Determination of climatic tolerance of five tree species in Pico Bonito National Park.

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Summary

Climate change is a global threat that is already evident and will continue to show its consequences in the future. The consequences are diverse, including on: means of production, family economy, loss of human lives, impact on ecosystems, to mention just a few elements. The present study seeks to understand the climatic tolerance of five tree species of Pico Bonito National Park, to determine their vulnerability to the changing climate and thus propose more structured conservation strategies that allow the permanence of these species and the ecosystem services that they provide. To carry out this task, ecological niche modelling was carried out in the KUENM R library program in the ssp245 scenario (realistic scenario) and sssp585 (pessimistic scenario) from the current period until the year 2100 in each scenario. From this modelling and points of presence, descriptive statistics were calculated to identify the range of environmental tolerance of the species. Finally, to directly measure the impact of climate change, the displacement of centroids was calculated altitudinally, longitudinally and latitudinally for each of the species in the future scenarios. It is predicted that *Dendropanax hondurensis* will be the most affected species, while *Eugenia coyolensis* will benefit in the future due to climate change.

Background

In this study, climate tolerance is defined as the range of environmental conditions where a species is best adapted to exist. From this it is possible to approach different analyses that allow us to know possible sites where a species is found, as well as to project the vulnerability of these species in the future as a consequence of climate change.

Pico Bonito National Park has 5 forest types, including: humid broadleaf forest, deciduous broadleaf forest, mixed forest, dense coniferous forest and sparse coniferous forest (ICF, 2019). The mixed forest has an average annual precipitation between 1136-1366 mm and an average annual temperature between 19.6-25.2°C. The humid broadleaf forest has an average annual precipitation between 1072-2500 mm and temperature in the range of 14.5-27.1°C. The deciduous broadleaf forest has an average annual precipitation between 1112-1188 mm, and temperature is between 24.1-25.4°C. The sparse coniferous forest has an average annual precipitation between 1133-1235 mm, and temperature between 22.1-24.4°C. Finally, the dense coniferous forest has an average annual precipitation between 1110-1441 mm and temperature between 18.1-25.1°C.

In order to fulfil the objectives of the present research, we seek to analyse from ecological niche modelling (ENM) those climatic conditions of greater suitability for 5 species present within the Pico Bonito National Park (PNPB): *Magnolia ciroorum* A. Vázquez, S. Estrada & D. Aguirre, *Magnolia atlantida* A. Vázquez, *Dendropanax hondurensis* M.J. Cannon & Cannon, *Eugenia coyolensis* Standl. and *Lonchocarpus yoroensis* Standl.

There are several definitions and methods for modelling the ecological niche. The current definition of ecological niche consists of the hypervolume formed from the responses of a species of interest to scenopoietic variables (Soberón, 2007); however, this has been and continues to be the subject of constant debate to this day. In general, there are two main branches of thought when talking about this concept:

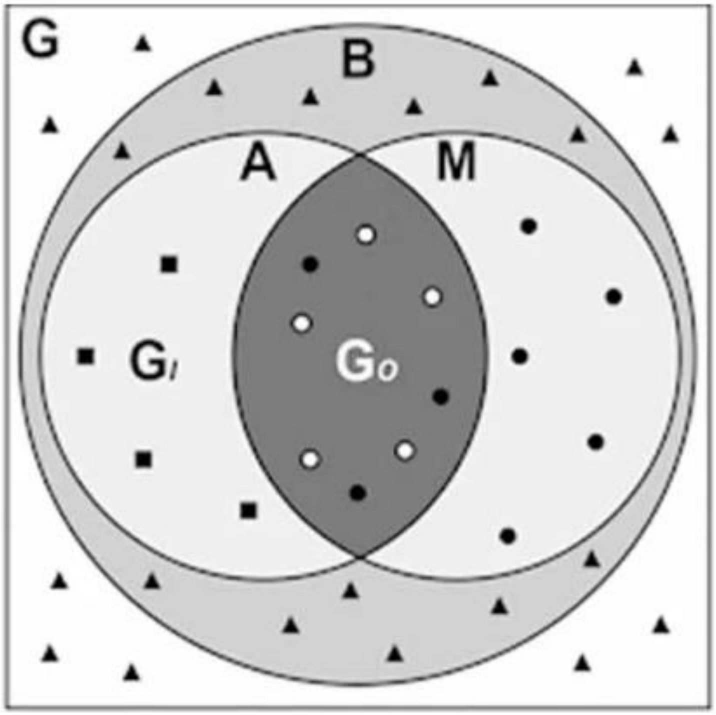
- Niche according to Grinell: in this conception, the ecological niche is defined as the set of "abiotic" (A) or "scenopoetic" variables that make a site "ideal" for a species to inhabit, i.e., it consists of non-interacting environmental variables that favour the presence of a species in a delimited area (Soberón, 2007). For Grinell, the variables that delimit the importance of a niche are: temperature, humidity, precipitation, slope, among others.
- Niche according to Elton: this consists of understanding the niche as the set of "biotic" variables (B) that favour the presence of a species in a delimited area, these are interacting, that is, it is based on the interaction of organisms of different species, with one species being able to influence the other reciprocally, therefore, it could also be defined as the function that each organism fulfills in each of the ecosystems where it is found. For Elton, the variables that define the importance of a niche are: predation, parasitism and mutualism (Soberón, 2007).

Something important to highlight is that the different types of variables are calculated at different resolutions. Abiotic variables are measured at large scales, thanks to the development of global technologies, such as the WorldClim program, or the development of satellites such as Sentinel and Landsat. Whereas, biotic variables are measured at small resolutions, of a few meters, at a local level. This creates a difficulty when wanting to perform niche analysis with both variables, as their very resolution does not allow it, since, at large scales it seems that abiotic variables do not have a considerable effect on the modelling of ecological niches, this phenomenon is known as Eltonian Noise Hypothesis (Fraterrigo et al., 2014; Soberón and Nakamura, 2009). Currently, niche modelling is performed only with abiotic variables.

Modelling also needs to consider the dispersal capacity of the species of interest (M), which refers to the sites where the species under study is currently found. For example, some species in Central America are adapted to dry forests, however, this does not imply that these same species are found in other dry forests in Asia or Africa.

All of the above is related in a BAM diagram (Figure 1). The diagram shows G denoting any geographical space, A abiotic variables, B biotic variables and M dispersal capacity. Within the diagram two new areas Go and Gi are denoted. Go refers to a site with suitable environmental conditions and access for a particular species. While Gi shows the areas with good conditions, but with no accessibility for the species. It should be noted that this diagram shows the modelling according to the hypothesis of eltonian noise, where the biotic variables are found throughout the geographic space, but do not have an impact on the distribution (Townsend and Soberón, 2012).

Figure 1. *BAM diagram depicting niche modelling.*



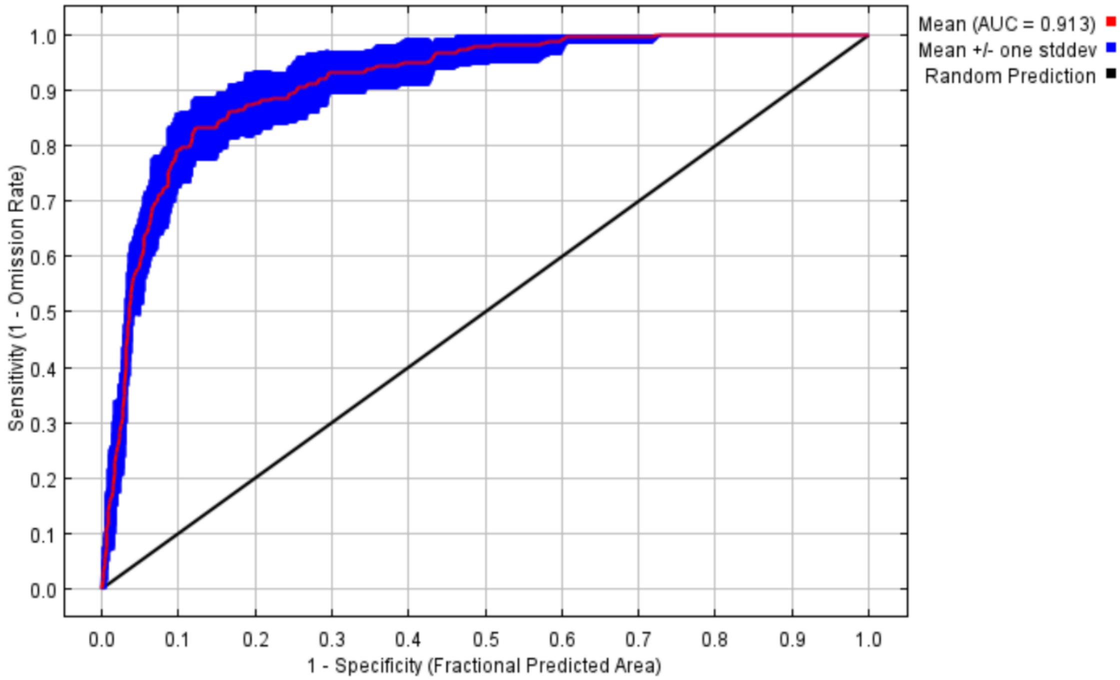
Note: In the diagram G refers to any geographic space. B refers to biotic variables. A. Refers to abiotic variables. M. refers to the clipping and dispersal polygon of the species. G_i refers to the potential areas of occupancy of the species. G_o refers to the realized niche of the species.

There are different methodologies to obtain ecological niche models, among these we can mention: Generalized Linear Models (GLM), Generalized Additive Models (MAG), Kernel Density Estimators, regression trees by machine Learning and the most used of all Maxent (Qiao, et al., 2015).

In order to perform niche modelling in Maxent, it is necessary to have climatic layers cut in M-space and points of presence of the species to be modelled. From this, the program calculates "suitable" sites of presence of the species, i.e., it generates a hypervolume of suitable conditions that is then projected in a geographic space (Towsend and Soberón, 2012).

Maxent has been further developed over time. Currently there is the KUENM package for R that allows models with higher reliability and accuracy (Cobos et al., 2018). This package shows 3 relevant results to understand the final models. The first one is the AUC curve plot, this value shows how accurate the model is (Figure 2). The y-axis of sensitivity refers to the proportion of true presences in the model, i.e. if the model predicts in a pixel presence and the presence points fall in the same region the sensitivity index will increase. Specificity is the inverse, true absences in the model, i.e. the sites where absence is predicted must not have any presence. The closer the AUC value is to one, the better the model, as for the graph, the closer it is to the upper left corner, the better the model created.

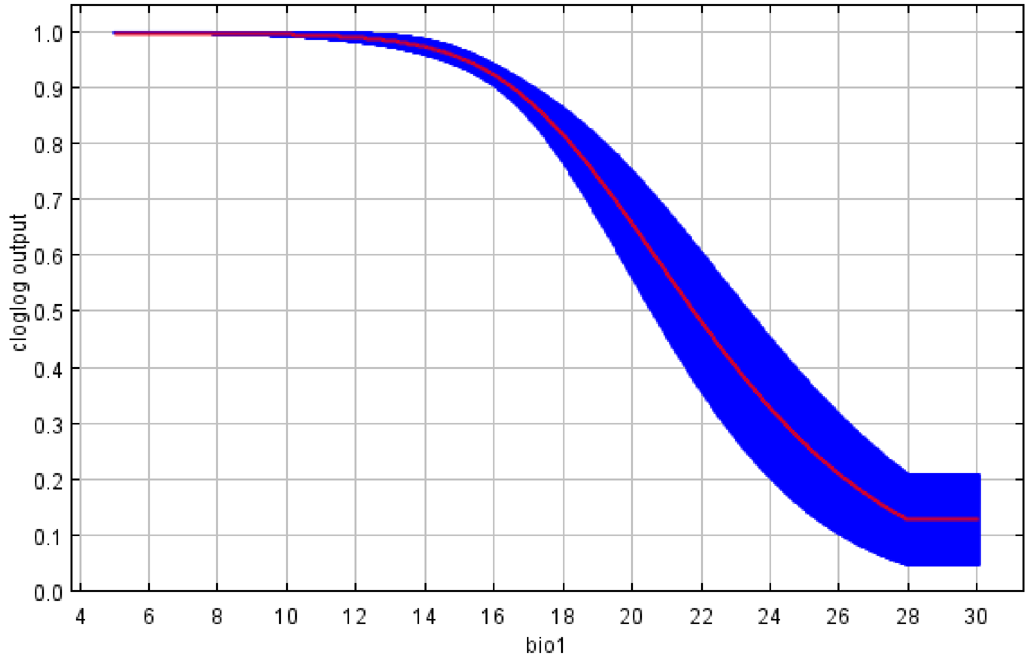
Figure 2. *Example AUC curve of Dendropanax hondurensis*



Note: x-axis refers to the specificity of the model, y-axis refers to the sensitivity. Red line represents the mean of the replicates. Blue area represents standard deviation. Black line represents a random hypothetical model.

The second important result is the geographic distribution map, that is, the projection of the hypervolume in the geographic area, which shows the current distribution areas and future modelling to evaluate the consequences of climate change. Finally, the third result refers to the relationship of the variables inserted into the model with the occurrence of the species, in this we can observe in greater detail the intervals that the species prefers most from the models and is one of the approaches to understand the climatic tolerance (Figure 3).

Relationship between average temperature and occurrence of Dendropanax hondurensis.



Note: The x-axis (bio 1) represents the mean annual temperature. The y-axis represents the species occurrence. Red line represents mean occurrence and blue area 1 standard deviation.

Objectives

- To perform a descriptive statistical analysis of the climatic tolerance of the five species under study.
- Model the ecological niche where the distribution centroids are calculated for each of the five tree species.

Methodology

For the present analysis it was necessary to collect information from: species presence points, environmental layers and dispersion polygon M. The points of presence were collected by FUPNAPIB personnel and stored in a database where the specimen's coordinates were included. At the same time, in order to have a larger volume of data, the GBIF database was used. The data were cleaned, duplicates were eliminated, the occurrence coordinate was validated and those points that did not have a coordinate as such were excluded.

The environmental variables were downloaded from the Worldclim platform. The reanalysis of climatology from 1980 to 2010 was downloaded as a current climate layer. And 6 forward layers were downloaded from the MPI-ESM1-2-HR global circulation model showing more accurate predictions for the region (Almazroui et al., 2021). All layers were downloaded at a resolution of 30 seconds. The 19 bioclimatic variables related to temperature and precipitation were downloaded for the scenarios SSP245 (Realistic scenario) and SSP585 (Pessimistic scenario) for the periods 2021-2040 (Period 2040), 2041-2060 (Period 2060), 2061-2080 (Period 2080 realistic scenario) and 2081-2100 (Period 2100 pessimistic scenario). It was not planned to work with this last layer of the pessimistic scenario at 2100, however, when trying to download the layers at 2080 in the pessimistic scenario, they showed an error, so it was decided to work with this other layer. We also worked with the ArcGIS base digital elevation model available online.

Regarding the first objective, the descriptive statistical analysis was performed by extracting values from the environmental layers mentioned above and the points of presence for each species using the extract value to point function in ArcGIS. From the extraction of these data, tables were processed in R and Python software, boxplots were plotted for each species, which allowed us to know medians, quartiles and general dispersion of the data. As a second approach to this objective, the responses of the variables to the occurrence of the niche modelling of each species were used.

To meet the second objective, we started from the points of presence that helped to delimit the M polygon using the minimum bounding geometry tool in ArcGIS, which allows us to make a minimum convex polygon. Only for *M. ciroorum and E. coyolensis* were the basins where the species points were found used, due to the fact that the points collected were very close to each other and did not allow a good model to be generated.

Once with the area M, the climatic layers were cut using the extract By mask function of ArcGIS, then these were saved in a .TIF file. A Pearson correlation analysis was performed on these 19 layers and those that presented a correlation greater than or equal to 0.7 had to be chosen between one of the two conflicting layers. Priority was always given to those layers that presented greater parsimony and those that represented the majority of the year.

The presence data were also processed in R software to randomly select 20% of the data and save them to validate the model and 80% were used to create the model. These data and the climatic layers were entered into KUENM where all class types were modelled, with regulators from 1 to 5 with jumps of 1, 500 iterations, 10 repetitions of final models, Cloglog parameterization with Jacknife and Clamping.

Some post-analysis was performed on the final models. The results were projected in UTM zone 16 corresponding to Honduras. A table of values was calculated by means of a raster calculator, the raster was transformed to polygon and then cut with the land use layer, to observe in the model only those pixels with forest cover and the pixels that had a probability greater than 50% where the species could be found were filtered. Finally, if it was desired to calculate flat displacement due to climate change, the centroids of these polygons were calculated and to observe the altitudinal displacement, the areas of the digital elevation model were cut and their averages were calculated.

Results

A total of 775 models were made for all species, of which 1 per species was selected depending on its significance and AICc value. If a model had two or more candidate models, the one with the most parsimony in the classes was chosen, for example, if one candidate model contained a linear relationship, while another had a linear-quadratic relationship, the model with the linear relationship was chosen because it contained only one type of class. Descriptive statistics, the AUC (accuracy) of the model and its projections will be presented for each species.

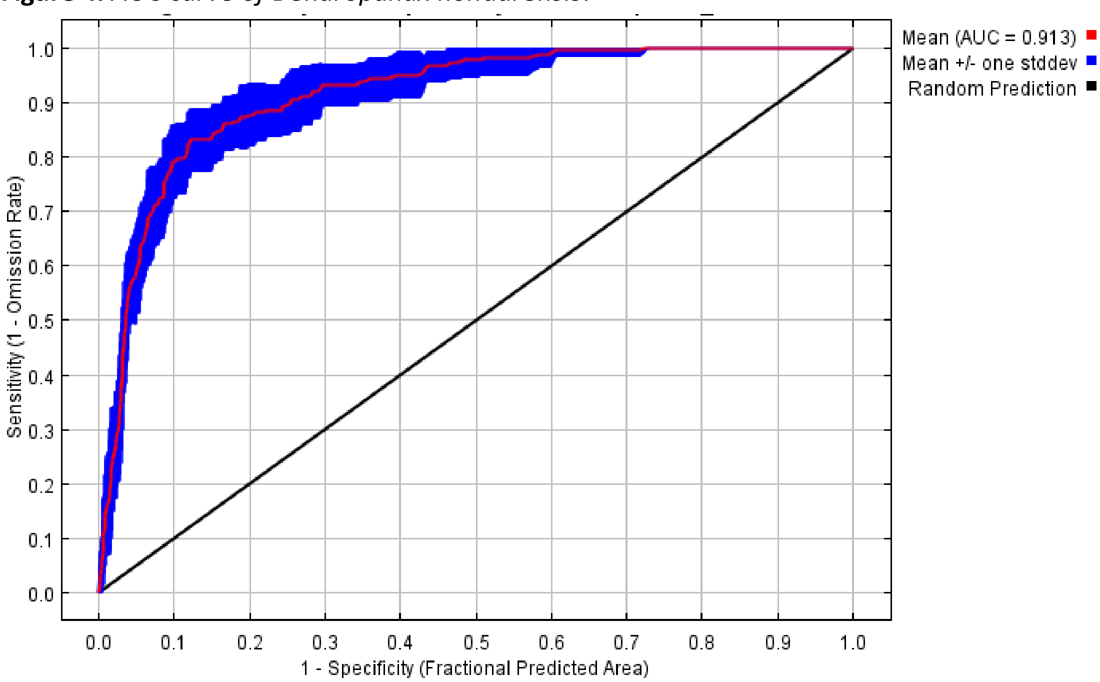
Descriptive Statistics

Dendropanax hondurensis

The model for this species was made with 28 points in total, it presents an AUC of 0.913 (Figure 4), that is, it is a model that fits quite well to identify real presences and absences in the geographic space. The model used for this species was M_1_F_q.

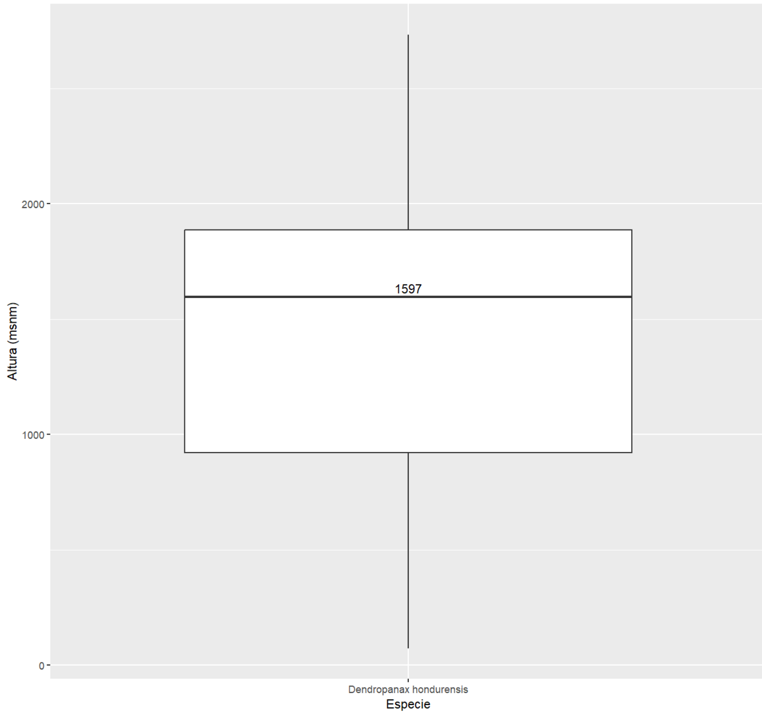
The descriptive statistics show that most of the species' points of presence are between 921 and 1886.5 meters above sea level, with a median of 1597 meters above sea level. It is the species with the highest altitude of all those modelled (Figure 5). As for average rainfall, according to Figure 6, it is observed that the species is most likely found between 1426.5 to 1700.75 with a median of 1592.5 mm, that is, it is found in relatively rainy places for the area, Figure 7 provides more details about this variable, this figure was obtained from the models in KUENM and it is observed that the species is not related to higher rainfall after 2000 mm per year and prefers places a little drier. As for temperature, it is observed that the species is found in sites with a temperature range between 16.27 and 22.58°C with a mean of 17.96°C (Figure 8). The temperature analysis according to the model predicts that the species prefers average annual temperatures below 22°C (Figure 9). The model also allows us to analyse an extra variable, the bioclimatic variable 7, which refers to the annual temperature range, in which it is observed that the species prefers little variation in temperature during the year, no more than 15.5 degrees between the hottest and coldest month (Figure 10), at the same time, when evaluating all the variables it is observed that variable 7 is the second most important when analyzing the occurrence of the species (Table 1). With climate change projections, this last indicator is a cause for concern, as the climate is expected to tend more towards extremes and therefore lead to an increase in this inter-annual range.

