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Impact of climate change on *Melipona beecheii* and socioeconomic assessment of meliponiculture in the mexican southeast

Impacto del cambio climático en Melipona beecheii y evaluación socioeconómica de la meliponicultura en el sureste mexicano

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Abstract

The present study aimed to show the impact of climate change on Melipona bees in the Yucatan Peninsula and the socioeconomic situation of Melipona honey producers. Meliponiculture is a very important activity for some Mayans in the Yucatan Peninsula. However, the production of Melipona honey and its territorial distribution has decreased in recent decades, compared to the last century. Fieldwork was carried out in the east of the state of Yucatan to assess honey production activities and the socioeconomic situation of the population that depends on them. Data from Worldclim was used to generate distribution models for Melipona bees as well as scenarios of the impact of climate change on these species in the next seven decades. The scenarios that assume the continued presence of Melipona bees in the next seven decades show disappointing results in the face of climate change. It is necessary to implement effective public policies that help promote the well-being of both Melipona bees and the population that depends on them.

Melipona bee, Honey producers, Socioeconomic situation, Yucatan

Resumen

El presente estudio tuvo como objetivo mostrar el impacto del cambio climático en las abejas meliponas de la Península de Yucatán y la situación socioeconómica de los productores de miel melipona. La meliponicultura es una actividad muy importante para algunos mayas de la Península de Yucatán. Sin embargo, la producción de miel de Melipona y su distribución territorial ha disminuido en las últimas décadas, en comparación con el siglo pasado. Se realizó un trabajo de campo en el oriente del estado de Yucatán para evaluar las actividades de producción de miel y la situación socioeconómica de la población que depende de ellas. Se utilizaron datos de Worldclim para generar modelos de distribución de las abejas Melipona, así como escenarios del impacto del cambio climático sobre estas especies en las próximas siete décadas. Los escenarios que asumen la continuidad de las abejas Meliponas en las próximas siete décadas muestran resultados decepcionantes ante el cambio climático. Es necesario aplicar políticas públicas eficaces que ayuden a promover el bienestar tanto de las abejas Melipona como de la población que depende de ellas.

Abeja melipona, Productores de miel, Situación socioeconómica, Yucatán

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Introduction

Meliponiculture has been a traditional activity in the Yucatan Peninsula, especially for rural Mayan producers who have for generations produced honey and related products from the Melipona beecheii Bennett bee (Villanueva-Gutiérrez & Collí-Ucán, 1996). Labougle & Zozaya (1986), Apud Correa-Benítez & Guzmán-Novoa (2011), point out that "Mesoamerican cultures managed to cultivate various species of the Melipona and Trigona genera, [...] particularly the Melipona beecheii Bennett species, which is still used in Yucatan and which in the Mayan language is called Xuna`an-Kab, Kolel`Kab or Po`ol-Kab".

Indeed, "native bees are primary and essential pollinators of the flowers of most wild and agricultural plants that require a pollinator" (Cane & Tepedino, 2001, p. 1) and it is constantly evolving and adapting (Oliveira et al., 2022; Eleutério et al., 2022). It is worth noting that, by enhancing pollination processes, stingless bees play an important role in the "environmental health" of their ecosystems (González-Acereto, 2012). For rural families, meliponiculture represents a secondary economic alternative that generates income, promotes ecotourism, and facilitates the preservation of ancestral knowledge.

Meliponiculture is currently facing daily threats from internal and external factors, such as climate change, environmental pollution, the lack of marketing channels and services, together with a devaluation of the consumption of Melipona honey due to a lack of information and culture about its ancestral value and the processes required for its production (personal communication with key actors during fieldwork) (May-Itzá et al., 2022). There are also negative externalities affecting the sector. For example, the indiscriminate use of deforestation in the Yucatan Peninsula, and the increasing environmental contamination with glyphosates. Furthermore, the demand for environmental services has consequences that affect the environment of the region, greatly impacting the agricultural, livestock, beekeeping, and aquaculture systems in the region.

Climate change is and will be an external factor that will have a direct and indirect impact on the production processes of honey and the conservation of Melipona bees. There is evidence that the consequences of climate change on beekeeping have also been observed in other parts of Latin America. Maia-Silva et al., (2020) conducted a one-year study on honey and pollen from five colonies of M. subnitida. During this period, the colonies fed on native trees, shrubs and herbaceous species, which shows the importance of all plant strata for the bees' diet. However, from 2012 to 2016 the plants on which these bees feed was ravaged by drought in the Brazilian Tropical Dry Forest.

