the extraction capacity, will be in the future, one way to conserve and use the natural resources that is given by nature today.

CONCLUSIONS

The distribution of escamoles (*L. apiculatum*) in Mexico shows a significant concentration in the central and northern regions of the country. The potential distribution covers 20% of the country and overlap with the presence points. We found that the consumption of escamoles is related to the points where records are found. However, the potential coverage goes beyond the consumption zones, thus opening some options to enlarge the extraction and conservation areas. The potential distribution of chapulines (*S. purpurascens*) according to the UMAP model is observed in central and southern Mexico, with a greater presence in some states and limited presence in others. In the case of *S. purpurascens* this species has a more restricted distribution, covering only 6% of the national territory.

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