Figure 4. *AUC curve of Dendropanax hondurensis.*



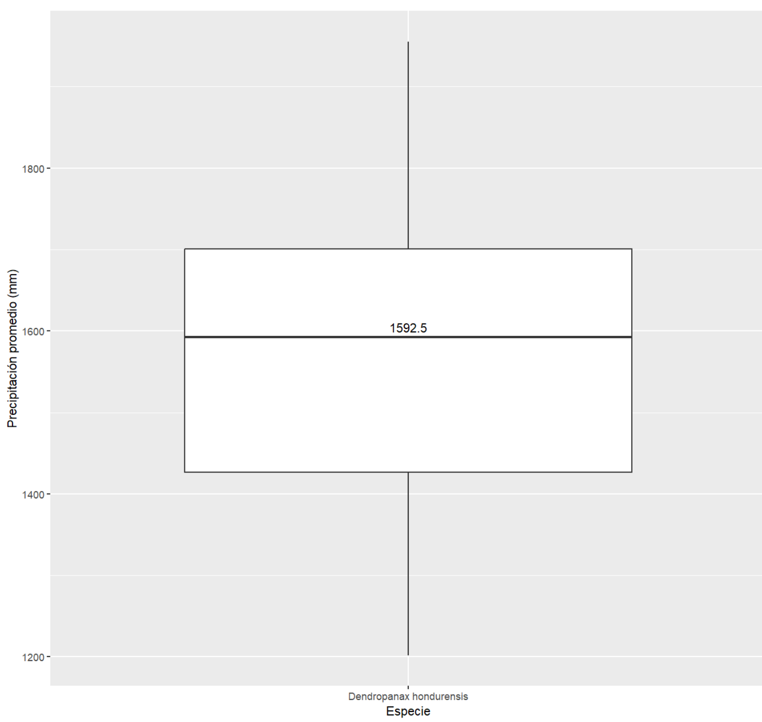
Note: x-axis refers to the specificity of the model, y-axis refers to the sensitivity. Red line represents the mean of the replicates. Blue area represents standard deviation. Black line represents a random hypothetical model.

Figure 5. *Average height of Dendropanax hondurensis occurrence points.*



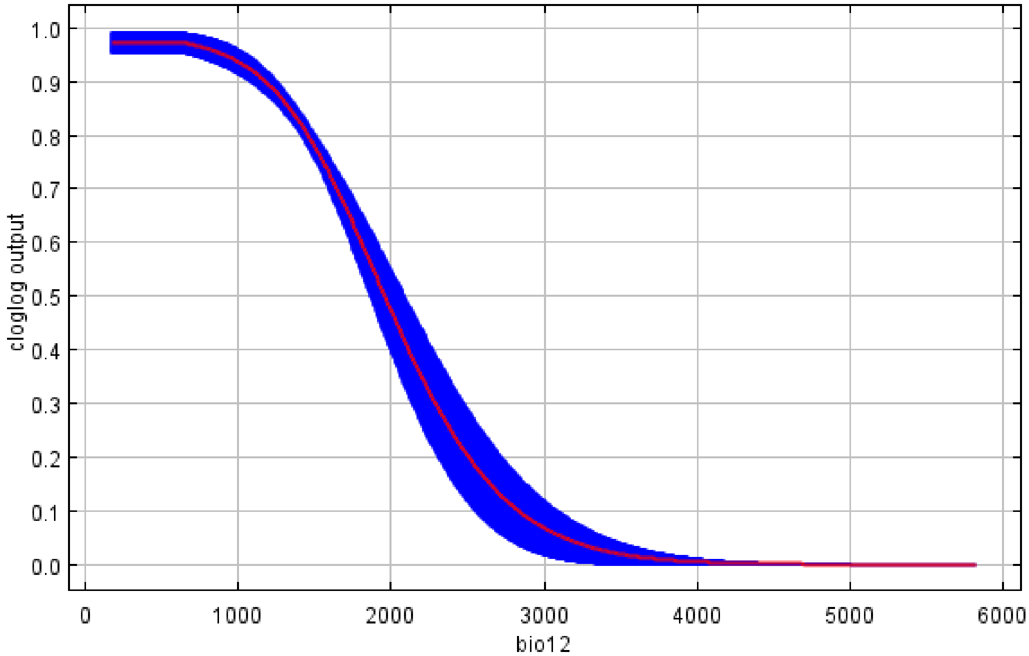
Note: x-axis represents the species of interest. Y-axis represents the height in meters above sea level. The value in the boxplot refers to the median of the species.

Figure 6. *Average precipitation of Dendropanax hondurensis occurrence points.*



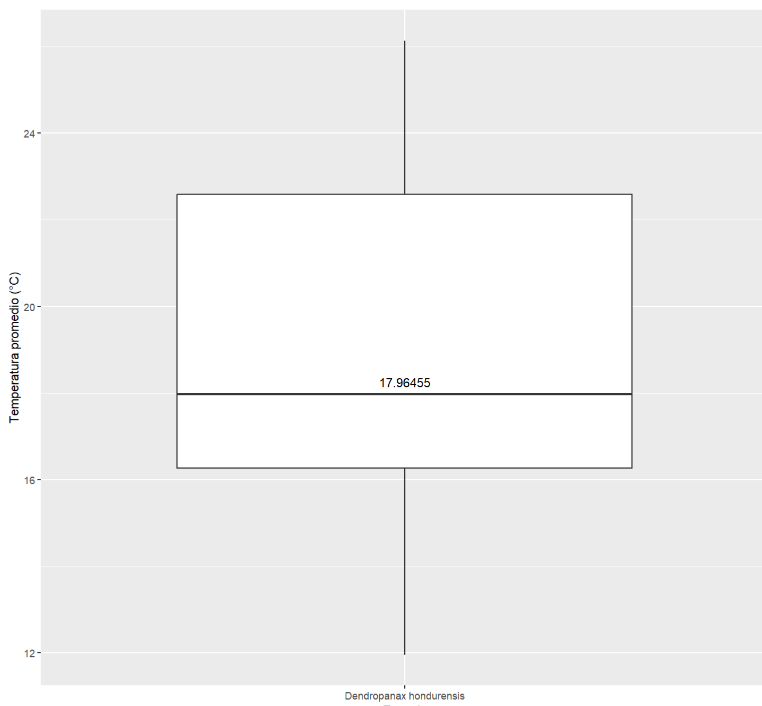
Note: x-axis represents the species of interest. y-axis represents precipitation in mm. The value in the boxplot refers to the median of the species.

Figure 7. *Average precipitation according to niche modelling M_1_F_q for Dendropanax hondurensis.*



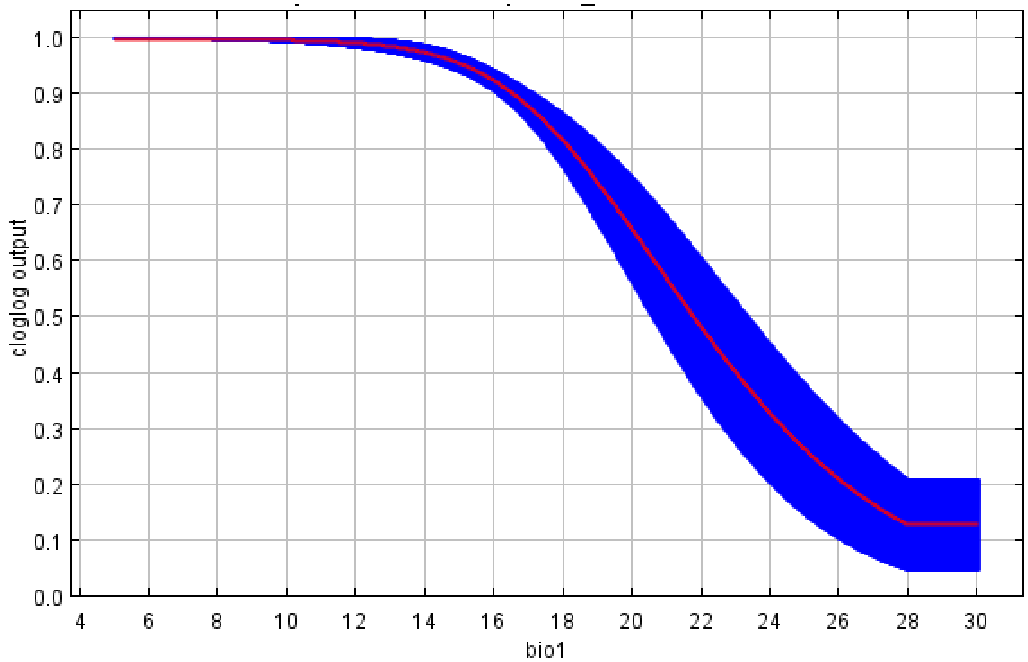
Note: x-axis represents the amount of precipitation in millimeters (bio12). y-axis represents the probability of occurrence of the species. Red line represents the mean of 10 model replicates. Blue area delimits one standard deviation.

Figure 8. *Average temperature of Dendropanax hondurensis occurrence points.*



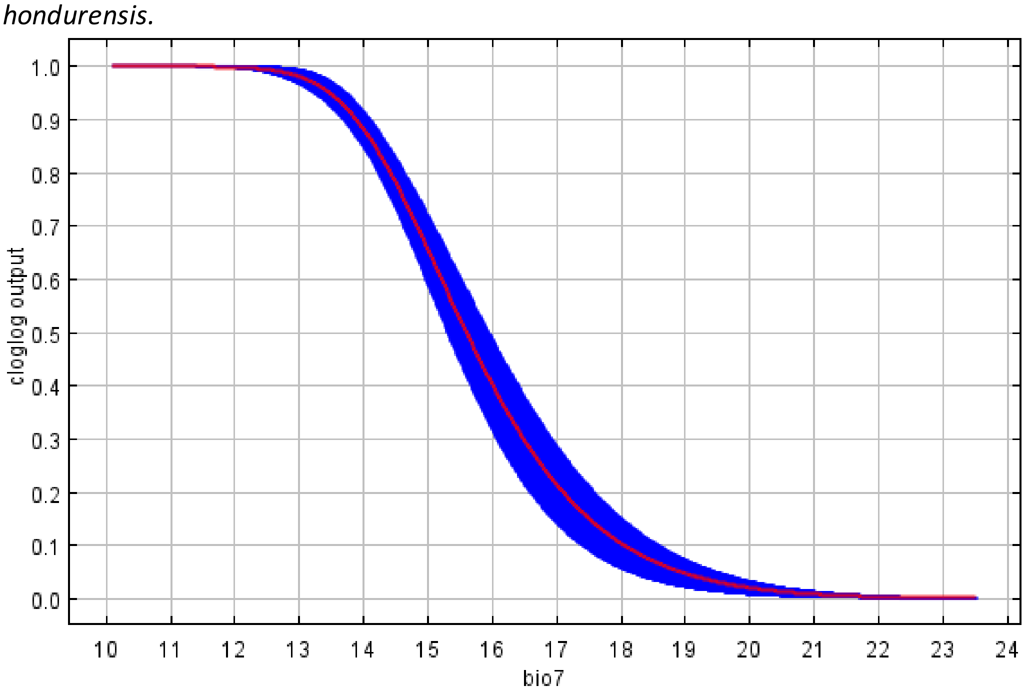
Note: x-axis represents the species of interest. y-axis represents temperature in °C. The value in the boxplot refers to the median of the species.

Figure 9. *Average temperature according to niche modelling M_1_F_q for Dendropanax hondurensis*.



Note: x-axis represents the amount of temperature (bio1). y-axis represents the probability of occurrence of the species. Red line represents the mean of 10 model replicates. Blue area delimits one standard deviation.

Figure 10. *Annual temperature range according to niche modelling M_1_F_q for Dendropanax hondurensis.*



Note: x-axis represents the annual temperature range (bio7). y-axis represents the probability of occurrence of the species. Red line represents the mean of 10 model replicates. Blue area delimits one standard deviation.

Table 1. *Percent contribution of modelled variables of Dendropanax hondurensis to the occurrence of the species.*

Variable	% of contribution
bio 1	42.5
bio 7	32.1
bio 12	20
bio 4	4.2
bio 15	1.2

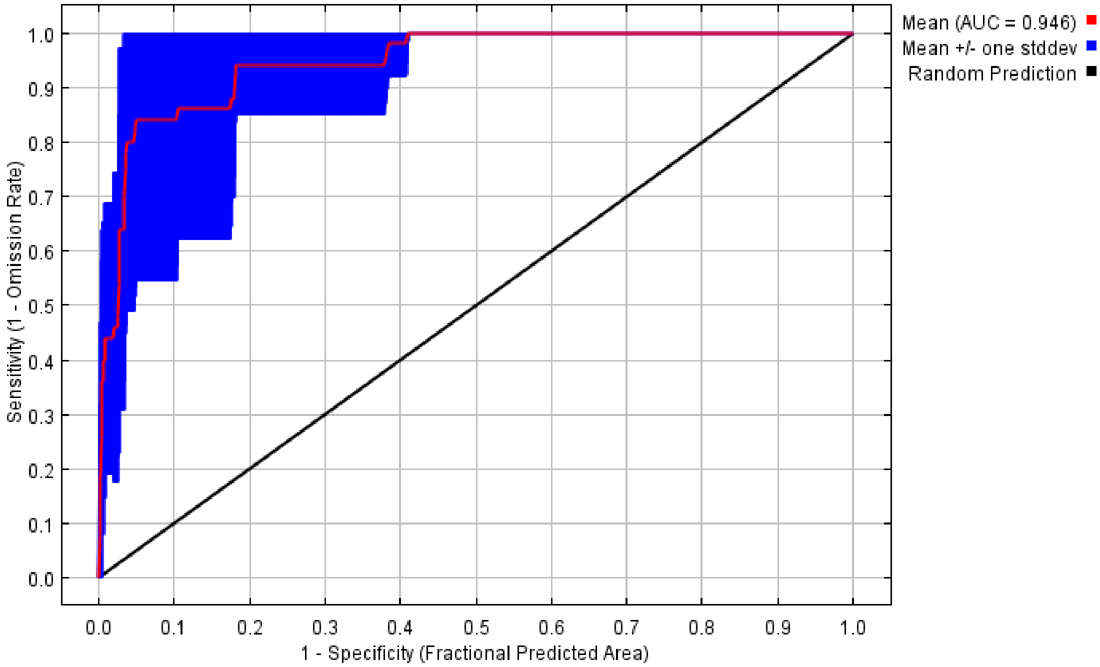
Note: bio 1 refers to mean annual temperature, bio 7 to annual temperature range, bio 12 to mean annual precipitation, bio 4 to seasonality of temperature (standard deviation x 100) and bio 15 to seasonality of precipitation.

Eugenia coyolensis

The model for this species was made with 11 points in total, it presents an AUC of 0.946 (Figure 11), however, the uncertainty is greater and is denoted in the standard deviation, this suggests that the model is not completely reliable, although it presents a good AUC value. In general, the problem with this model is not the number of points but the small dispersion of the points in the geographic space, making it impossible to fully document the range of variation of preference of the species. The model selected for this species was M_1_F_lt.

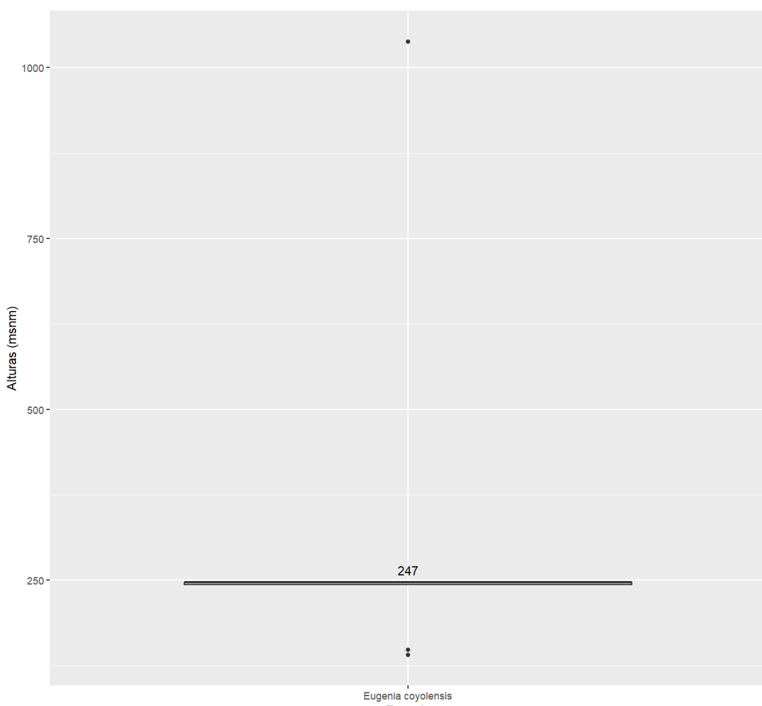
Regarding descriptive statistics, it is observed that the points are located at 247 meters above sea level (Figure 12), it is in a precipitation range between 1252.5 and 1296.5 mm (Figure 13). Regarding the precipitation of the niche modelling, it is observed that the standard deviation is quite high, which makes the data uncertain for this variable in the model, however, it seems that the species prefers precipitation values less than 1600 mm (Figure 14). In terms of temperature this species is found at 26.34°C (Figure 15). According to niche modelling the species prefers average temperatures higher than 26°C (Figure 16). Finally, from the modelling, information was obtained on bioclimatic variable 2, which consists of the temperature variation between day and night, where it is observed that the species prefers variation ranges greater than 10.5°C, therefore, future scenarios seem to benefit the species, since it is expected that there will be a greater occurrence of extreme temperatures, increasing this range (Figure 17). Bioclimatic variable 2 is the most important variable for the occurrence of the species with a 50.1% contribution (Table 2).

Figure 11. *AUC curve of Eugenia coyolensis.*



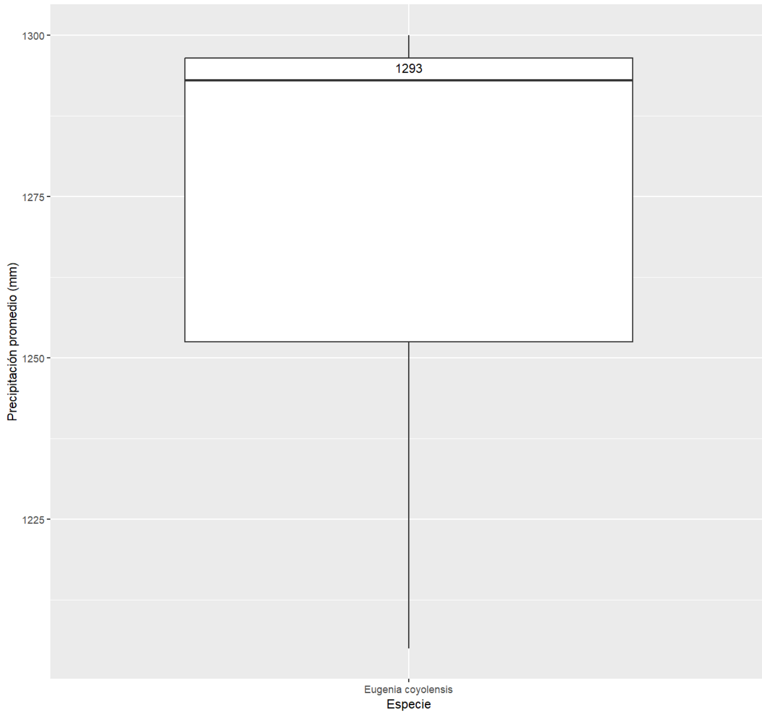
Note: x-axis refers to the specificity of the model, y-axis refers to the sensitivity. Red line represents the mean of the replicates. Blue area represents standard deviation. Black line represents a random hypothetical model.

Figure 12. *Average height of Eugenia coyolensis occurrence points.*



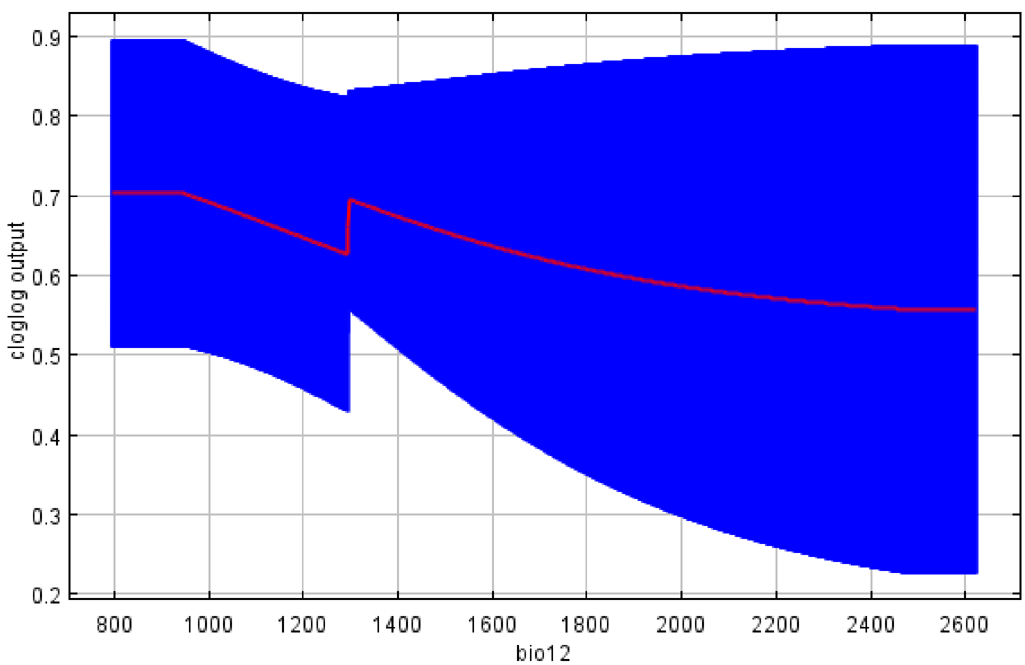
Note: x-axis represents the species of interest. Y-axis represents the height in meters above sea level. The value in the boxplot refers to the median of the species.

Figure 13. *Average precipitation of Eugenia coyolensis occurrence points.*



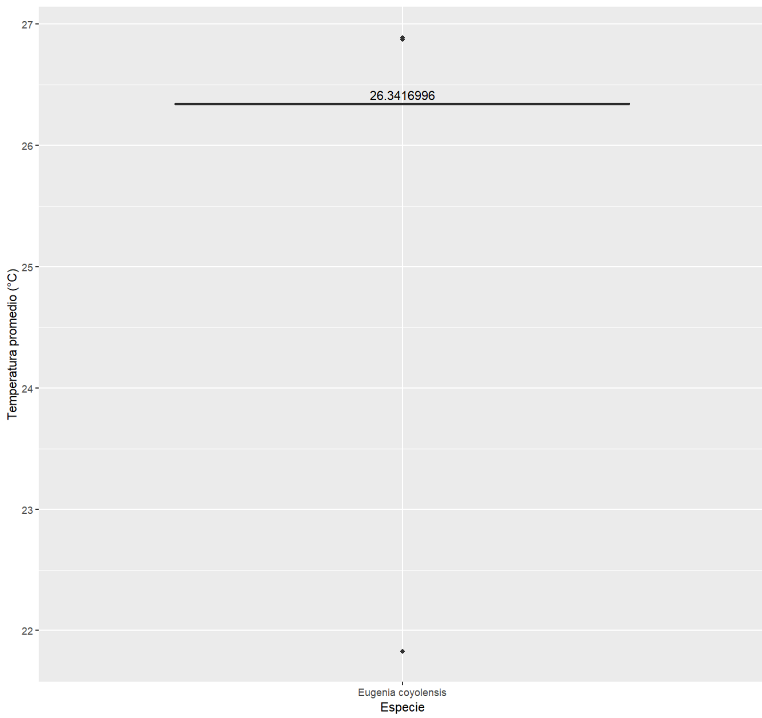
Note: x-axis represents the species of interest. y-axis represents precipitation in mm. The value in the boxplot refers to the median of the species.