It is considered that the time of year (collection period) is an important variable that greatly influences the physicochemical characteristics of honey according to the bee species (Sant'ana et al., 2020; Real-Luna et al., 2022). Richard et al. (2019) point out that "climate change can modulate the environmental stimuli that trigger polyphenisms and/or some epigenetic marks, thus modifying in the short and long term the discrete phenotypic proportions within populations", including bees.

For many years, Melipona bees have been highly valued in the Mayan culture. According to the (Instituto Nacional de Ecología A.C. (s/f.): "In America, before the arrival of the Spaniards in the fifteenth century, the different species of the genus Apis did not exist. However, the cultures established in the area interacted with stingless bees, also called meliponas. For more than a thousand years, ancient Mesoamerican cultures traded and used as tribute the honey and wax produced by these bees."

In the last two decades, there have been significant changes in the production structure of beekeeping, mainly in the case of native bees of the Yucatan peninsula, as a consequence of the negative effects of various climatological events that have hit mainly the rural areas of the region. Sánchez (2019, p. 119) point out that the "impact of climate change on meliponiculture and beekeeping has affected this species". A year with less-than-ideal environmental conditions (flowering, weather, rain, etc.) can lead to having a single harvest instead of the usual two.

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Unfortunately, there is currently no accessible or transparent official census on the location of meliponiculture units in the Yucatan Peninsula. Ideally, each federal entity would generate a database to identify the economic activity of its population, which would help improve the decision-making process of public policymakers. In this case, the closest thing we had access to is the National Survey of Household Income and Expenses of the Instituto Nacional de Geografía y Estadística (ENIGH-INEGI, 2020).

However, there are some efforts by state governments in this regard. For example, the (Gobierno del Estado de Yucatán (2018, p. 1) stated in 2018 that it had started a state inventory of meliponiculture. It indicated that it had 70% progress on it and had recorded “2,949 hives of 87 producers, 40 women and 47 men, from 24 municipalities”. Based on this information, it can be assumed that, in 2018, there would have been around 4,213 hives of 124 producers, 57 women and 67 men (own interpolation). However, the number of productive hives can increase or decrease because of changing climatic conditions.

Primary sources (ENIGH-INEGI, 2020) were used to assess the importance of meliponiculture production in the Yucatan Peninsula. Available statistics show that among families with beekeeping activities, it is women who work on honey production. But even in these cases, the oldest male is usually recognized as the household head, "according to current stereotypes" (Instituto de las Mujeres, 2010, p. 52).

In the Yucatan Peninsula, women traditionally play a preponderant role in the cultivation of apis or Melipona bees, which can contravene patriarchal stereotypes about home management. "What is the problem? It is the very concept on which “patriarcl cultural patterns” are rooted. The use of the term "headship" is absolutely violent because it allows relationships within the home to become hierarchical. From the devaluation of domestic work to the impossibility for women to become "heads", except in the absence of men, this is all implicated in the concept of "Head of the Household"(Navarro-Ochoa, 2010, p. 126).

We find the value of the Melipona bee and its associated products in both tangible and intangible elements of Mayan society. For example, honey was used by Mayan priests to cure diseases of the eyes, ears, and skin, as well as for other therapeutic purposes in the community (Sánchez, 2019). Melipona honey is part of the culture and traditions of Mayan society. Today, the production of Melipona honey is mainly done within the territory of the Yucatan Peninsula and is then marketed to other parts of the country. Expanding the concept of valorization involves integrating a complexity of factors and dimensions associated with local realities and development processes (Champredonde & Gonzalez-Cosiorovski, 2016).

Methods

Within the framework of the CONACYT-CIATEJ Project "Microbiological and organoleptic revaluation and differentiation of Melipona beecheii honey and its contribution to the development of indigenous communities", different municipalities in the east of the State of Yucatan were visited on April 25-30 to evaluate the cultural aspects of the management of Melipona bees and the social, economic, and environmental benefits of honey production for Mayan indigenous families.