Figure 14. *Average precipitation according to niche modelling M_1_F_lt for Eugenia coyolensis.*



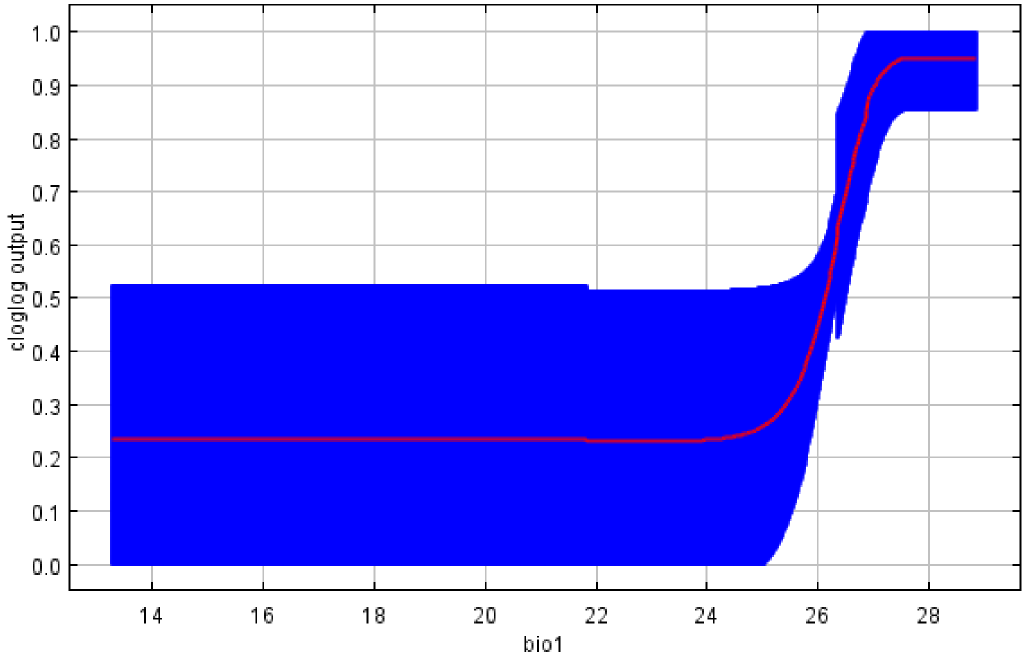
Note: x-axis represents the amount of precipitation in millimeters (bio12). y-axis represents the probability of occurrence of the species. Red line represents the mean of 10 model replicates. Blue area delimits one standard deviation.

Figure 15. *Average temperature of Eugenia coyolensis occurrence points.*



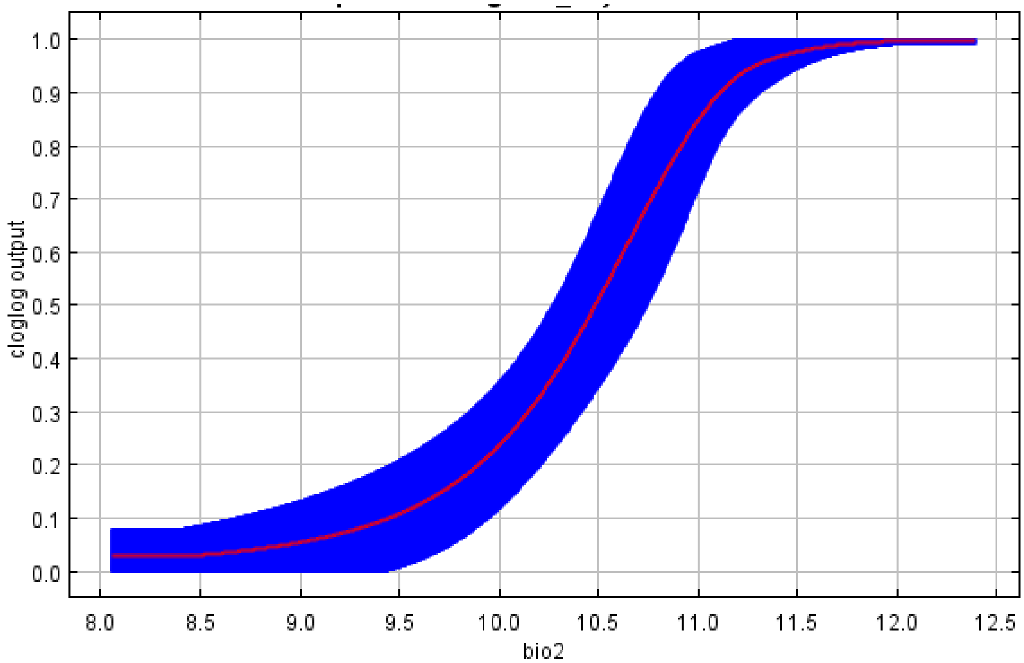
Note: x-axis represents the species of interest. y-axis represents temperature in °C. The value in the boxplot refers to the median of the species.

Figure 16. *Average temperature according to niche modelling M_1_F_lt for Eugenia coyolensis.*



Note: x-axis represents the amount of temperature (bio1). y-axis represents the probability of occurrence of the species. Red line represents the mean of 10 model replicates. Blue area delimits one standard deviation.

Figure 17. *Daily temperature range according to niche modelling M_1_F_lt for Eugenia coyolensis.*



Note: x-axis represents the daily temperature range (bio2). y-axis represents the probability of occurrence of the species. Red line represents the mean of 10 model replicates. Blue area delimits one standard deviation.

Table 2. *Percent contribution of modelled Eugenia coyolensis variables to species occurrence.*

Variable	% of contribution
bio 2	50.1
bio 1	35.9
bio 18	9.4
bio 12	3.9
bio 4	0.8

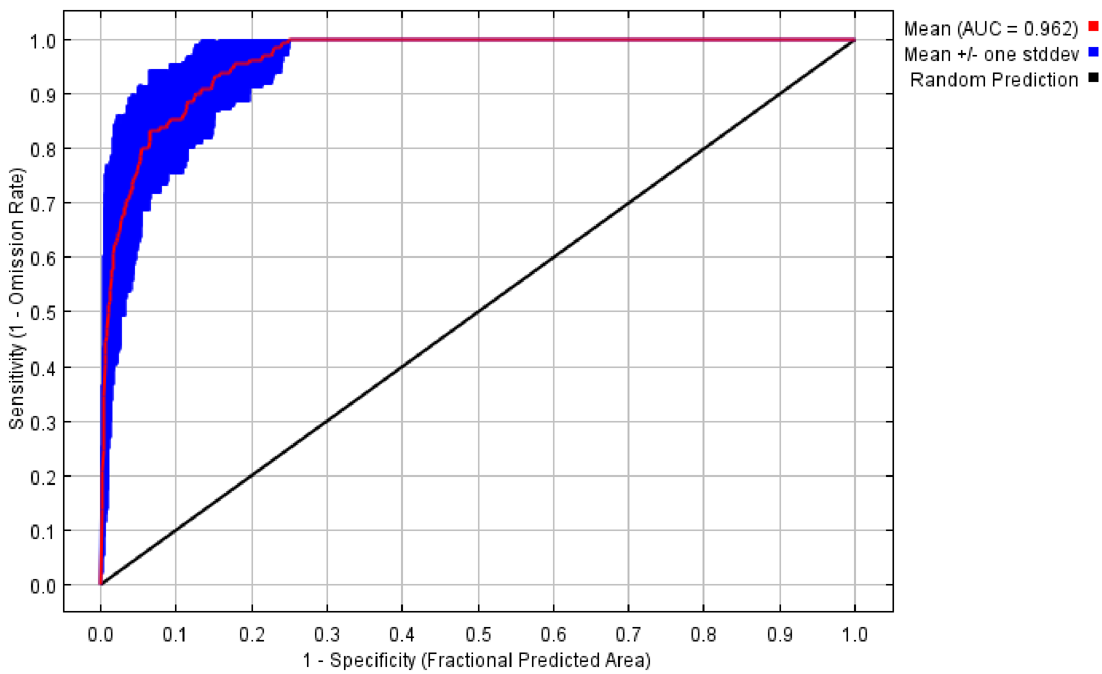
Note: bio 2 refers to daily temperature range, bio 1 to annual average temperature, bio 18 refers to warmest room precipitation, bio 12 to average annual precipitation, bio 4 to seasonality of temperature (standard deviation x 100).

Lonchocarpus yoroensis

The model for this species was made with 21 points in total, it presents an AUC of 0.962 (Figure 18), it is a model that adjusts quite well to reality, it also presents little standard deviation, so this model is quite reliable. The model used for this species was M_1_F_lqt.

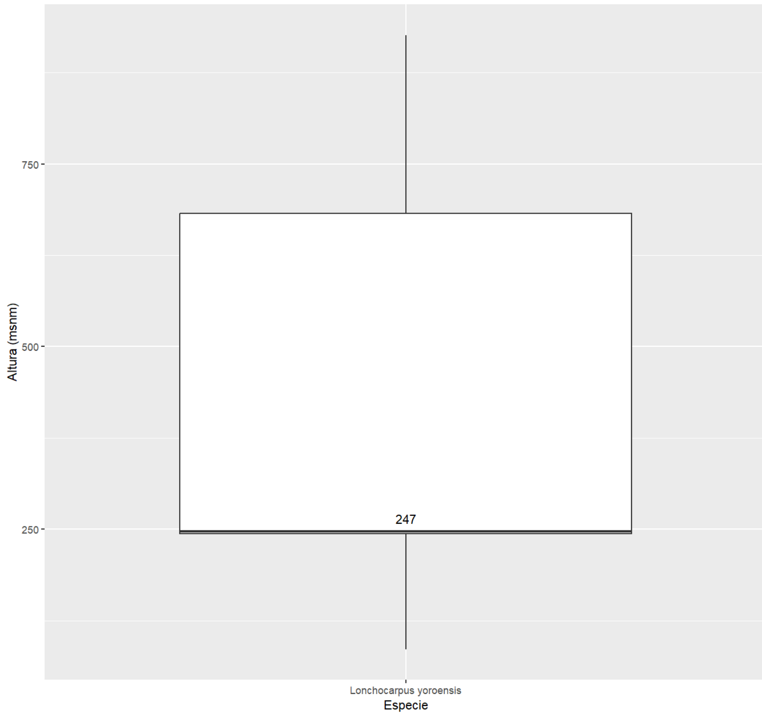
The descriptive statistics show that 50% of the occurrences are between 244 and 682 meters above sea level (Figure 19). In the case of precipitation, it is observed that the species is found in a range between 1116mm to 1300mm (Figure 20), the niche model reflects that the species prefers values below 1400mm, increasing its occurrence the drier the environment (Figure 21). In terms of temperature, the species is found in a range of 23.6°C to 26.1 °C (Figure 22). The modelling predicts that the species is found in average temperatures above 20°C, increasing its occurrence the higher the temperature increases. The standard deviation at lower temperatures is too wide, so it is necessary to evaluate this variable with more points; however, above 23.5°C the certainty is greater (Figure 23). Finally, the bioclimatic variable 2 of daily temperature range was analysed (Figure 24), this species shows a pattern contrary to *E. coyolensis*, since it prefers a smaller variation at 10.5°C. This analysis is validated when analyzing all the modelled variables, as bioclimatic variable 2 is the second most predictive of the probability of the species (Table 3). This species is slightly more vulnerable to variations in climate due to climate change, since an increase in extreme events would increase the variation.

Figure 18. *AUC curve of Lonchocarpus yoroensis.*



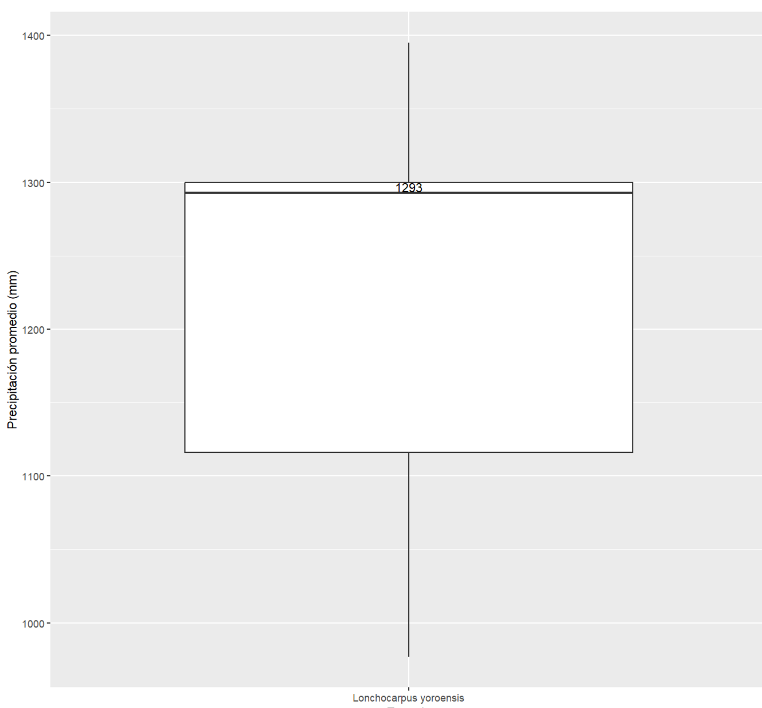
Note: x-axis refers to the specificity of the model, y-axis refers to the sensitivity. Red line represents the mean of the replicates. Blue area represents standard deviation. Black line represents a random hypothetical model.

Figure 19. *Average height of Lonchocarpus yoroensis occurrence points.*



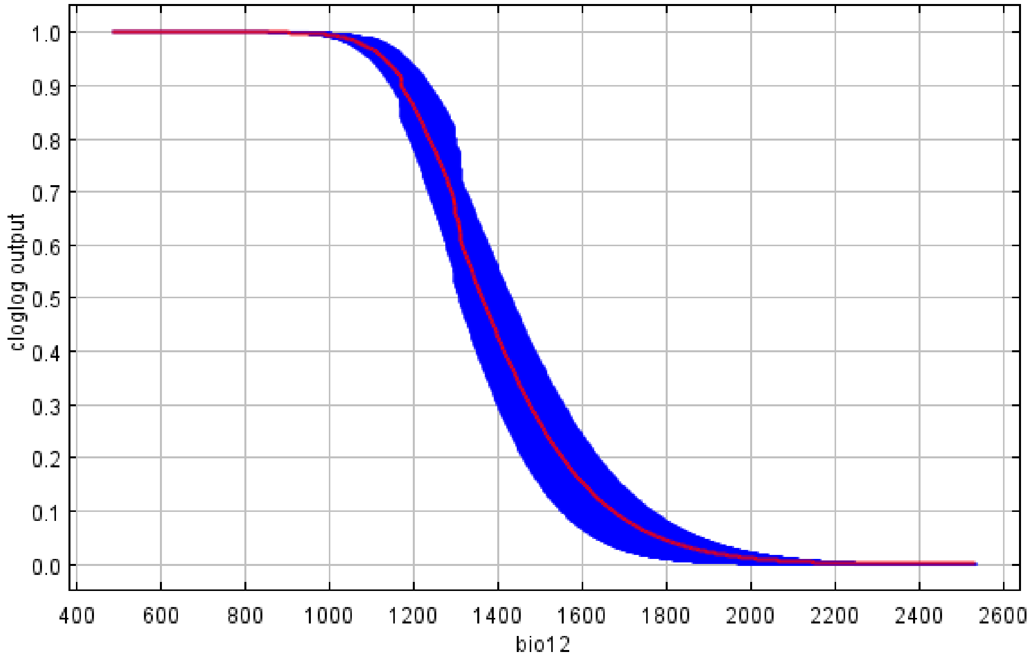
Note: x-axis represents the species of interest. Y-axis represents the height in meters above sea level. The value in the boxplot refers to the median of the species.

Figure 20. *Average precipitation of Lonchocarpus yoroensis occurrence points.*



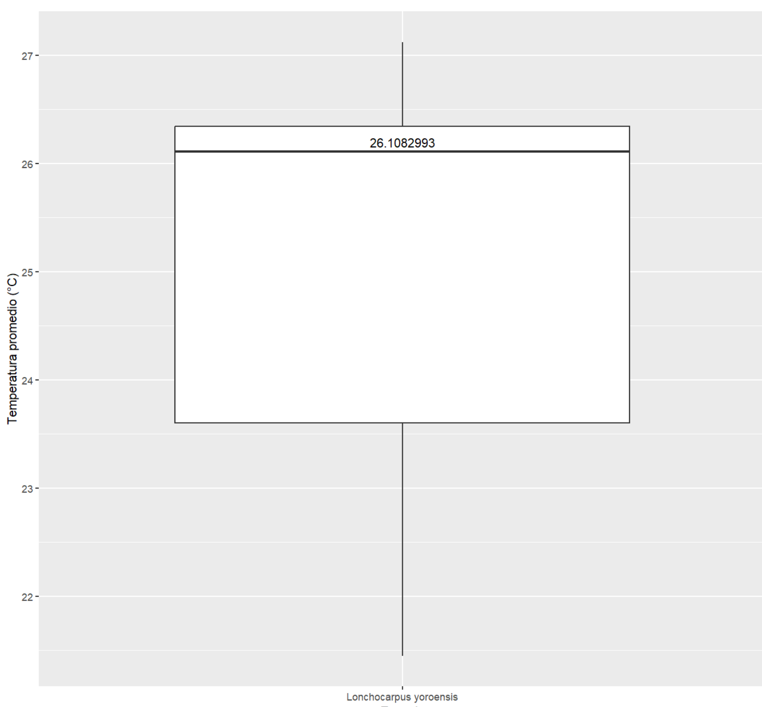
Note: x-axis represents the species of interest. y-axis represents precipitation in mm. The value in the boxplot refers to the median of the species.

Figure 21. *Average precipitation according to niche modelling M_1_F_lqt for Lonchocarpus yoroensis.*



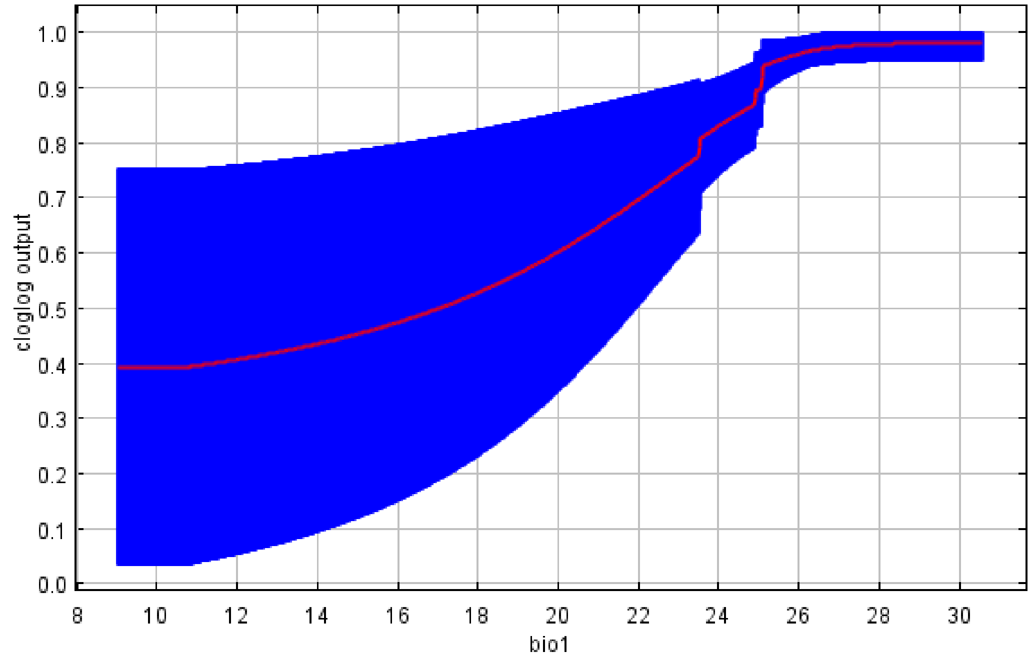
Note: x-axis represents the amount of precipitation in millimeters (bio12). y-axis represents the probability of occurrence of the species. Red line represents the mean of 10 model replicates. Blue area delimits one standard deviation.

Figure 22. *Average temperature of Lonchocarpus yoroensis occurrence points.*



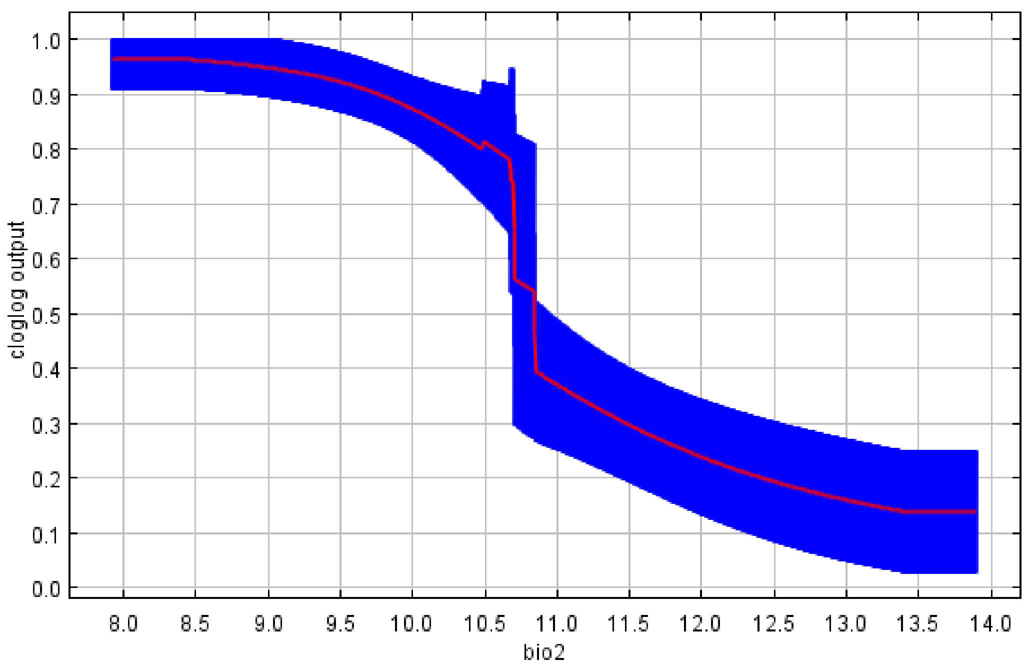
Note: x-axis represents the species of interest. y-axis represents temperature in °C. The value in the boxplot refers to the median of the species.

Figure 23. *Average temperature according to niche modelling M_1_F_lqt for Lonchocarpus yoroensis.*



Note: x-axis represents the amount of temperature (bio1). y-axis represents the probability of occurrence of the species. Red line represents the mean of 10 model replicates. Blue area delimits one standard deviation.

Figure 24. *Daily temperature range according to niche modelling M_1_F_lqt for Lonchocarpus yoroensis.*



f the species. Red line represents the mean of 10 model replicates. Blue area delimits one standard deviation.