We conducted fourteen interviews with Melipona producers. It should be noted that it is currently very complex to identify them because there is no official register of producers. Non-random, snowball sampling was used to select participants. The sample is considered representative given its characteristics, which are described in the results section. The agricultural section of the National Household Income and Expenditure Survey (ENIGH-INEGI, 2020) was used as a primary source to segment the population working on the production of honey in the Yucatan Peninsula and assess the relevant socioeconomic indicators.

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The emergence of new statistical techniques and tools for geographic analysis has made it easier to develop predictive models of species and habitat distribution. This allows us to study climate change and its repercussions on bee species. The present study includes a prospective analysis of the effects of climate change on southeastern Mexico for the next seven decades. It seeks to contextualize the main challenges that lie ahead for the beekeeping sector and thereby highlight the main direct and indirect effects that can harm the population that works on the production of Melipona honey. Guisan et al. (2013) point out that, "Species distribution models (SDMs), commonly known as ecological niche models, ENMs, among other names; [...] are currently the main tools used to derive spatially explicit predictions of environmental suitability for species" as studied by Franklin (2010), Elith & Leathwick (2009), and Guisan & Thuiller (2005).

The prospective climate change model was developed in the statistical software R® with the Wallace model, using the shiny software package. An analysis of the spatial biodiversity of the bee Melipona beecheii Bennett was generated for the Yucatan Peninsula. Information from the Global Biodiversity Information Facility (GBIF, 2022) was used to identify the main territories and localities with a presence of this bee species. This allowed to stratify the localities surrounding those in which the presence of Melipona bees had been identified. The information on the socioeconomic characteristics of the local population was complemented by considering the presence of Melipona bees.

Once the geographical positions of Melipona bees were found, a radius of 5 kilometers was established around them to focus the research and improve the database by adding relational points corresponding to the states of Campeche, Quintana Roo and Yucatan and reducing the effect of spatial sampling bias. WorldClim agro-climatological databases corresponding to 2.5 minutes of arc ≈ 5 km were also obtained (Hijmans et al., 2005). "Bioclimatic variables are derived from the monthly values of temperature and precipitation to generate biologically more significant variables" (Worldclim, 2022) to use them for spatial analysis.

The following variables were selected:

BIO1 = Average annual temperature.

BIO2 = Midday range (monthly average (maximum temperature – minimum temperature)).

BIO3 = Isothermality (BIO2/BIO7) (×100).

BIO4 = Temperature seasonality (standard deviation ×100).

BIO5 = Maximum temperature of the warmest month.

BIO6 = Minimum temperature of the coldest month.

BIO10 = Average temperature of the warmest quarter.

BIO11 = Average temperature of the coldest quarter.

BIO12 = Annual rainfall.

BIO13 = Precipitation of the wettest month.

BIO14 = Precipitation of the driest month.

BIO15 = Precipitation seasonality (Coefficient of variation).

BIO16 = Wettest quarter rainfall.

BIO17 = Driest quarter rainfall.

The research was geographically focused by drawing a minimized area (minimum convex polygon) around the localities of occurrence of the bee. Non-spatial partitions were then made and the locations with presence of Melipona bees were randomly assigned. The aim was to reduce to a minimum any sampling bias. Besides, the model was not used to analyze transfer over time (Shcheglovitova & Anderson, 2013; Pearson *et al*., 2007). The Maxent module of the Wallace package of R® was used to build the distribution model (niche) of the species under study. This allowed us to identify "test" and "training" localities in the model of the scenarios of spatial presence and absence of bees over a period of time. We established a baseline with 61 points with presence of Melipona bees based on GBIF information. Of this total, 30 points were used for model training and 31 for testing.

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The Maxent model was used with the transformation of the logistic scale (Phillips et al., 2017) whose assumption is that the prevalence of the species is equal to 0.5 (Merow et al., 2013). The Wallace software package calculates the output of this model based on the values of the predictor variables for each cell and plots the prediction on the map.

Following the method used by Dorji et al. (2020, p. 4), the sequential models were selected according to 10th percentile training presence test omission (hereafter, 'percentile OR') and "balance training omission, predicted area and threshold values test omission" (hereafter "balance OR"). Percentile OR was chosen (Radosavljevic & Anderson, 2014); Galante et al., 2018) over the " minimum training presence test omission" (Shcheglovitova & Anderson, 2013); because the latter is more sensitive to extreme localities and over-predicts when there are many calibration locations (Radosavljevic & Anderson, 2014). Balance OR was used to assess the usefulness of a new threshold rule and its OR in selecting the optimal model. Different sequential combinations of the two OR, A UCTEST and AUCDIFF were used to formulate four sequential approaches.