Table 3. *Percent contribution of modelled Lonchocarpus yoroensis variables to species occurrence.*

Variable	% of contribution
bio 12	35.3
bio 2	25.1
bio 1	17.9
bio 3	9.9
bio 15	6.4
bio 19	5.3

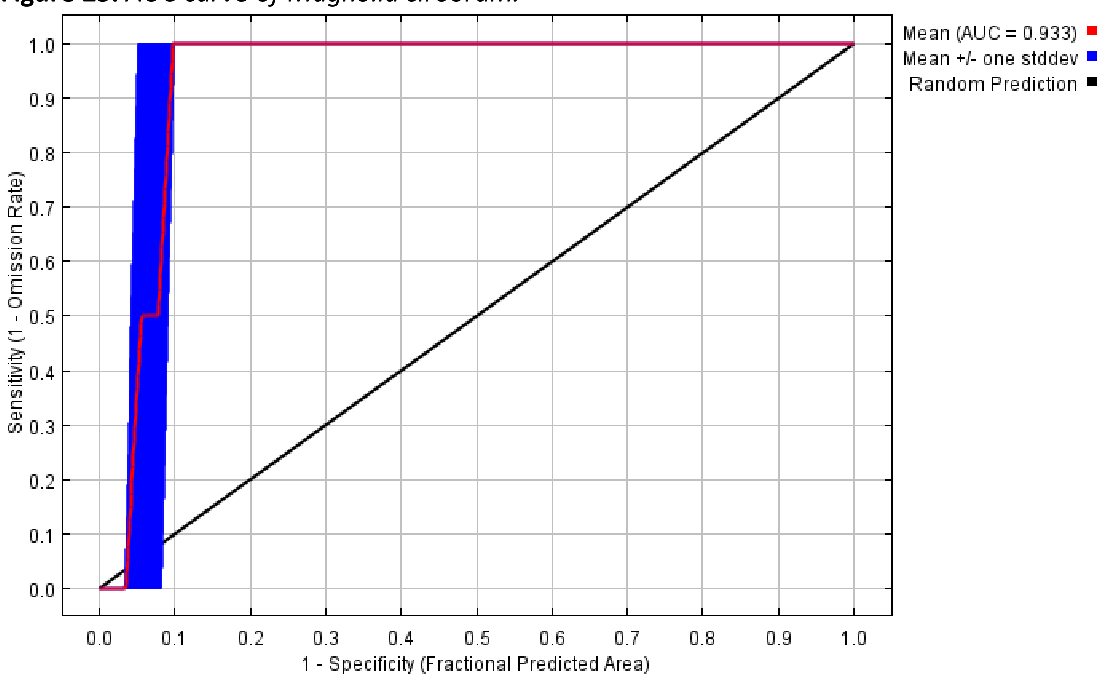
Note: bio 12 refers to average annual precipitation, bio 2 to daily temperature range, bio 1 to average annual temperature, bio 3 refers to isothermality, bio 15 refers to precipitation seasonality and bio 19 refers to precipitation of the coldest room.

Magnolia ciroorum

The model for this species was made with 13 points in total, it presents an AUC 0.933, the model used was M_2_F_lh (Figure 25). Again, the problem with this model is that the points are concentrated in a very small region, this model is the least reliable of all.

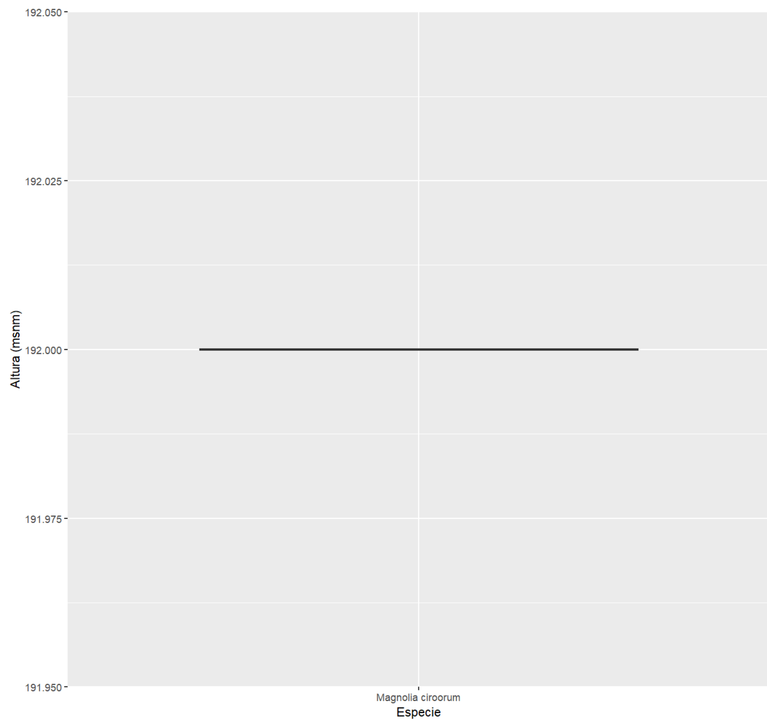
The descriptive statistics show that the species is found at 192-371 masl (Figure 26), in the case of average precipitation it is observed that the species is found between 1475 and 1833 mm (Figure 27). Precipitation in the model does not yield specific precipitation values and has a standard deviation that is too high (Figure 28). In the case of the average temperature, it is observed that the species is between 25.27 and 26.125°C (Figure 29), the average temperature was not modelled because it was highly correlated with the average precipitation. It can be observed that the variables are not correctly modelled, since most of them have 0% importance in the occurrence of the species and only 1 has 100% importance (Table 4).

Figure 25. *AUC curve of Magnolia ciroorum.*



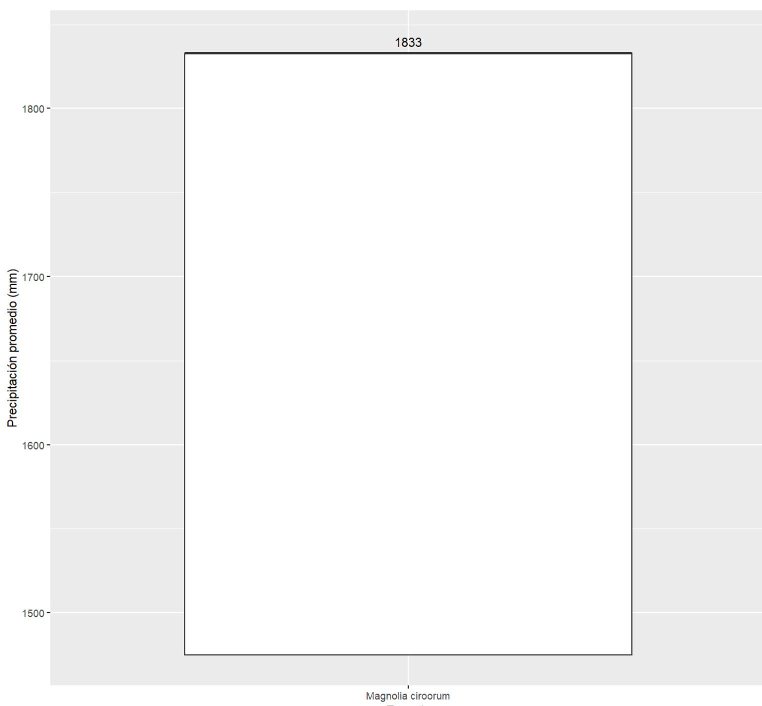
Note: x-axis refers to the specificity of the model, y-axis refers to the sensitivity. Red line represents the mean of the replicates. Blue area represents standard deviation. Black line represents a random hypothetical model.

Figure 26. *Average height of Magnolia ciroorum occurrence points.*



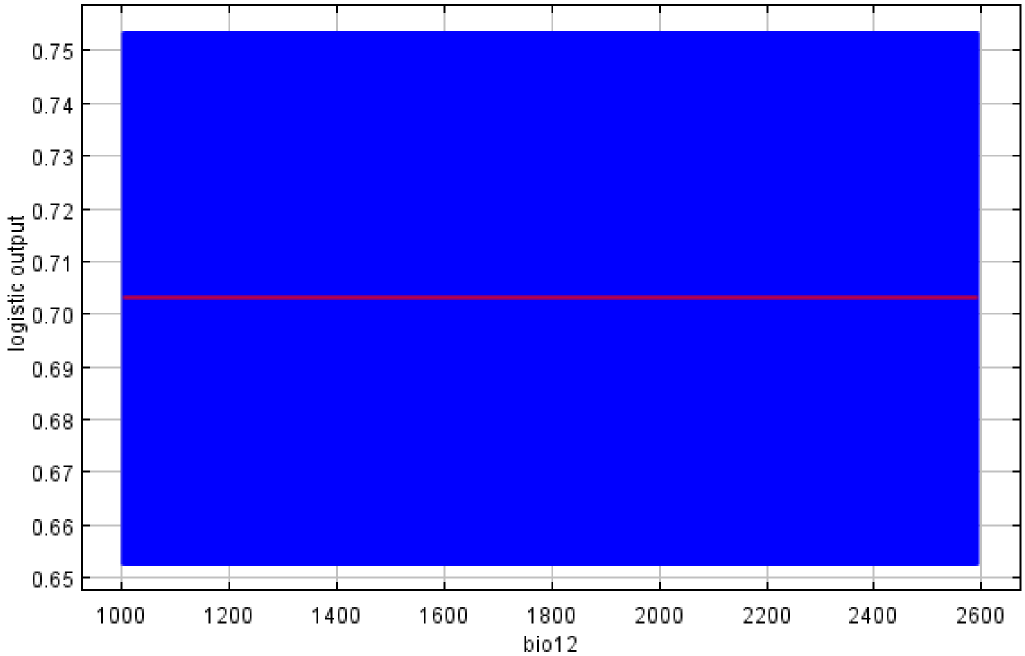
Note: x-axis represents the species of interest. Y-axis represents the height in meters above sea level. The value in the boxplot refers to the median of the species.

Figure 27. *Average precipitation of Magnolia ciroorum occurrence points.*



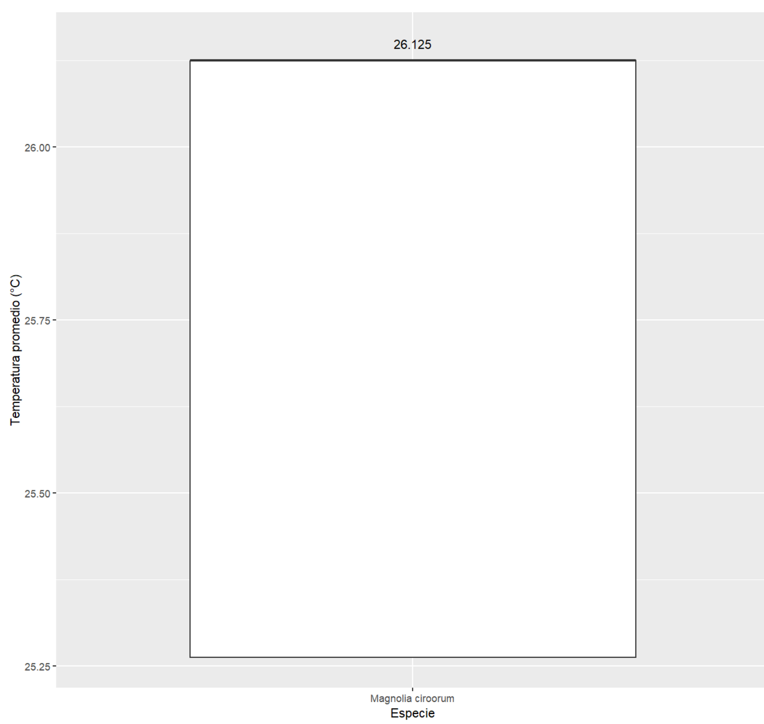
Note: x-axis represents the species of interest. y-axis represents precipitation in mm. The value in the boxplot refers to the median of the species.

Figure 28. *Average precipitation according to niche modelling M_2_F_lh for Magnolia ciroorum.*



Note: x-axis represents the amount of precipitation in millimeters (bio12). y-axis represents the probability of occurrence of the species. Red line represents the mean of 10 model replicates. Blue area delimits one standard deviation.

Figure 29. *Average temperature of Magnolia ciroorum occurrence points.*



Note: x-axis represents the amount of temperature (bio1). y-axis represents the probability of occurrence of the species. Red line represents the mean of 10 model replicates. Blue area delimits one standard deviation.

Table 4. *Percent contribution of modelled Magnolia ciroorum variables to species occurrence.*

Variable	% of contribution
bio 18	100
bio 7	0
bio 4	0
bio 2	0
bio 15	0
bio 12	0

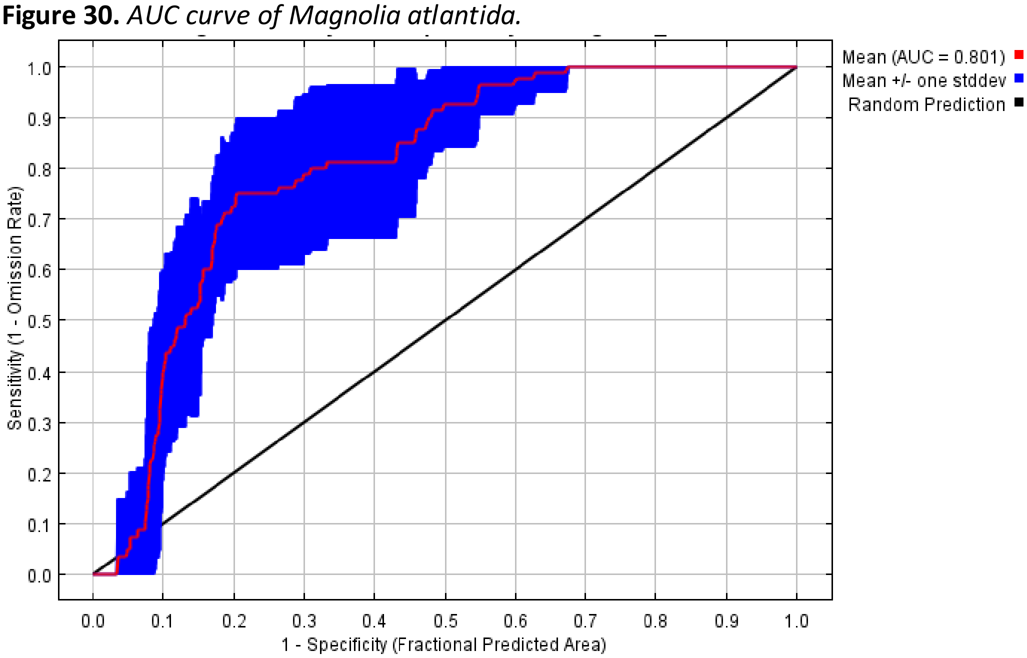
Note: bio 18 refers to warmest room precipitation, bio 7 refers to annual temperature range, bio 4 refers to temperature seasonality, bio 12 refers to average annual precipitation, bio 2 to daily temperature range, bio 15 to precipitation seasonality.

Magnolia atlantida

The modelling of this species was performed with 12 points. It presents an AUC of 0.801 with a moderate standard deviation, i.e. this model is slightly good, it does not present the best AUC, but its deviation is not exaggerated either. The model used for the projections was M_1_F_l (Figure 30).

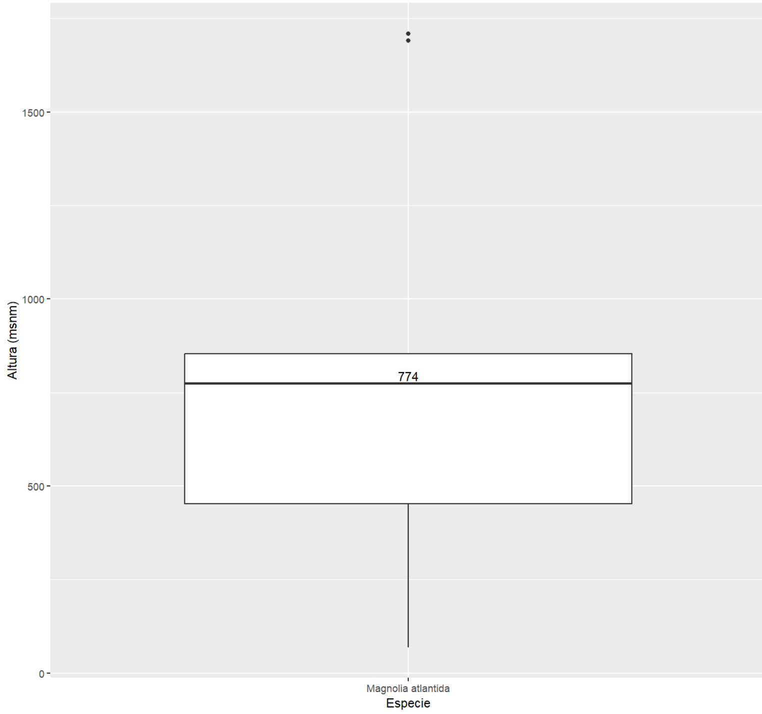
In the case of the descriptive statistics analysis, it is observed that the species is found between 452 and 852 meters above sea level (Figure 31). In terms of average precipitation, the species is found between 1229 and 1396.5 mm (Figure 32). The modelled precipitation variable shows that the species prefers sites with precipitation between 1000 to 1500 mm (Figure 33). The average temperature reflects that the ideal range of the species is between 22.67 to 23.91°C (Figure 34). From the modelled average temperature, it is not possible to make certain statements because the variable presents too much standard deviation (Figure 35). Finally, the daily temperature range indicates that the species prefers sites with a range no greater than 9.4°C (Figure 36). According to Table 5, variables 12 and 2 represent almost 80% of the importance when modelling the occurrence of the species.

Figure 30. *AUC curve of Magnolia atlantida.*



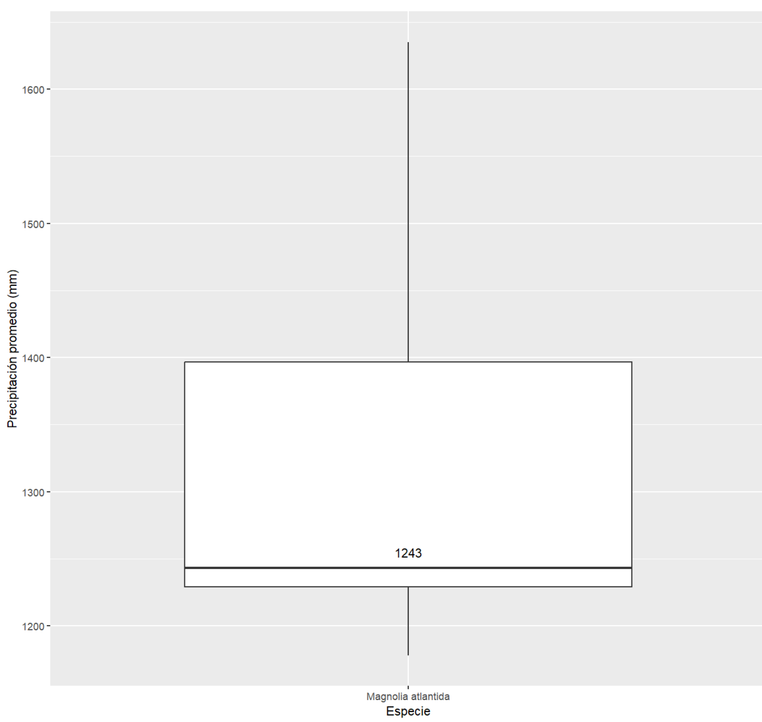
Note: x-axis refers to the specificity of the model, y-axis refers to the sensitivity. Red line represents the mean of the replicates. Blue area represents standard deviation. Black line represents a random hypothetical model.

Figure 31. *Average height of Magnolia atlantida occurrence points.*



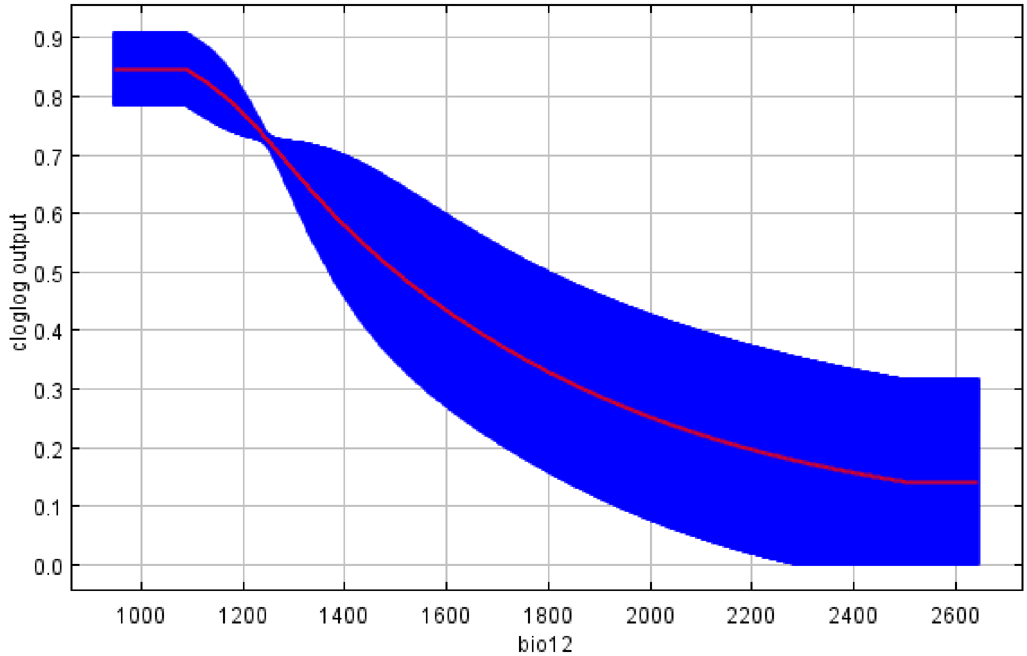
Note: x-axis represents the species of interest. Y-axis represents the height in meters above sea level. The value in the boxplot refers to the median of the species.

Figure 32. *Average precipitation of Magnolia atlantida occurrence points.*



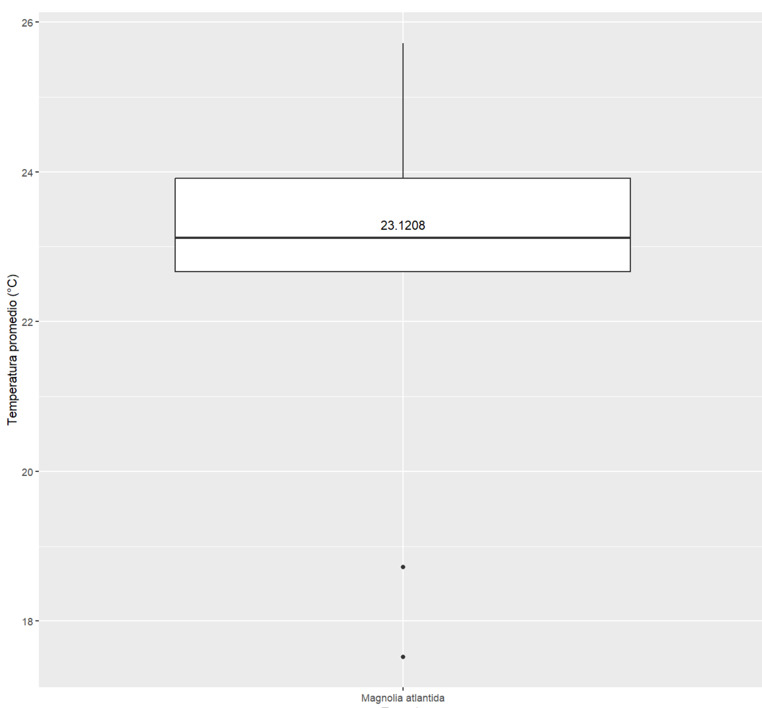
Note: x-axis represents the species of interest. y-axis represents precipitation in mm. The value in the boxplot refers to the median of the species.

Figure 33. *Average precipitation according to niche modelling M_1_F_l for Magnolia atlantida.*



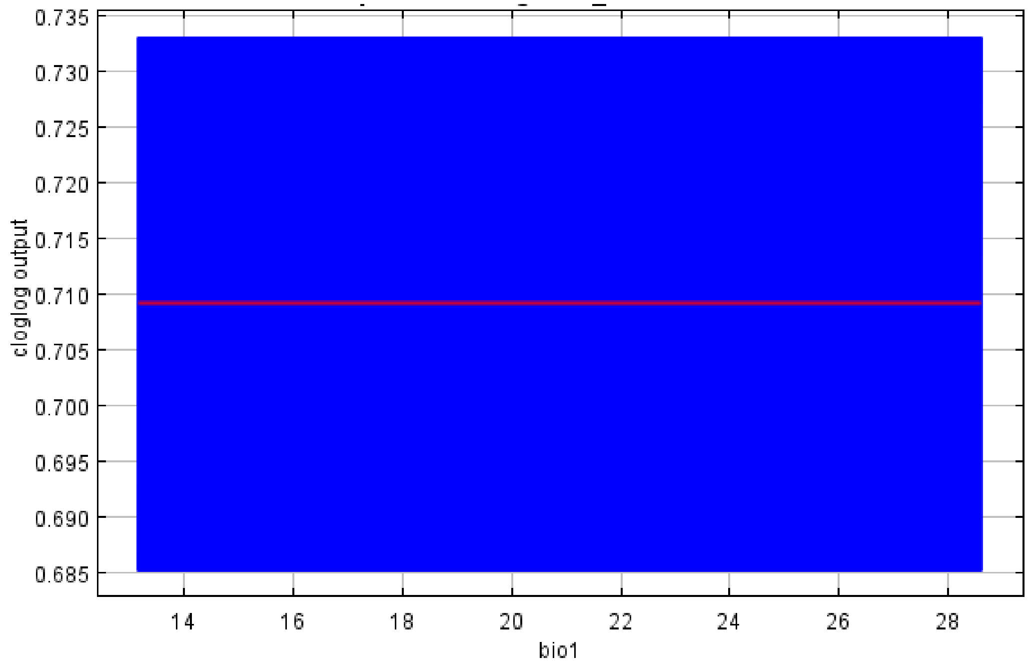
Note: x-axis represents the amount of precipitation in millimeters (bio12). y-axis represents the probability of occurrence of the species. Red line represents the mean of 10 model replicates. Blue area delimits one standard deviation.

Figure 34. *Average temperature of Magnolia atlantida occurrence points.*



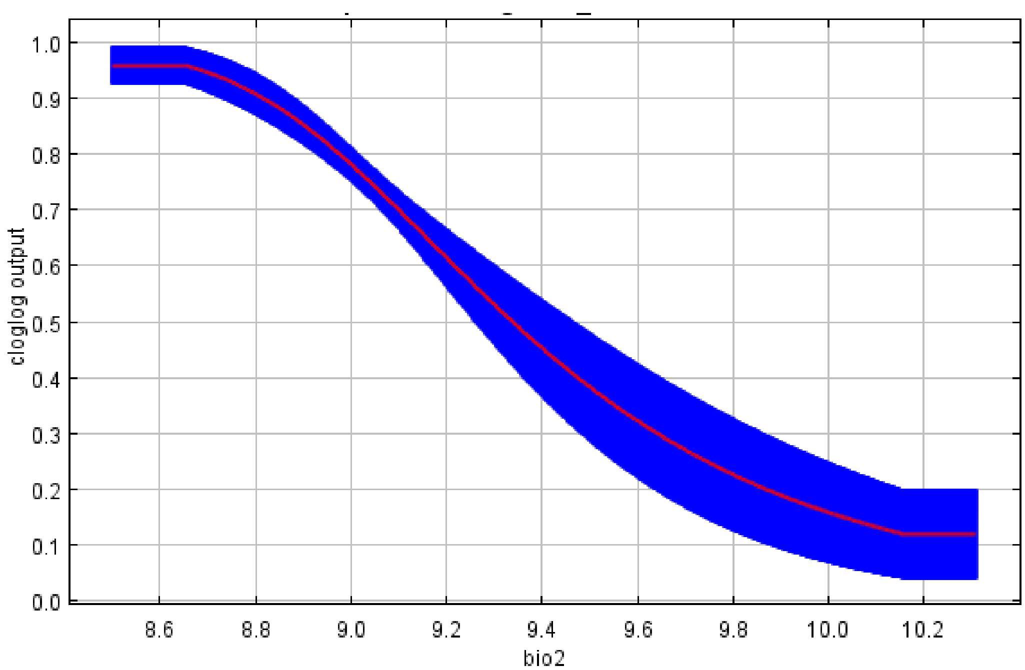
Note: x-axis represents the amount of temperature (bio1). y-axis represents the probability of occurrence of the species. Red line represents the mean of 10 model replicates. Blue area delimits one standard deviation.

Average temperature according to niche modelling M_1_F_l for Magnolia atlantida.



Note: x-axis represents the amount of temperature (bio1). y-axis represents the probability of occurrence of the species. Red line represents the mean of 10 model replicates. Blue area delimits one standard deviation.

Figure 36. *Daily temperature range according to niche modelling M_1_F_l for Magnolia atlantida.*



Note: x-axis represents the daily temperature range (bio2). y-axis represents the probability of occurrence of the species. Red line represents the mean of 10 model replicates. Blue area delimits one standard deviation.

Table 5. *Percent contribution of modelled Magnolia atlantida variables to species occurrence.*

Variable	% of contribution
bio 2	45.8
bio 12	35.2
bio 15	18.7
bio 4	0.4
bio 1	0

Note: bio 2 refers to daily temperature range, 12 to average annual precipitation, bio 15 to seasonality of precipitation, bio 4 to seasonality of temperature, bio 1 refers to average annual temperature.

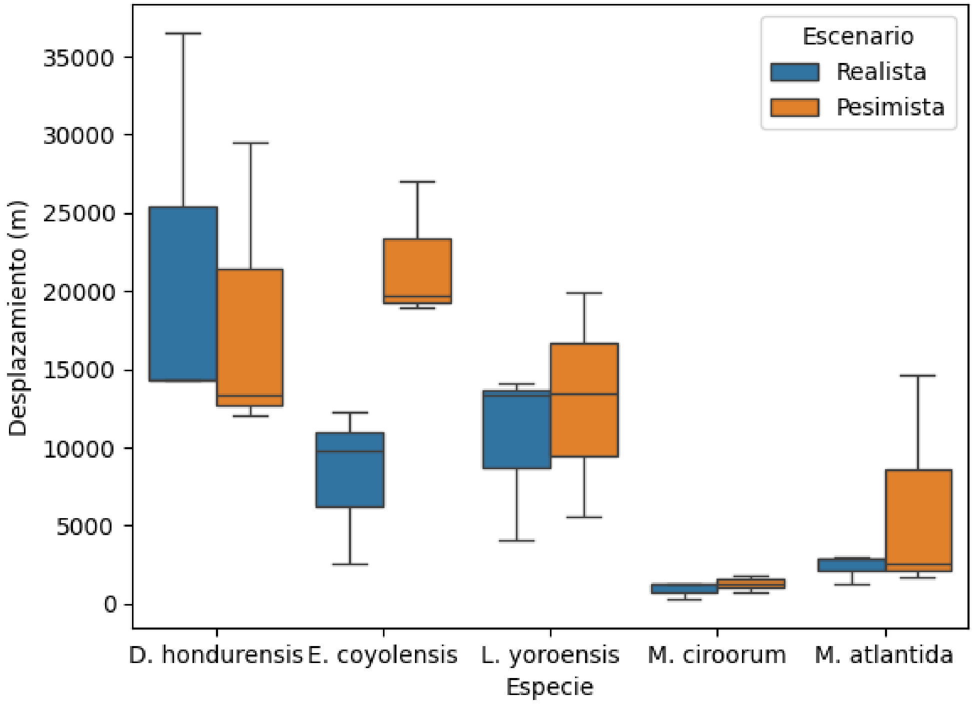
Centroid Displacement

In decreasing order of greatest displacement in the realistic scenario, *D. hondurensis* has the greatest displacement (Figure 37). The species moves the most in the pessimistic 2040 to 2060 period with 29.5km. It is followed by *L. yoroensis* with similar perspectives between the realistic and pessimistic scenarios. This was followed by *E. coyolensis, with* the greatest displacement in the pessimistic scenario by far, and *M. atlantida* in second to last place, followed by *M. ciroorum* in last place. *M. ciroorum* was the model with the fewest number of points of presence, which meant that its M was quite small, implying that the displacement is smaller, since it is a recent species with few records.

Regarding the scenarios (Figure 38), it can be observed that displacement is relatively similar between the current-2040 and 2040-2060 periods, interestingly, displacement tends to be lower in 2080. Finally, Table 6 shows the displacement totals according to each scenario at 2080 realistic scenario and 2100 pessimistic scenario. Here it is corroborated that *D. hondurensis* will show the greatest displacement of centroids; it is also important to highlight the difference in displacement between the pessimistic and realistic scenarios for *M. atlantida*.

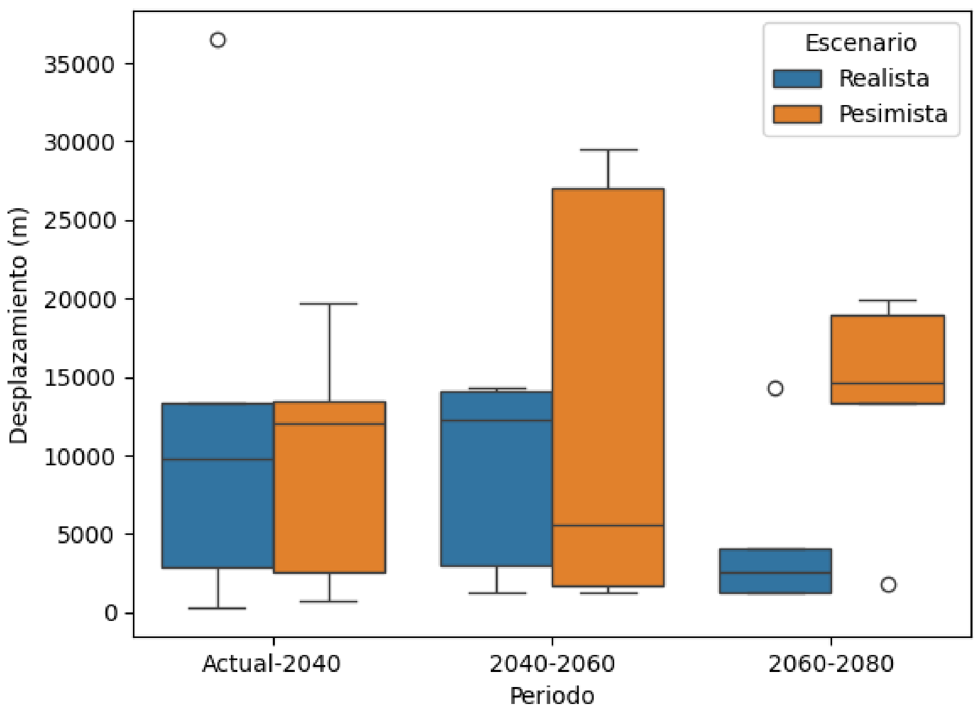
In terms of heights, *D. hondurensis* is the species that is found at the highest altitude of all. In the realistic scenario, *E. coyolensis* presents the greatest increase in height, followed by *D. hondurensis, M. atlantida* and *M. ciroorum* decrease in height in this scenario. It is interesting to note that the year 2060 is the year in which all species increase the most in height on average (Table 7, Figure 39). In the pessimistic scenario, the same two species show the greatest increase in height, the only one showing a decrease is *M. atlantida*. The 2100 period shows the greatest change in heights (Table 8, Figure 40).

Figure 37. *In-plane displacement by species of the five species under analysis.*



Note: X-axis represents the species under analysis. y-axis represents the displacement in meters. Each color represents the scenario analysed.

Figure 38. *In-plane displacement by period of the five species under analysis.*



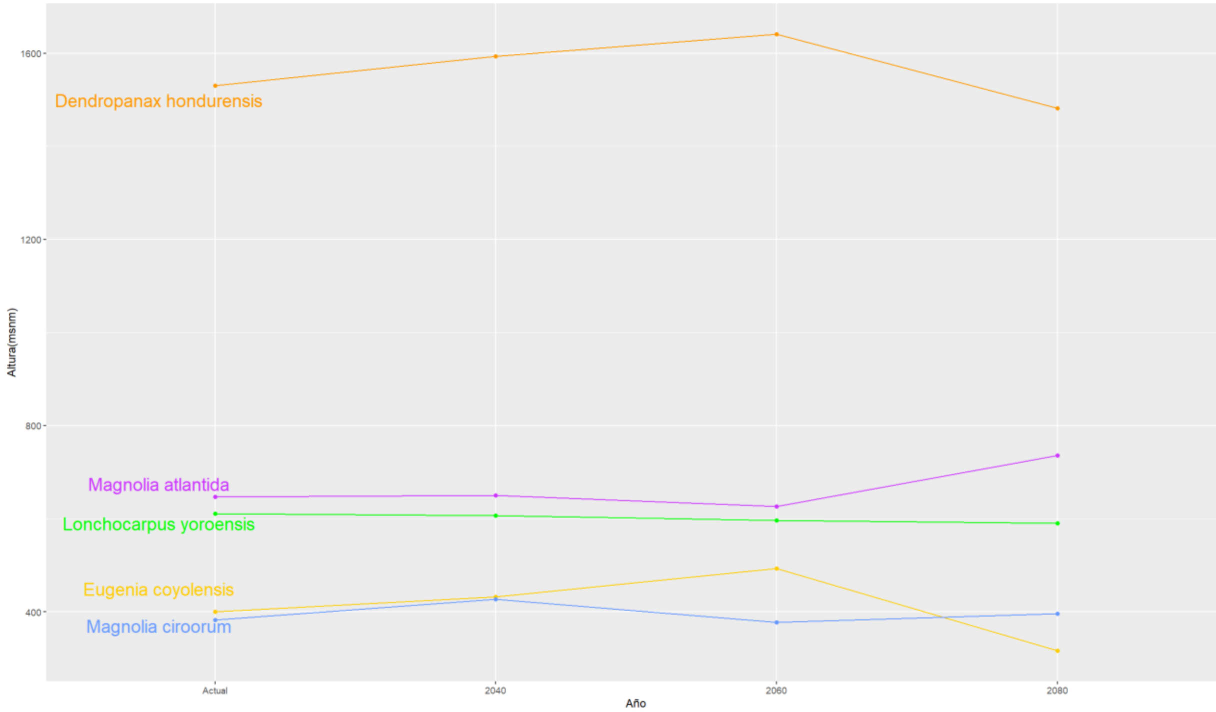
Note: X-axis represents the period under analysis. y-axis represents the displacement in meters. Each color represents the scenario under analysis.

Table 6. *Total species displacement in realistic and pessimistic scenarios.*

Species	Scenario	Travel (km)
Dendropanax hondurensis	Realistic	37.54
Dendropanax hondurensis	Pessimistic	43.61
Eugenia coyolensis	Realistic	19.42
Eugenia coyolensis	Pessimistic	13.41
Lonchocarpus yoroensis	Realistic	4.78
Lonchocarpus yoroensis	Pessimistic	4.78
Magnolia ciroorum	Realistic	0.31
Magnolia ciroorum	Pessimistic	0.55
Magnolia atlantida	Realistic	5.52
Magnolia atlantida	Pessimistic	17.26

Note: the total displacement is determined by subtracting the 2080 or 2100 scenario minus the current scenario.

Figure 39. *Graph of heights for each species per year in a realistic scenario.*



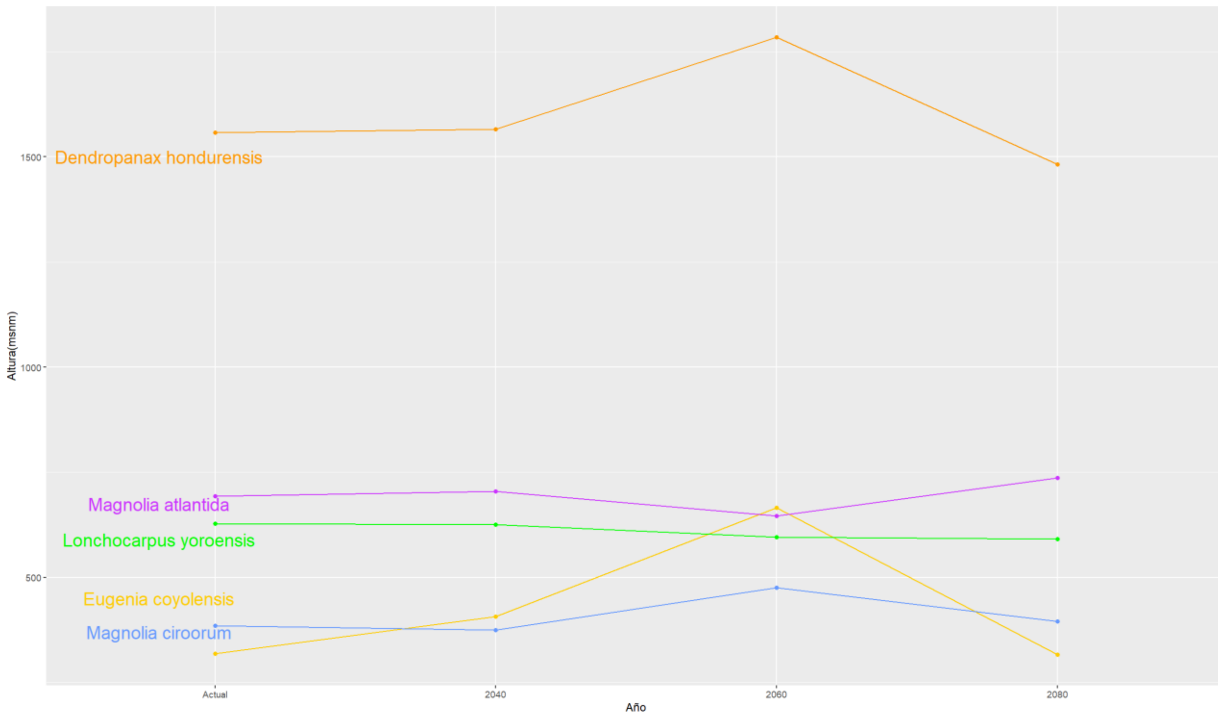
Note: x-axis refers to the year under analysis, y-axis represents height in meters. Each line refers to a specific species.

Table 7. *Altitudinal displacement values in realistic scenario.*

Species	Current	2040	2060	2080	Total
Dendropanax hondurensis	1482.41	47.94	63.00	48.13	159.07
Magnolia atlantida	736.08	-88.58	3.06	-23.68	-109.20
Lonchocarpus yoroensis	590.72	20.21	-4.37	-10.36	5.48
Magnolia ciroorum	395.72	-13.53	45.14	-50.31	-18.70
Eugenia coyolensis	316.88	83.06	31.76	61.54	176.36
Average	704.36	9.82	27.72	5.06	42.60

Note: Current column refers to the current height of the species polygons. Columns 2040, 2060, 2080 refer to the increase or decrease in height with respect to the previous period. The Total column refers to the delta between the most distant period (2080) and the current period. The pink color indicates a loss, while the green color indicates an increase in height.

Figure 40. *Graph of heights for each species per year in a realistic scenario.*



Note: x-axis refers to the year under analysis, y-axis represents height in meters. Each line refers to a specific species.

Table 8. *Altitudinal displacement values in pessimistic scenario.*

Species	Current	2040	2060	2100	Total
Dendropanax hondurensis	1482.41	75.69	7.22	219.60	302.52
Magnolia atlantida	736.08	-43.01	12.02	-58.56	-89.55
Lonchocarpus yoroensis	590.72	37.41	-2.52	-29.41	5.48
Magnolia ciroorum	395.72	-11.03	-9.95	100.66	79.68
Eugenia coyolensis	316.88	1.55	88.47	258.23	348.26
Average	704.36	12.12	19.05	98.10	129.28

Note: Current column refers to the current height of the species polygons. Columns 2040, 2060, 2080 refer to the increase or decrease in height with respect to the previous period. The Total column refers to the delta between the most distant period (2080) and the current period. The pink color indicates a loss, while the green color indicates an increase in height.

Dendropanax hondurensis

An analysis of the species distribution maps shows that the area where the ideal characteristics of the species are found is decreasing within the PNPB, in the pessimistic scenario to 2100 the area is reduced to approximately 30% of its current distribution. A similar case occurs in the realistic scenario, less drastic, but always with a considerable reduction. The points of presence used in the modelling are also shown to show the variability of climates used in the modelling (Figure 41-48).