The model was used to estimate future scenarios of the effect of climate change on Melipona bees for the next seven decades (Franklin, 2010; Ficetola et al., 2007). The climate change model used to create the scenarios was NorESM1-M. The following component models were used: CAM-OSLO to represent the environment; CLM to represent the land; CICE to represent sea ice; MICOM-HAMOCC to represent the ocean.

Results

The population that works in the production of Melipona honey has an age range between 19 and 71 years. In meliponiculturist households, 77.8% of the people dedicated to this activity correspond to the female gender. Most Melipona honey-producing units are run by women.

In most of the producer units that were surveyed, the volume of annual production fluctuated between 0.300 kg and 45 kg since the production of honey is usually a secondary economic activity, even though it supports other types of economic activities such as ecotourism, restaurants, and rural medicinal stores. The production of Melipona honey serves thus as a regional economic generator. It should be pointed out that an increase in the number of people dedicated to meliponiculture does not necessarily mean an increase in production due to the reduced economies of scale in this activity. For example, six people from one household produce 20 kg in the town of Tahmek, while in the town of Kantunil in Quintana Roo one person produces 45 kg.

Rural families dedicated to the production of Melipona honey reported having positive medicinal benefits from the use of the product; 89.4% of the population said they had made savings in medicines by substituting them for Melipona honey. The majority of the interviewed population uses Melipona honey for eye care and cataract cleaning, among other uses, as shown in Figure 1.

Figure 1 Use of the honey of the bee Melipona beecheii Bennett among producing families

The ecosystem of activities and products of Melipona bees also generates tourism activities, in which 28.6% of the participants are men and 71.4% are women. Half of the people interviewed said they perform ancestral rituals of gratitude for the production of honey. On average, 2.71 people work directly in each Melipona producing unit, with a minimum of 1 and a maximum of 6 people. Of the producers who sell Melipona honey in the markets, 35.7% indicated that they have significant savings in the consumption of honey derivatives, which substitute market products.

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Most of the producing families could consume the honey themselves but have greater incentives to sell this product in the market and thus obtain additional income.

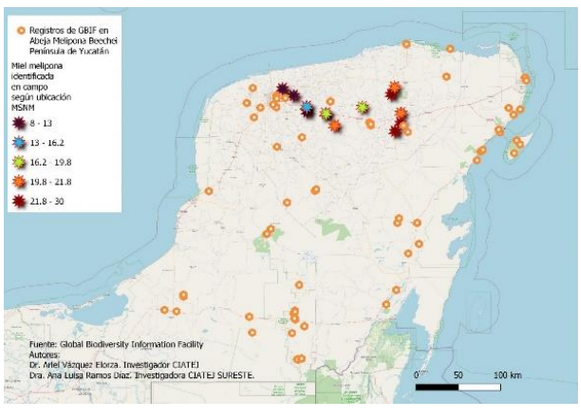

Figure 2 Presence of the Melipona beecheii Bennett bee in the Yucatan Peninsula
Source: Own elaboration based on information from Global Biodiversity Information Facility (GBIF, 2022) and fieldwork

The production and presence of the Melipona bee can be explained by multiple environmental, ecological, social, and economic factors. To contextualize the effects of climate change on this economic and cultural activity, the results yielded by the Maxent model are presented below. The scenarios generated extend to the year 2070 and make it possible to estimate the effect of climate change on the presence of the species according to the level of generated greenhouse gas (GHG) emissions. Figure 3 shows the model configuration and the different combinations of characteristics of Melipona bees.

Figure 3a shows the current distribution of the Melipona beecheii Bennett bees in Latin America. Figure 3 b shows the territorial presence of the bee in the Yucatan Peninsula. The model was evaluated using receiver operating characteristic analysis of the threshold-independent area under the curve (AUC), threshold-dependent minimal training presence (mtp), and 10th percentile (p10) training presence according to the Representative Concentration Trajectories (RCP). The results of the calculation of the territory with minimal training presence and an RCP2.6 are shown in Figure 3c. RCP4.5 is shown in Figure 3e; RCP6.0 in Figure 3g and RCP8.5 in Figure 3i.