Figure 41. *Map of points of presence of Dendropanax hondurensis.*

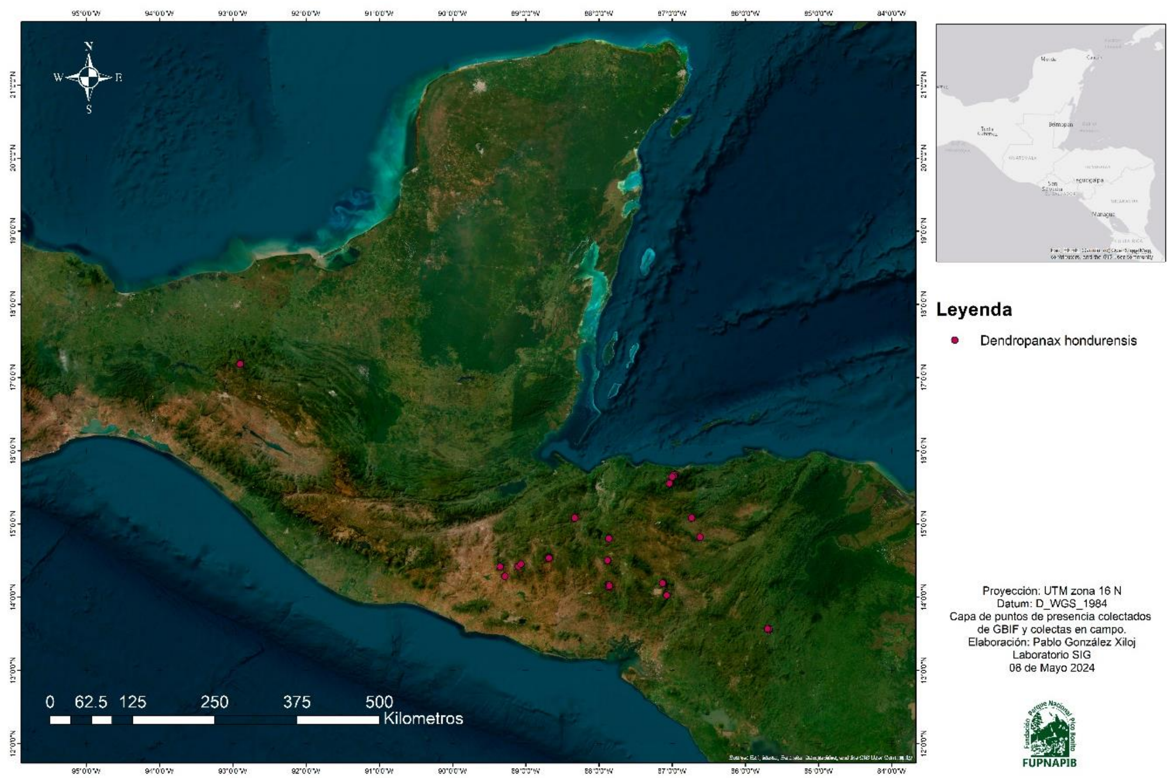
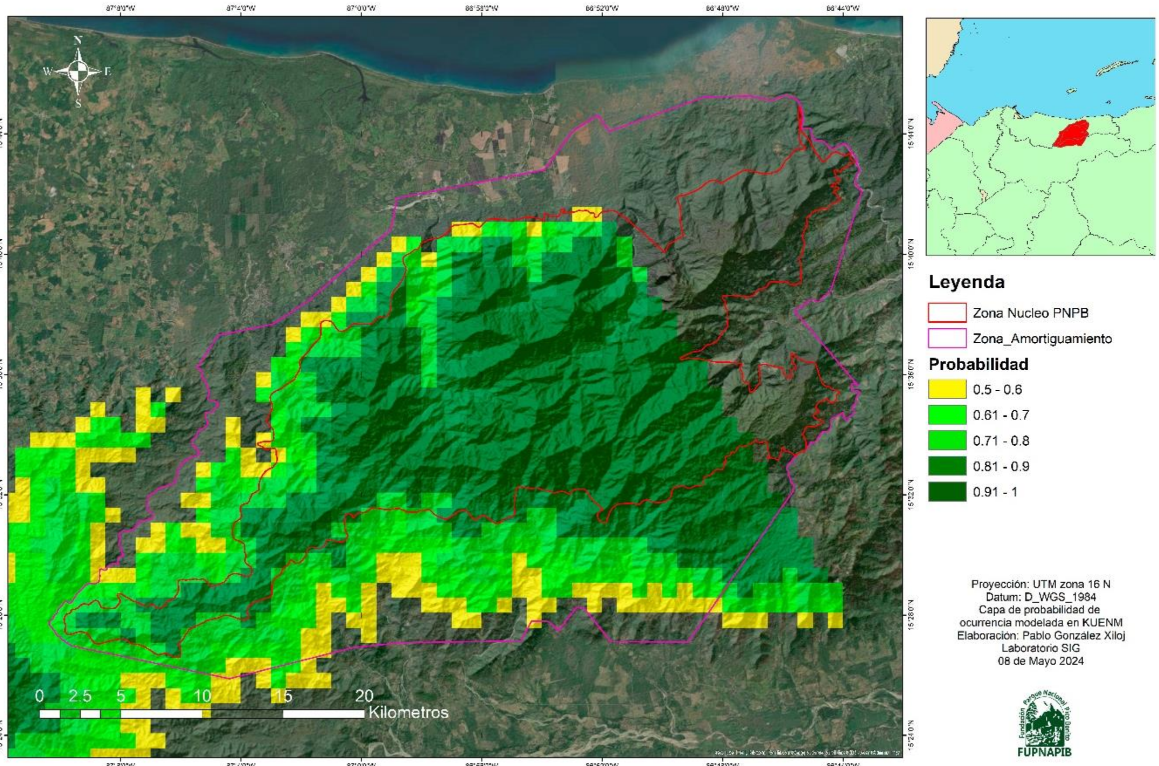
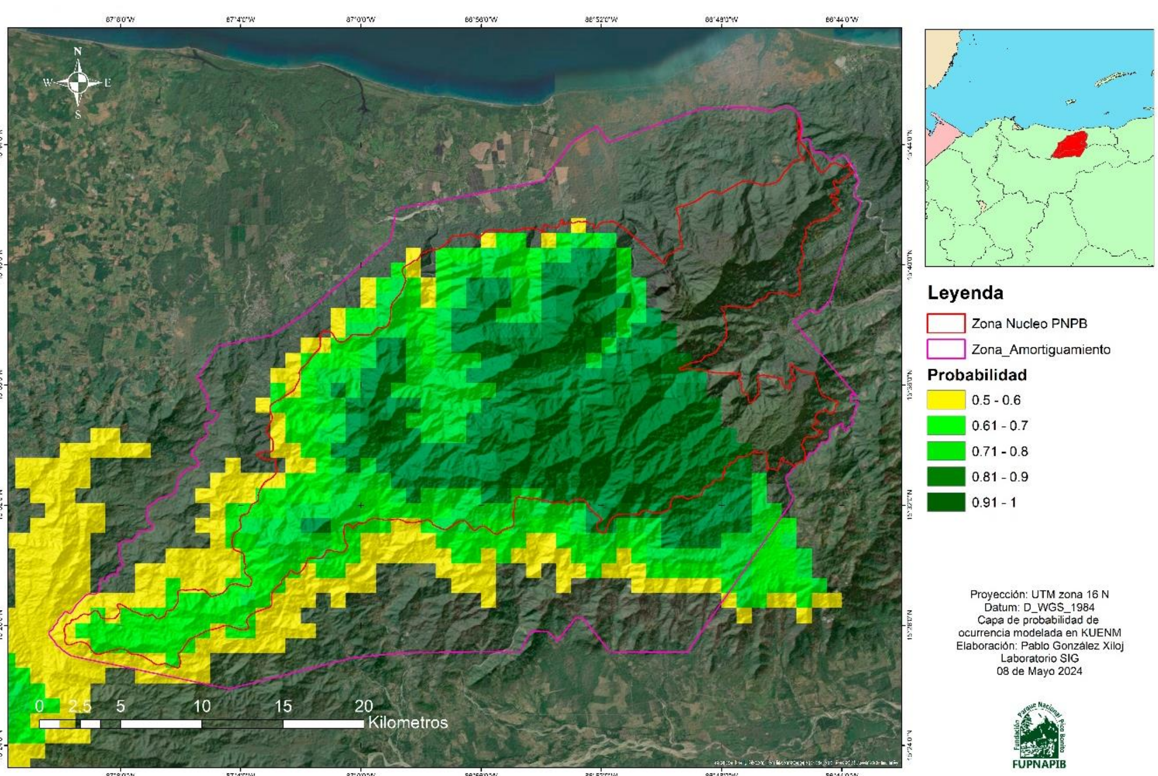


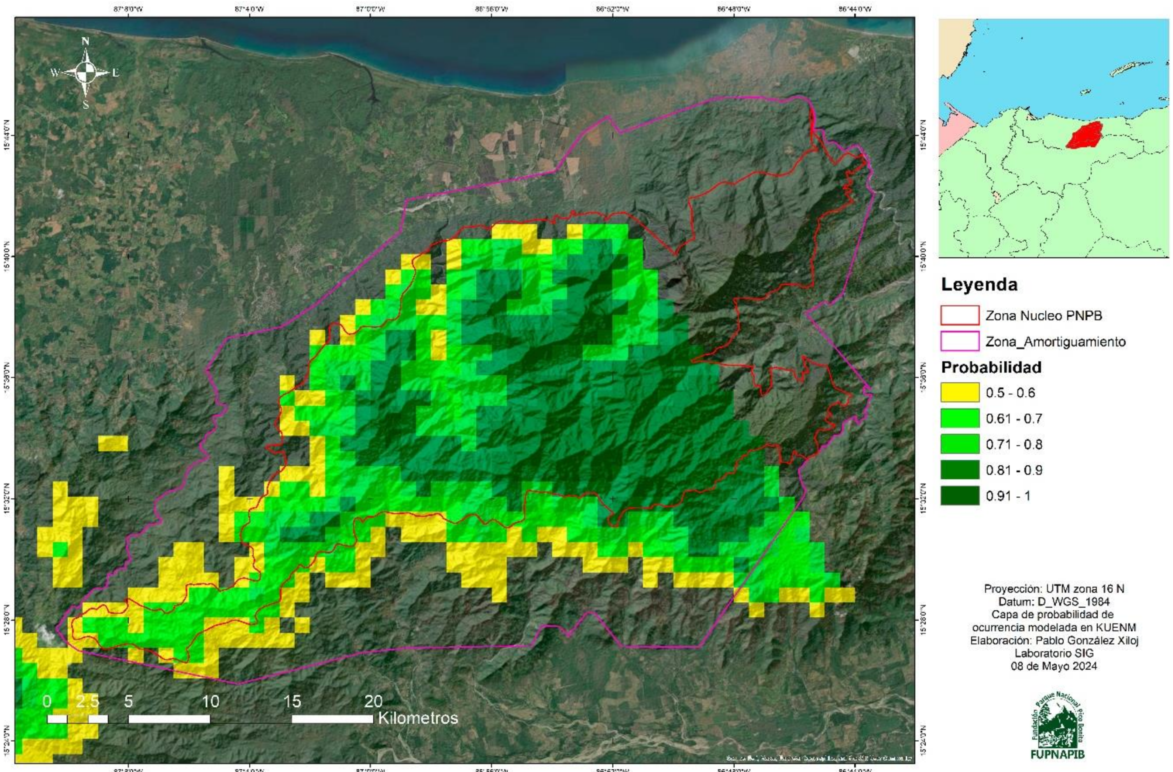
Figure 42. *Map of probability of current occurrence of Dendropanax hondurensis.*



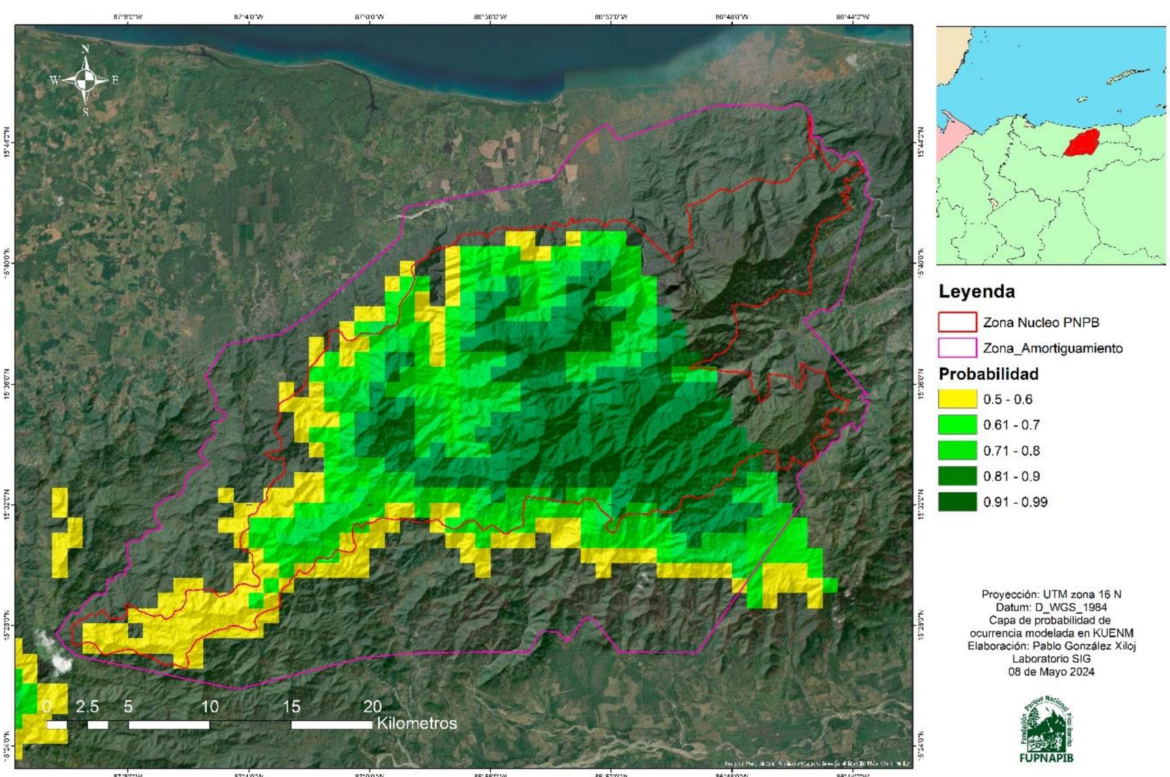
Map of probability of occurrence to 2040 realistic scenario Dendropanax hondurensis.



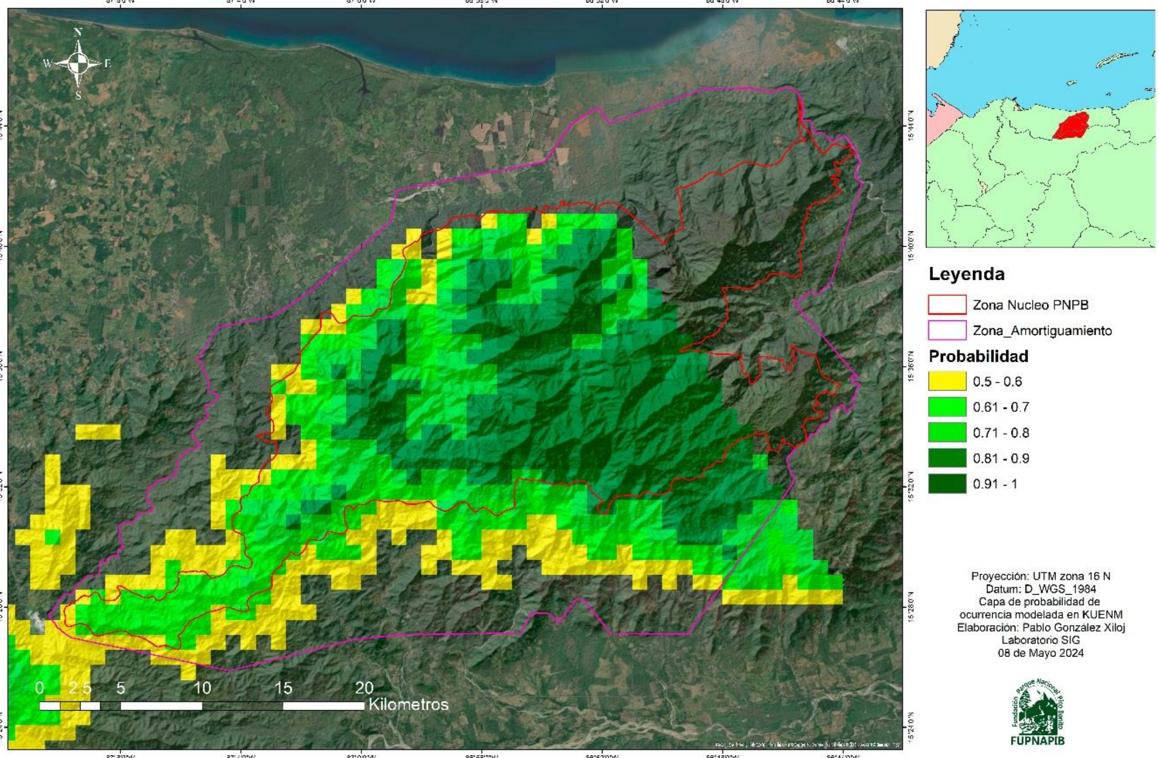
Map of probability of occurrence at 2060 realistic scenario Dendropanax hondurensis.



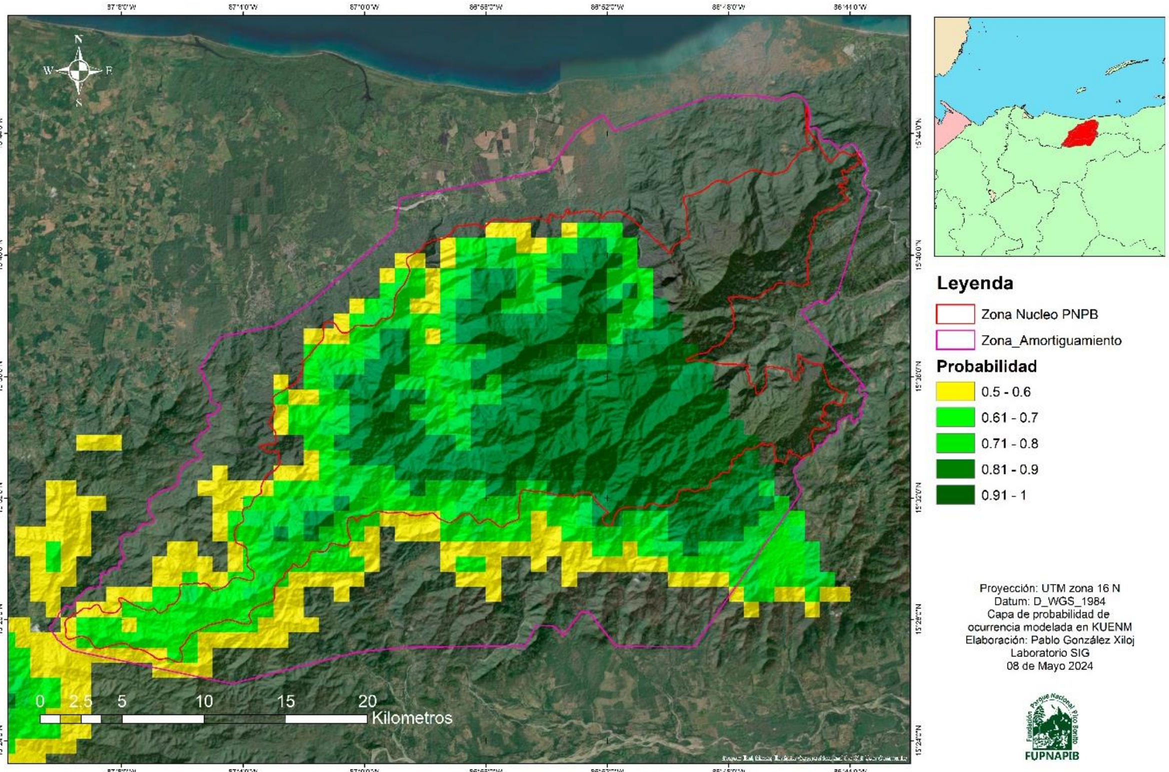
Map of probability of occurrence at 2080 realistic scenario Dendropanax hondurensis.



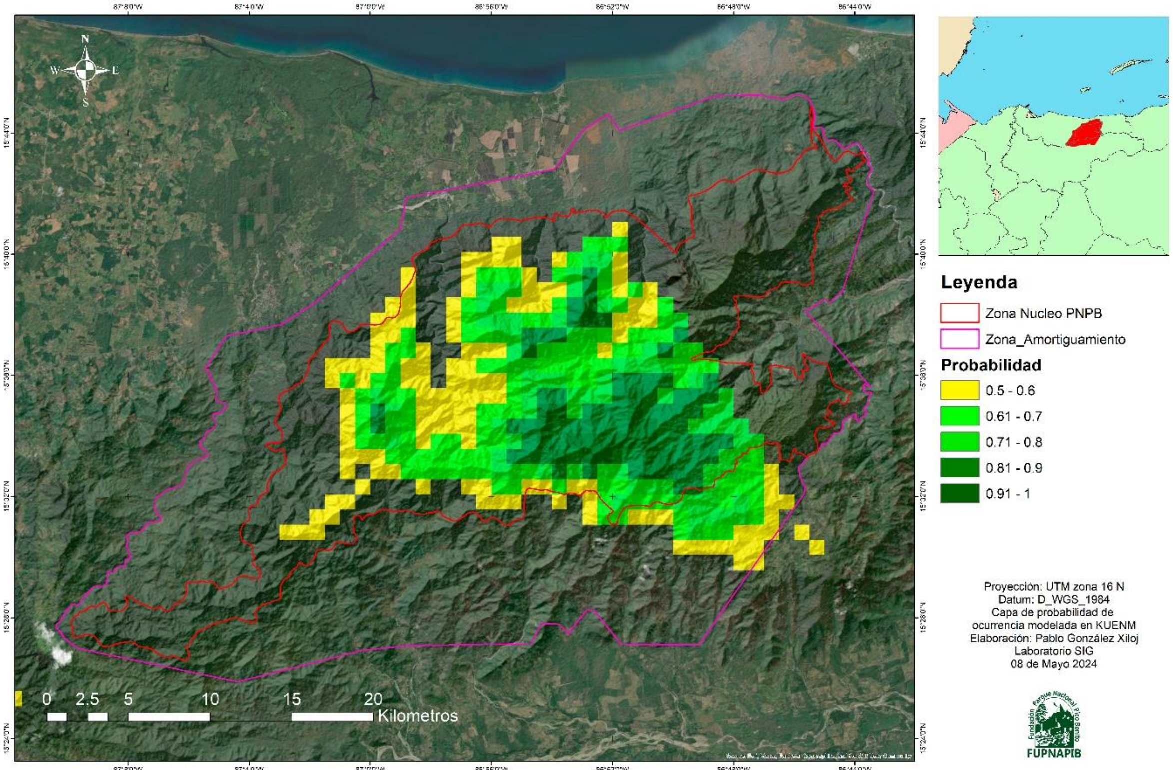
Map of probability of occurrence in 2040 pessimistic scenario Dendropanax hondurensis.



Map of probability of occurrence in 2060 pessimistic scenario Dendropanax hondurensis.



Map of probability of occurrence at 2100 pessimistic scenario Dendropanax hondurensis.



Eugenia coyolensis

In general, it is observed that the greatest probability of occurrence is in the dry area of the Olanchito region outside the PNPB. In the future, it is observed that the area of distribution increases as time passes in both scenarios. In both the pessimistic and realistic scenarios, the species begins to increase in altitude as it approaches the park in 2080 and 2100. It is also observed that in general the occurrence increases in the area. The points of presence used in the modelling are also shown to show the variability of climates used in the modelling (Figure 49-56).

Figure 49. *Map of Eugenia coyolensis presence.*

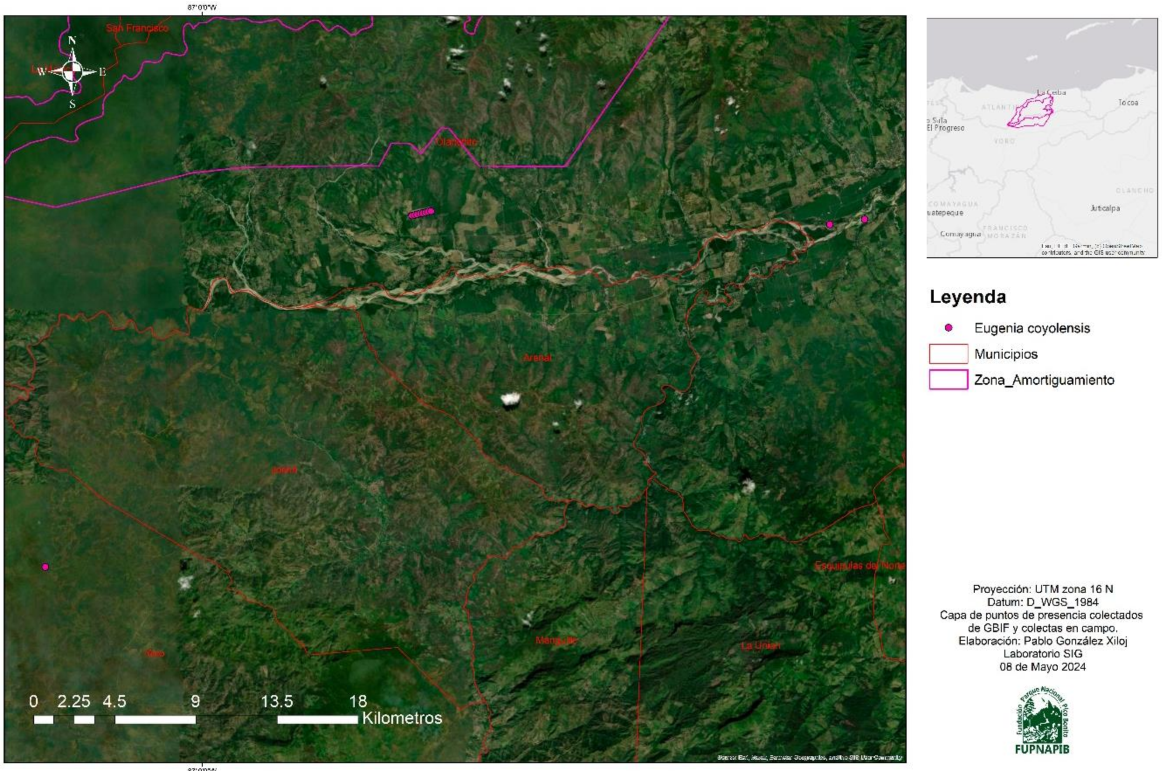


Figure 50. *Map of probability of current occurrence of Eugenia coyolensis.*

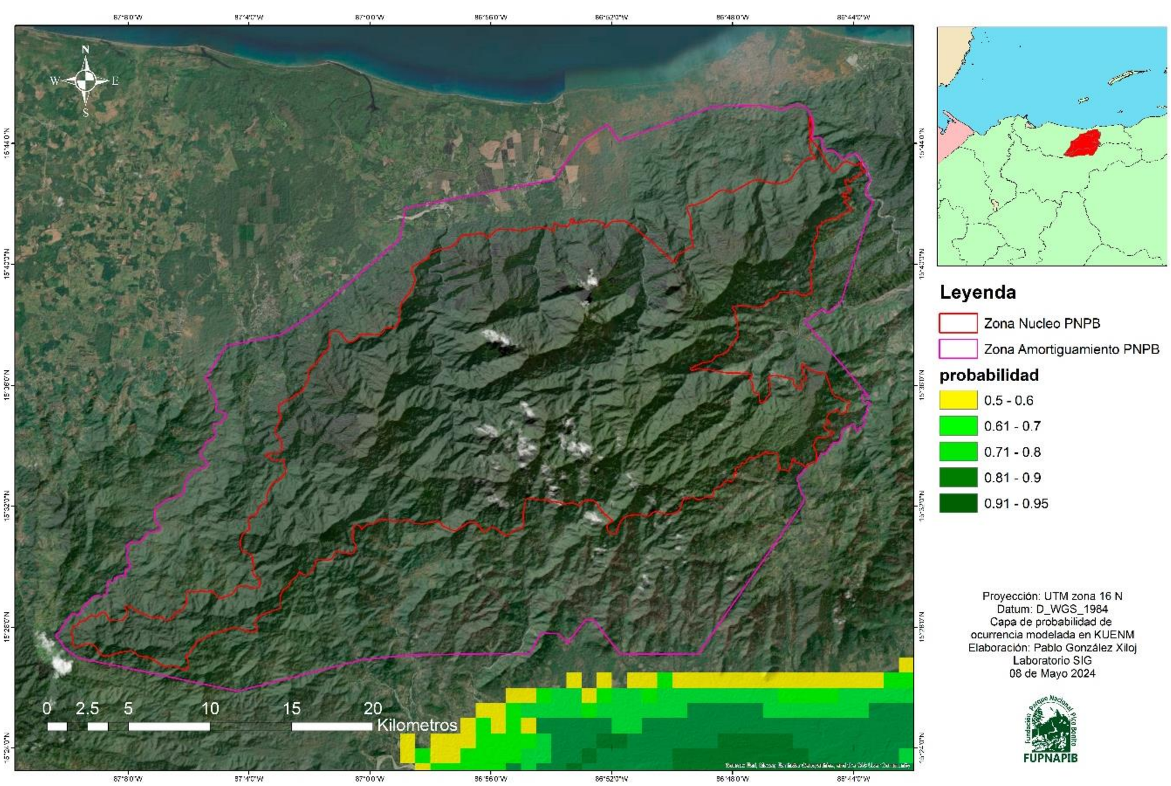


Figure 51. *Map of probability of occurrence 2040 realistic scenario Eugenia coyolensis.*

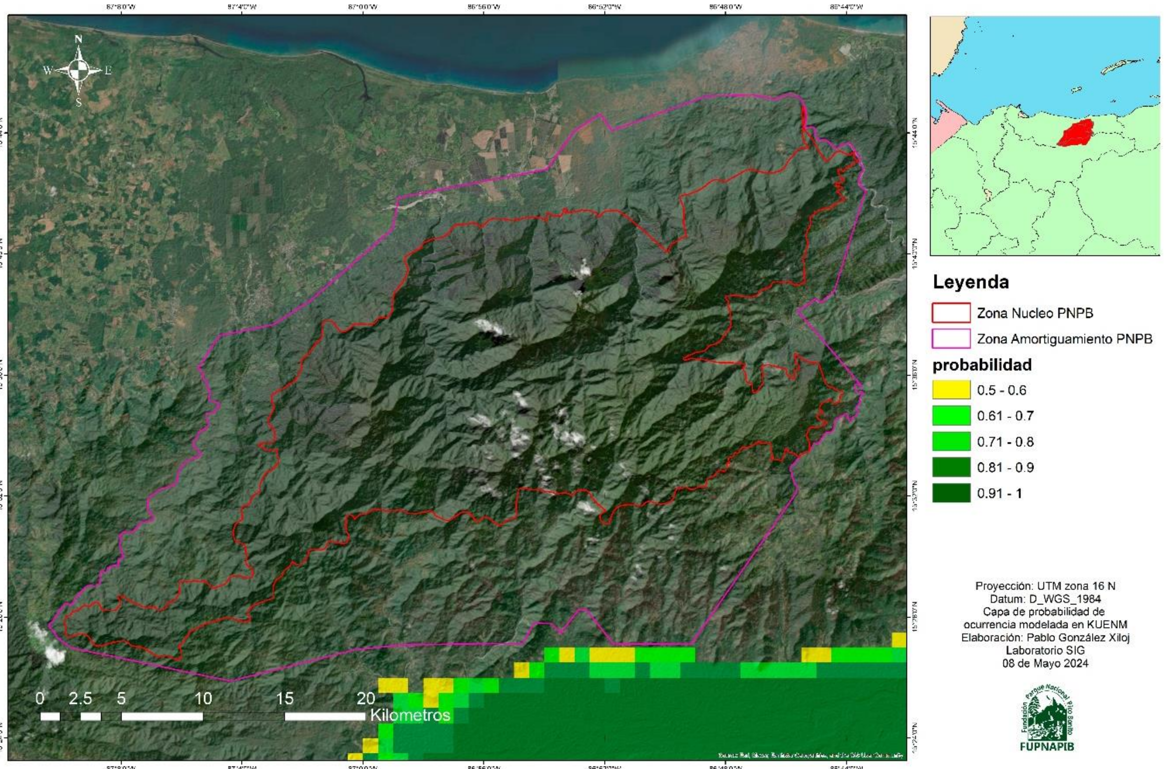
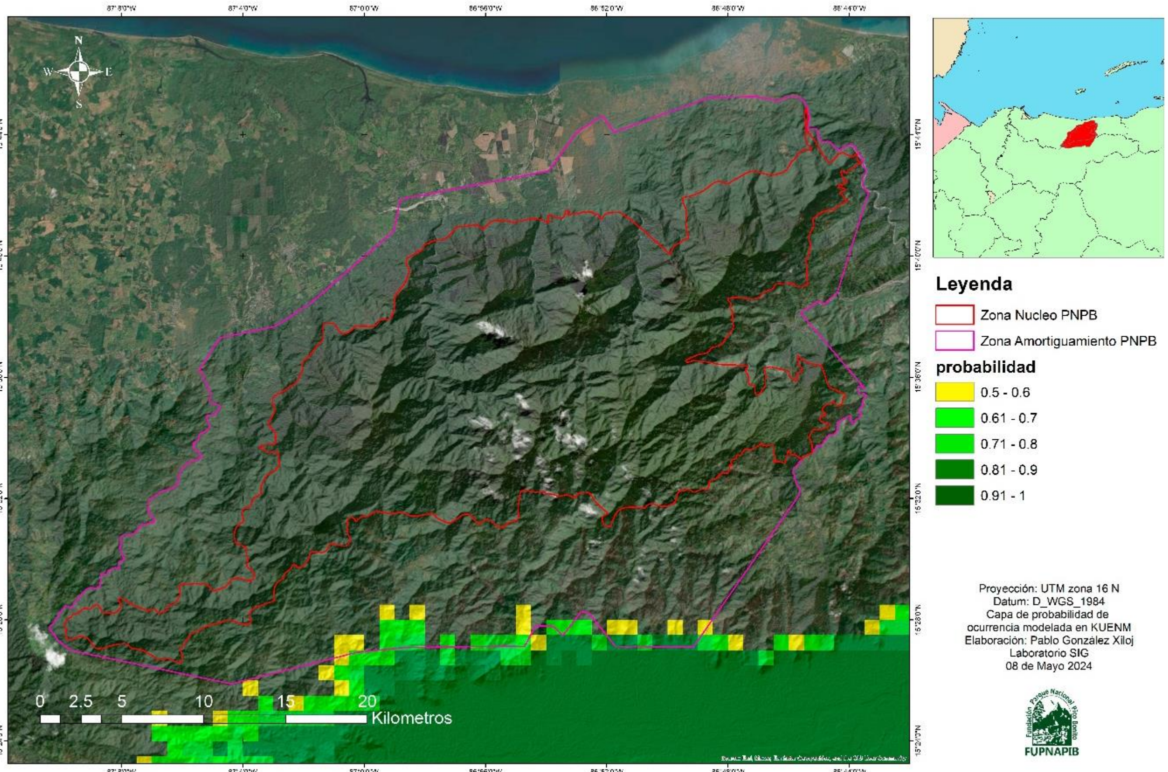


Figure 52. *Map of probability of occurrence 2060 realistic scenario Eugenia coyolensis.*



Map of probability of occurrence 2080 realistic scenario Eugenia coyolensis.

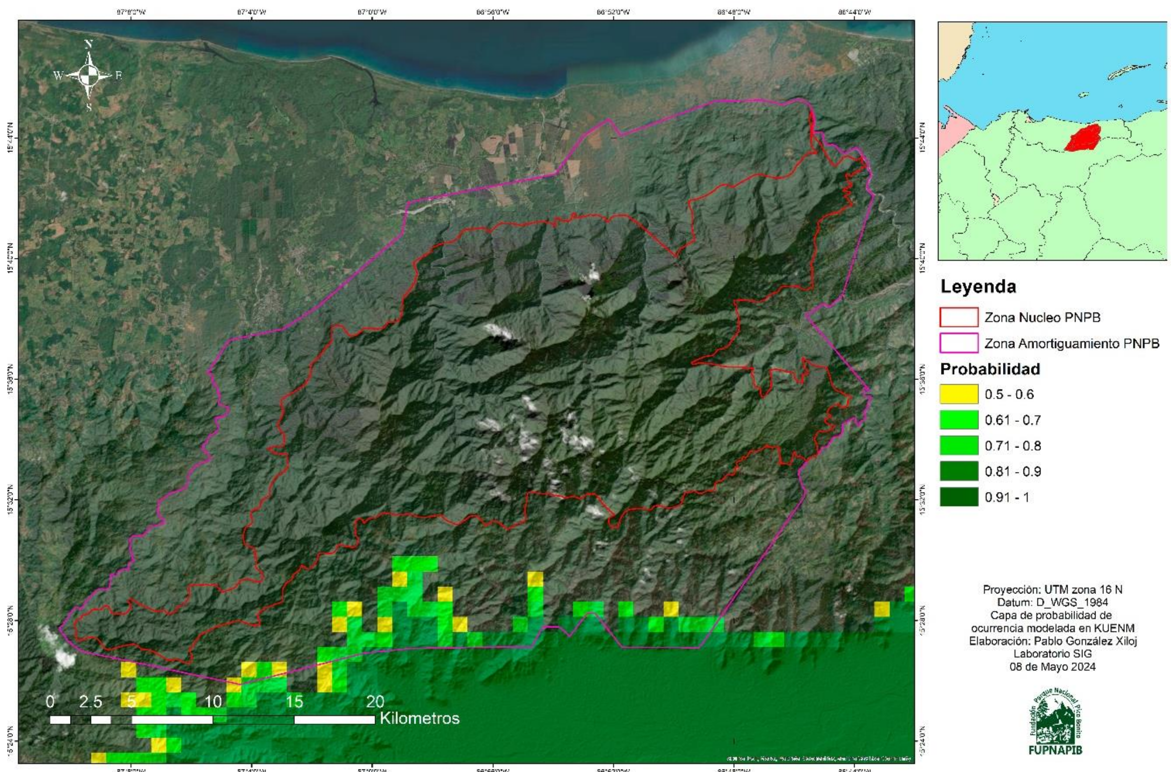


Figure 54. *Map of probability of occurrence 2040 pessimistic scenario Eugenia coyolensis.*

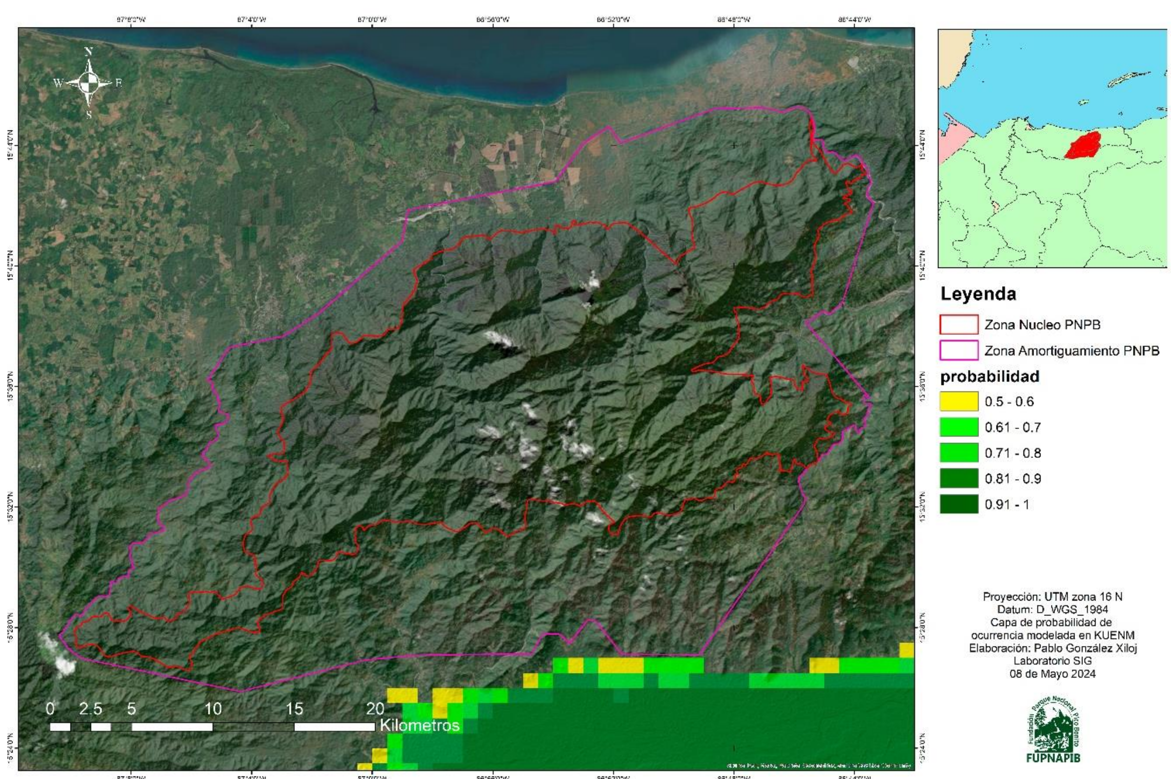


Figure 55. *Map of probability of occurrence 2060 pessimistic scenario Eugenia coyolensis.*

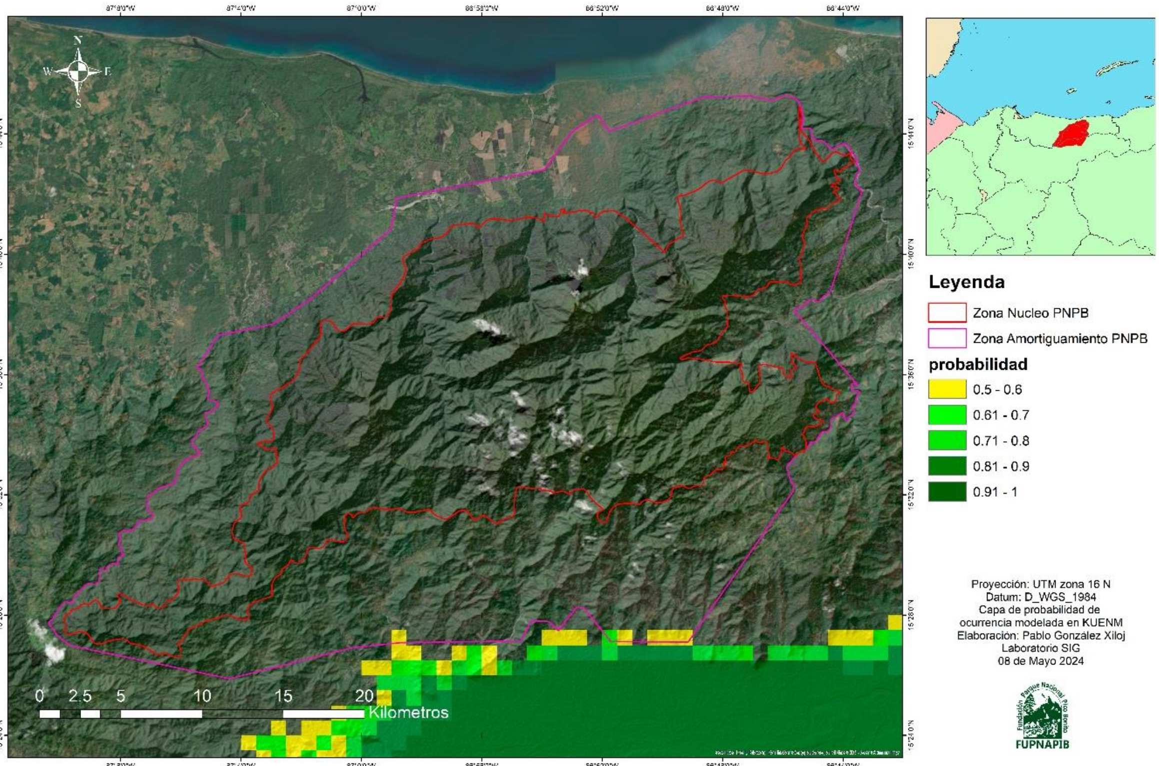
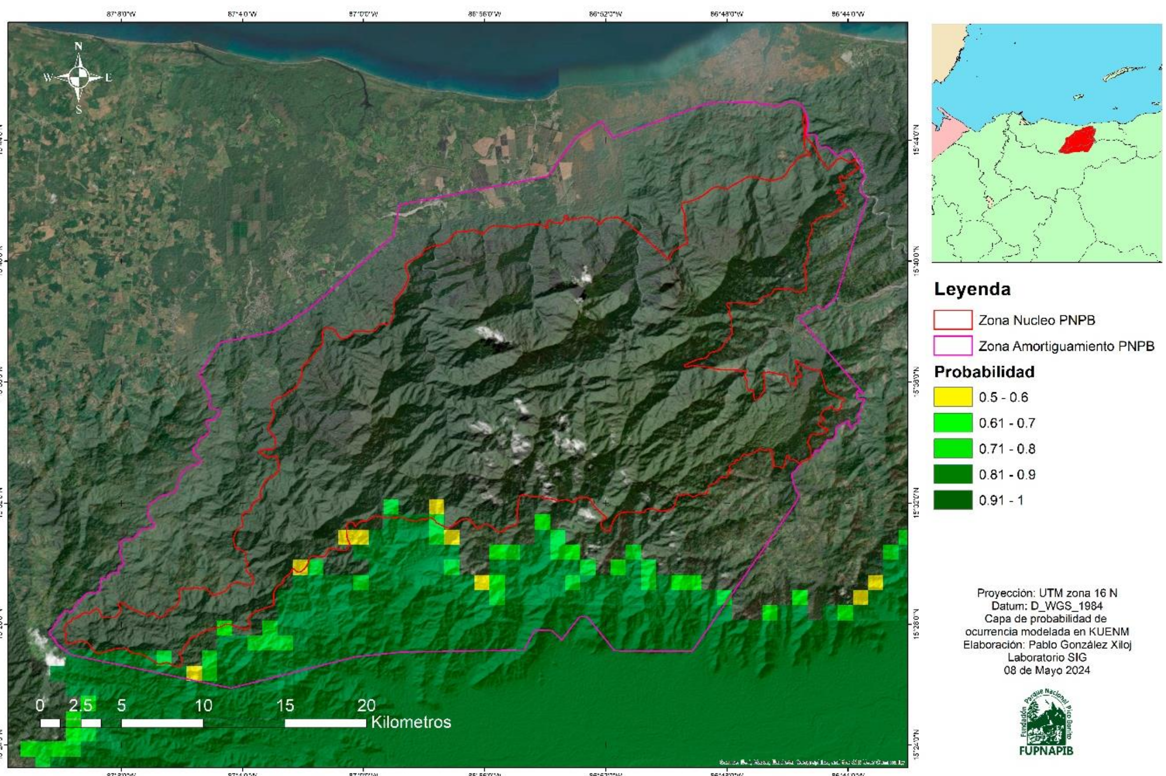


Figure 56. *Map of probability of occurrence 2100 pessimistic scenario Eugenia coyolensis.*



Lonchocarpus yoroensis

It is observed that at present the occurrence of the species is related to the area of the dry corridor of Olanchito, in the future it is observed that the occurrence increases in the foothills in both scenarios and the central flat area is decreasing the probability of occurrence, this is probably due to the increase of extreme events in the dry plateau so that the species will tend to decrease its occurrence in the region. This is congruent with the analysis of the bio2 variable. The points of presence with which the modelling was done are also shown to show the variability of climates that were used to perform the modelling (Figure 57-64).