The latter (RCP8.5) would mean an absolute loss of the presence of *Melipon*a bees in the Yucatan Peninsula since it tends to enlarge too much the non-presence areas in the distribution of bees, especially in the cases in which the data comes from the 10th percentile model. According to the results of the present study, the best option is to use the 10th percentile training presence, which considers the probability that 10% of the training presence records are skipped, especially the outliers. These results indicate that the continued presence of Melipona bees in the Yucatan Peninsula is largely uncertain.

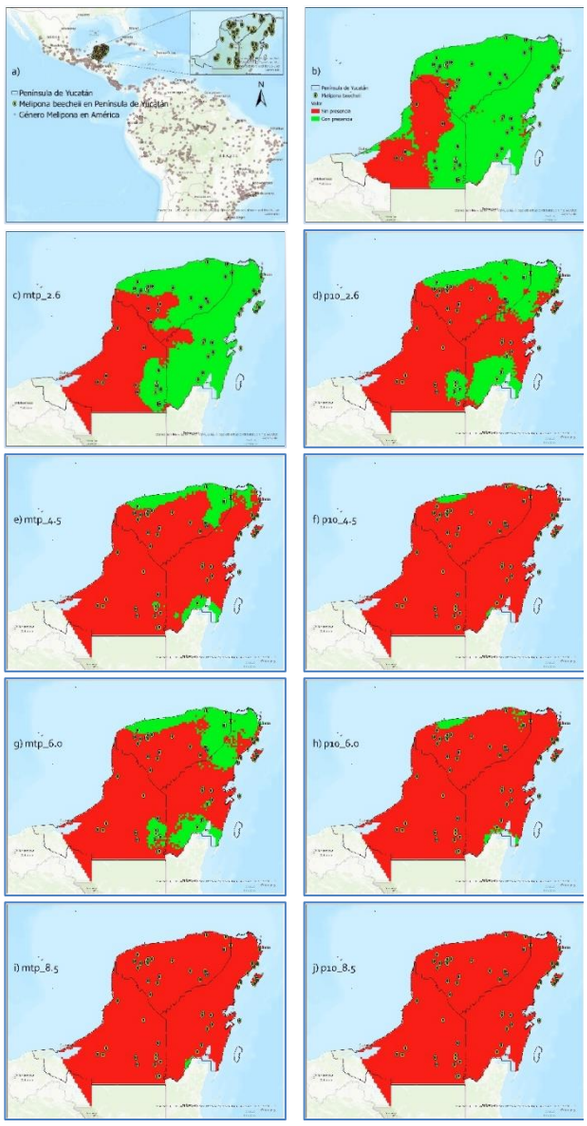

Figure 3 Scenarios of the loss of the presence of the bee Melipona beecheii Bennett in the south and southeast of Mexico and the Caribbean

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Conclusions and discussion

The production of Melipona honey is strongly linked to Mayan traditions and culture in the Yucatan Peninsula, including ceremonial activities that have lasted through several centuries. It also represents an important source of honey, honey-derivatives, and wax. It has significant medicinal and healing properties that are used by the producing Mayan families. The positive externalities are not limited to the production of Melipona honey since this activity represents a regional alternative for the promotion and development of rural community tourism. However, much remains to be done to increase the value of Melipona throughout Mexico. The social and economic benefits of the production of Melipona honey include both its intangible value for its contributions to family union, gastronomy, and health, as well as its tangible value in the generation of additional income for families, substitution of medicine products, creation of community jobs, empowerment of women and cultural production and transmission.

In the majority of producer households, this activity symbolizes a bond of family union and cohesion between the members of the household. In most cases, it is the women who attend and direct this activity, creating sources of employment. The whole family usually participates in it, including children, youth and the elderly. It is necessary to promote a revaluation of the importance of the production of Melipona honey among consumers so that the price paid for the product and the consumption of it incorporates the efforts and natural and cultural resources used in it. Moreover, the production of Melipona greatly benefits the pollination of important crops and vegetation in the region.

The results of prospective models regarding the absence or presence of the Melipona bee in the Yucatan Peninsula show significant risks of presence in the next seven decades.

This assumes that greenhouse gas emissions will increase, leading to higher temperatures, climate change, and pollution, coupled with an over-exploitation of natural resources. This reality makes the presence of the Melipona bee in the Yucatan Peninsula very uncertain. Public policy decision-makers should take this information into account and start designing strategies to promote the growth and competitiveness of the sector.

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