Figure 57. *Map of Lonchocarpus yoroensis presence points.*

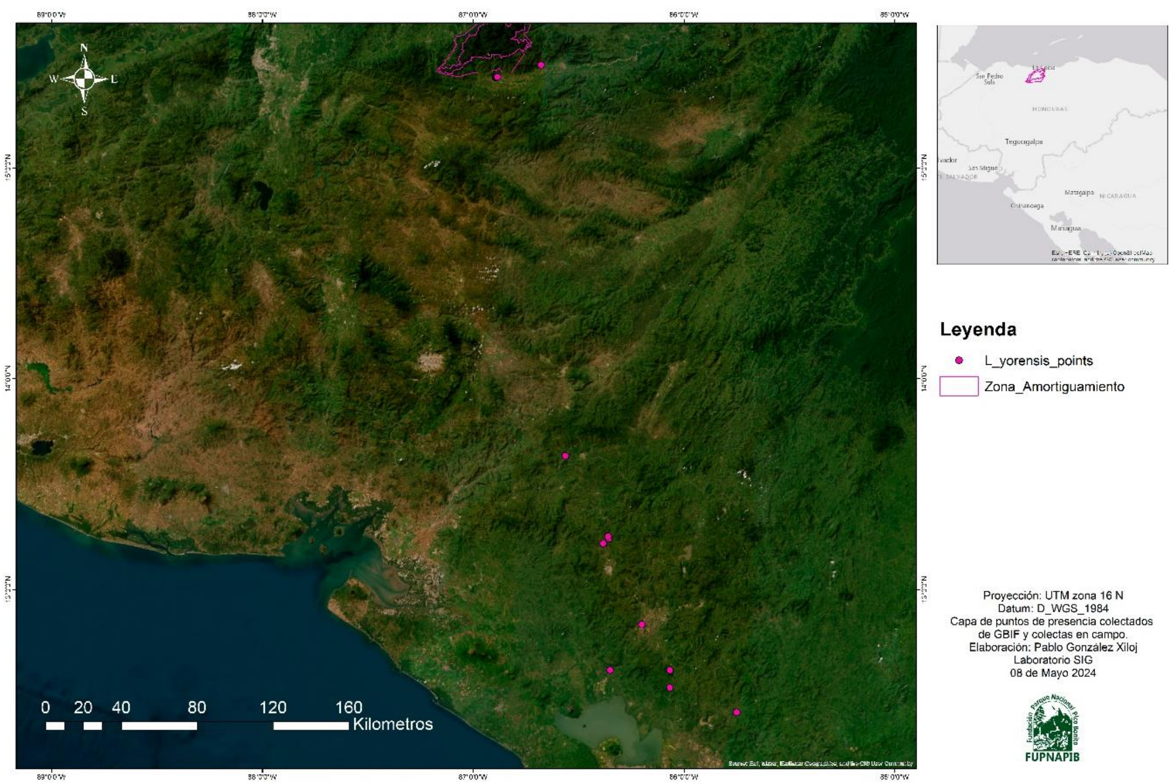


Figure 58. *Map of probability of current occurrence Lonchocarpus yoroensis.*

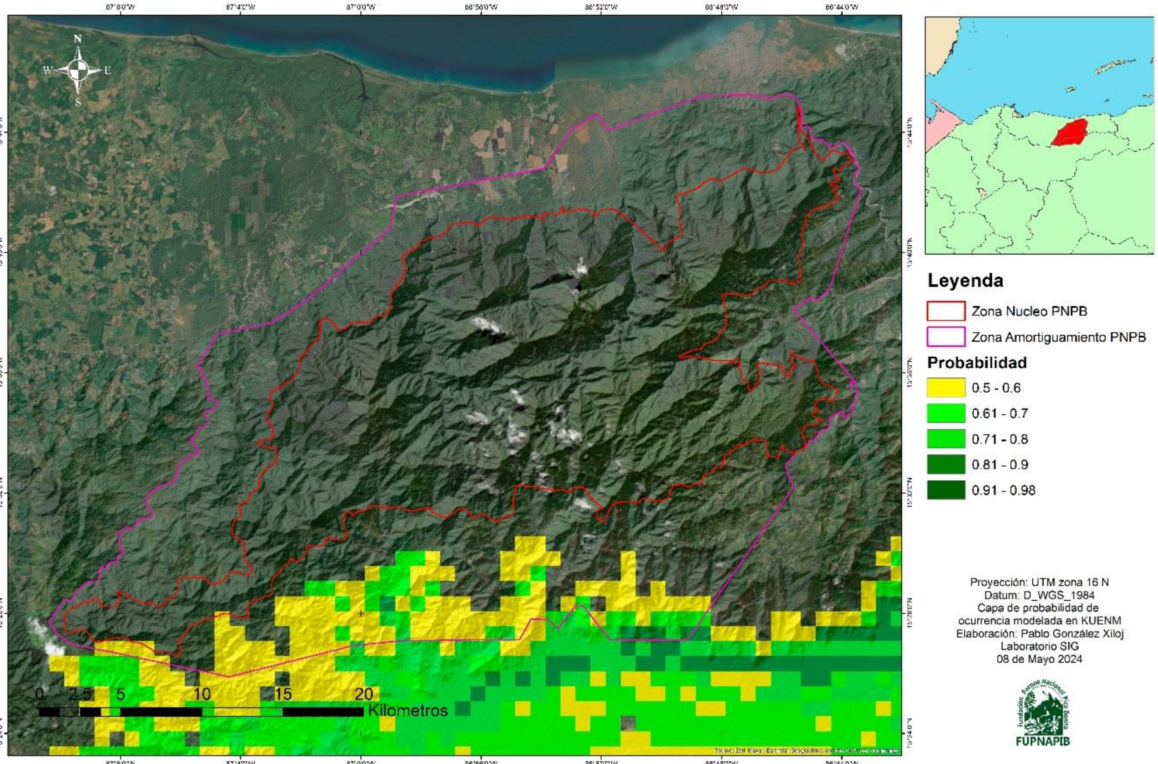
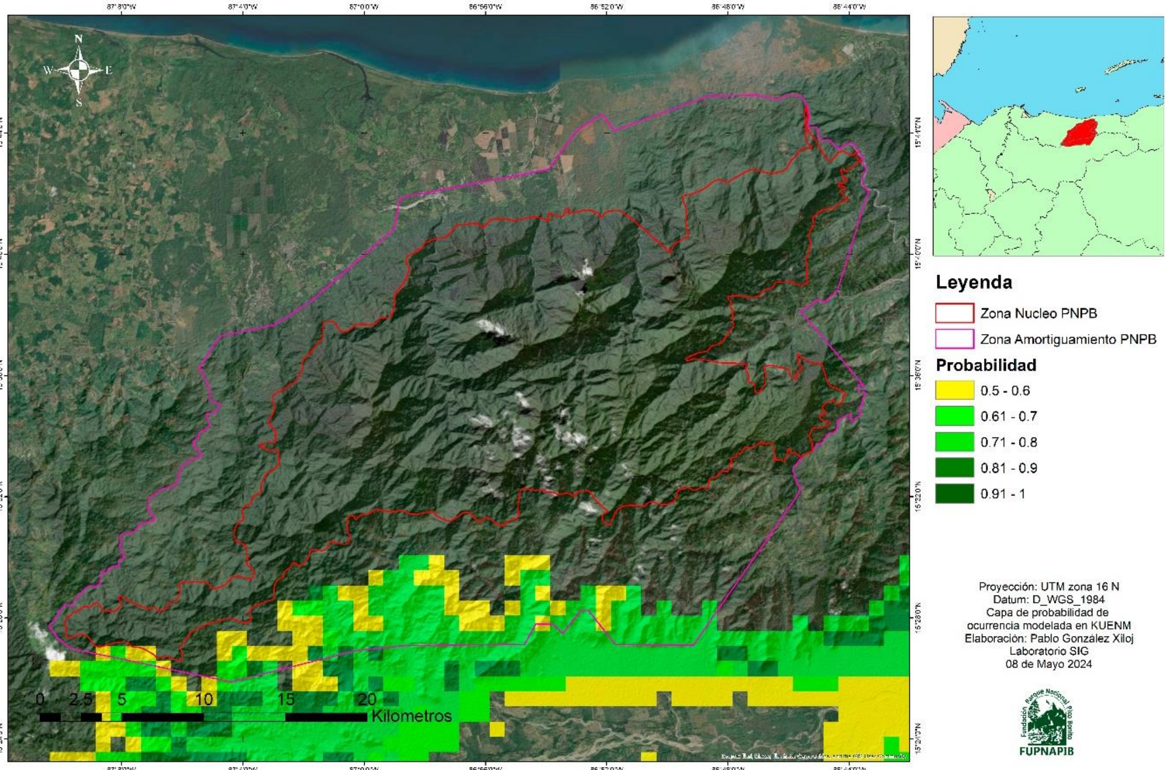


Figure 59. *Map of probability of occurrence 2040 realistic scenario Lonchocarpus yoroensis.*



Map of probability of occurrence 2060 realistic scenario Lonchocarpus yoroensis.

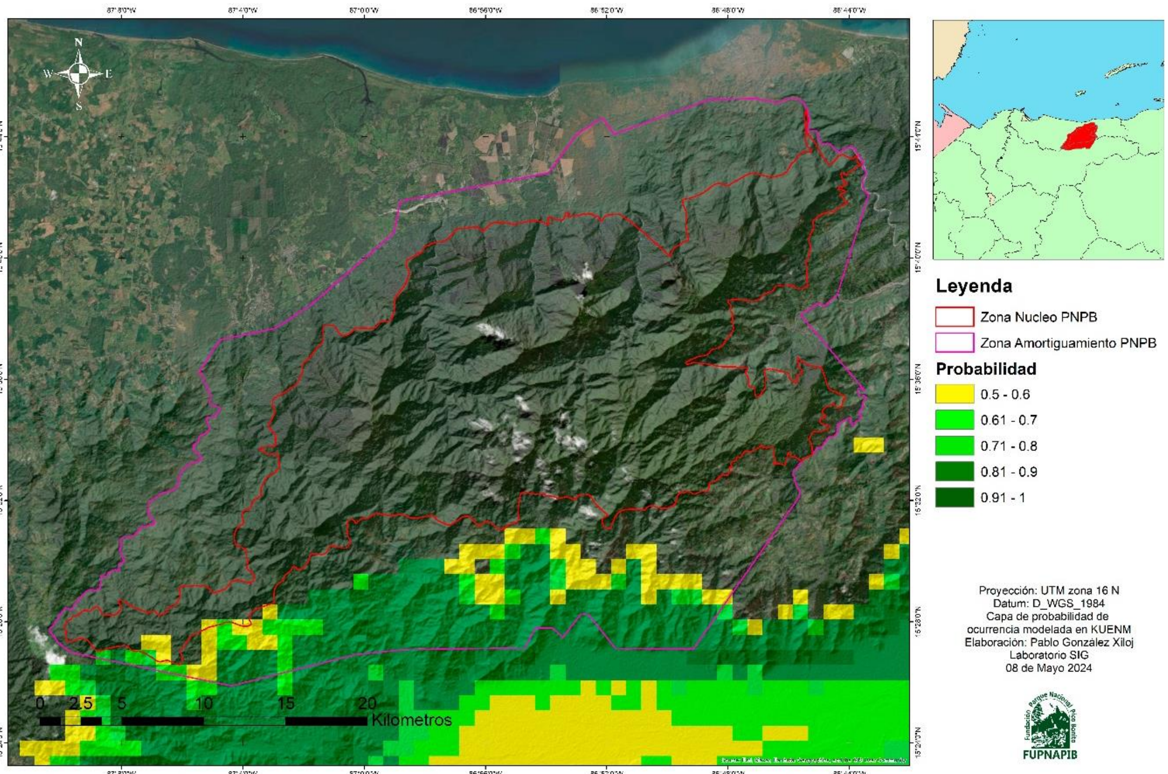


Figure 61. *Map of probability of occurrence 2080 realistic scenario Lonchocarpus yoroensis.*

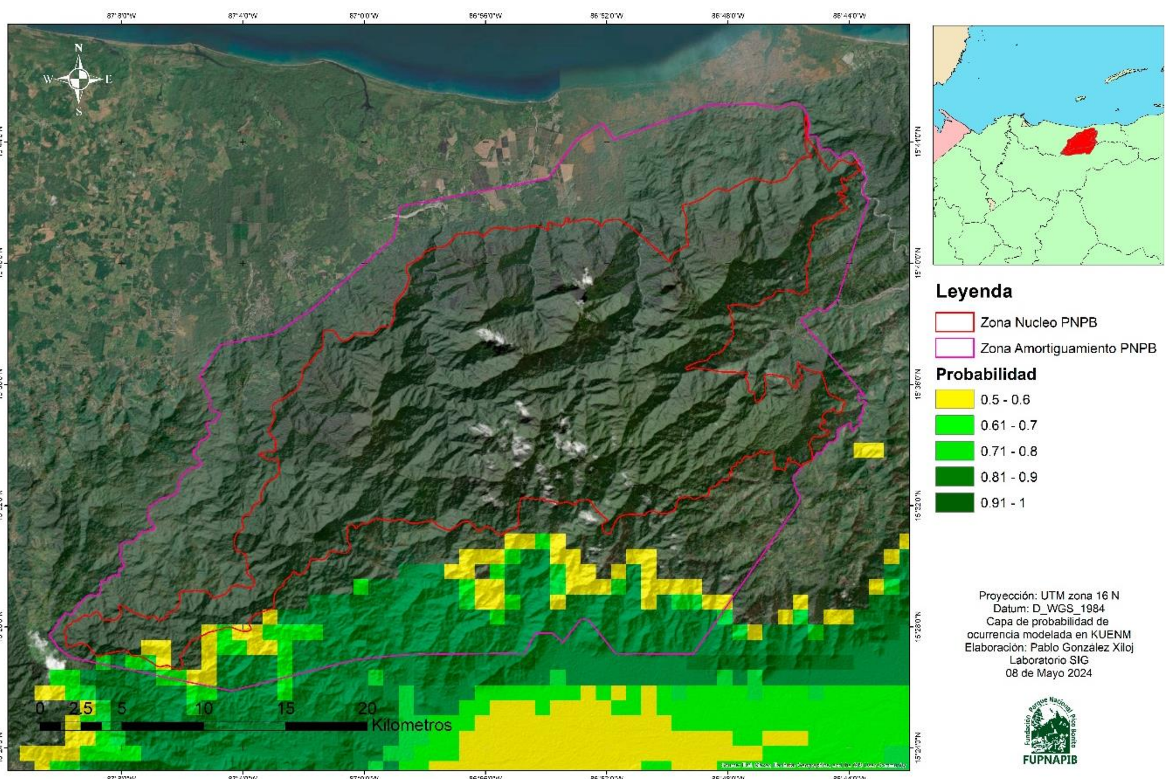


Figure 62. *Map of probability of occurrence 2040 pessimistic scenario Lonchocarpus yoroensis.*

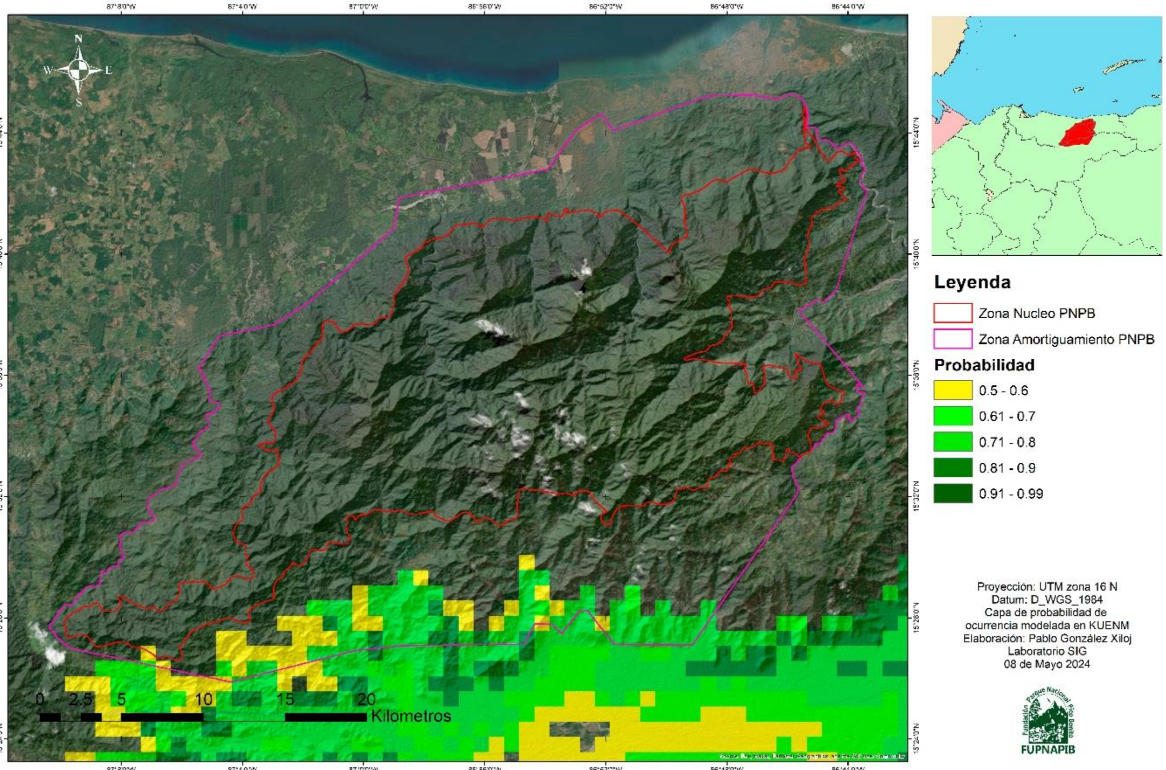


Figure 63. *Map of probability of occurrence 2060 pessimistic scenario Lonchocarpus yoroensis.*

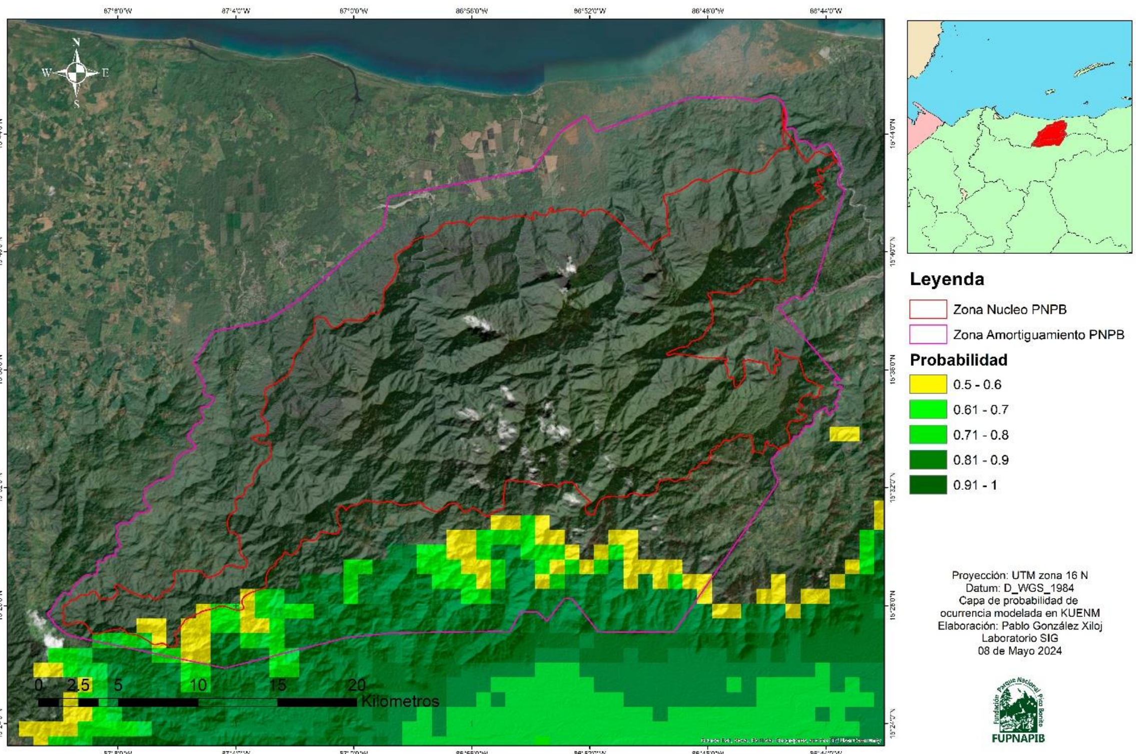
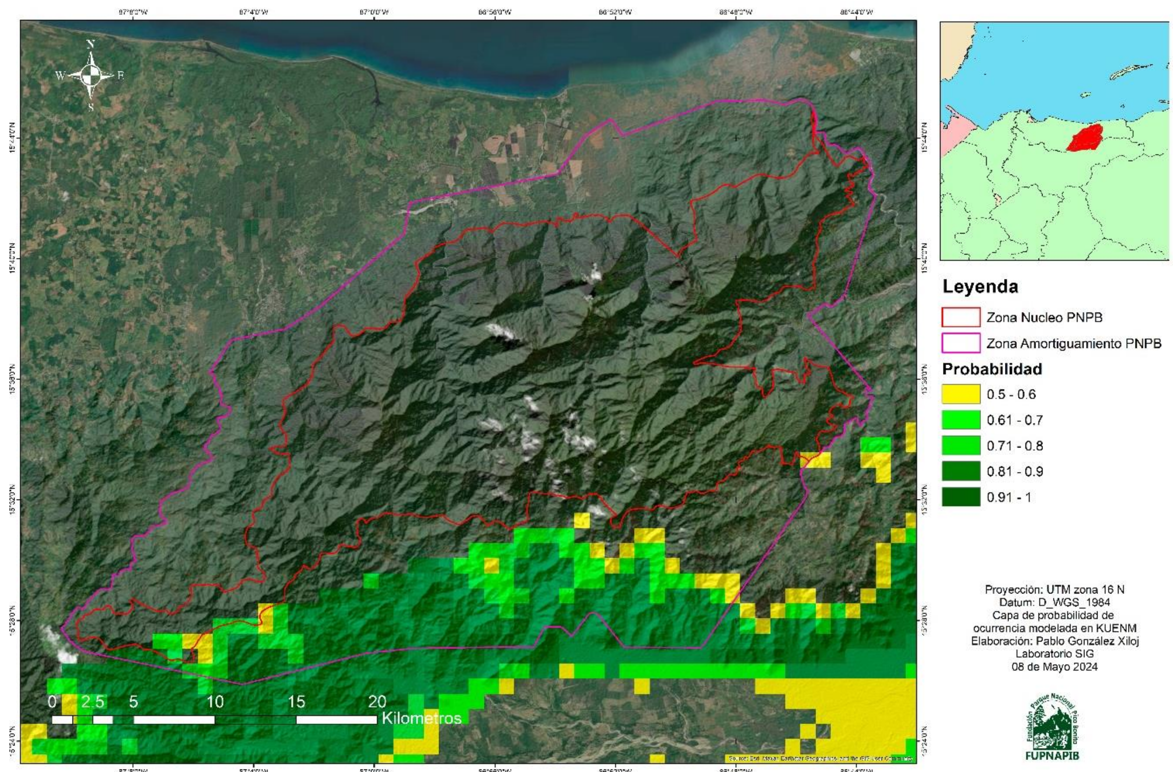


Figure 64. *Map of probability of occurrence 2100 pessimistic scenario Lonchocarpus yoroensis.*



Magnolia ciroorum

This species is restricted to the northwestern area of the park; the realistic scenario shows a decrease in occurrence in 2060 and an increase in 2080. A similar case occurs in the pessimistic scenario, with the exception that by 2100 the increase in occurrence is much greater. The points of presence used in the modelling are also shown to show the variability of climates used in the modelling (Figure 65-72).

Figure 65. *Points of presence of Magnolia ciroorum.*

Figure 66. *Map of probability of current occurrence Magnolia ciroorum.*

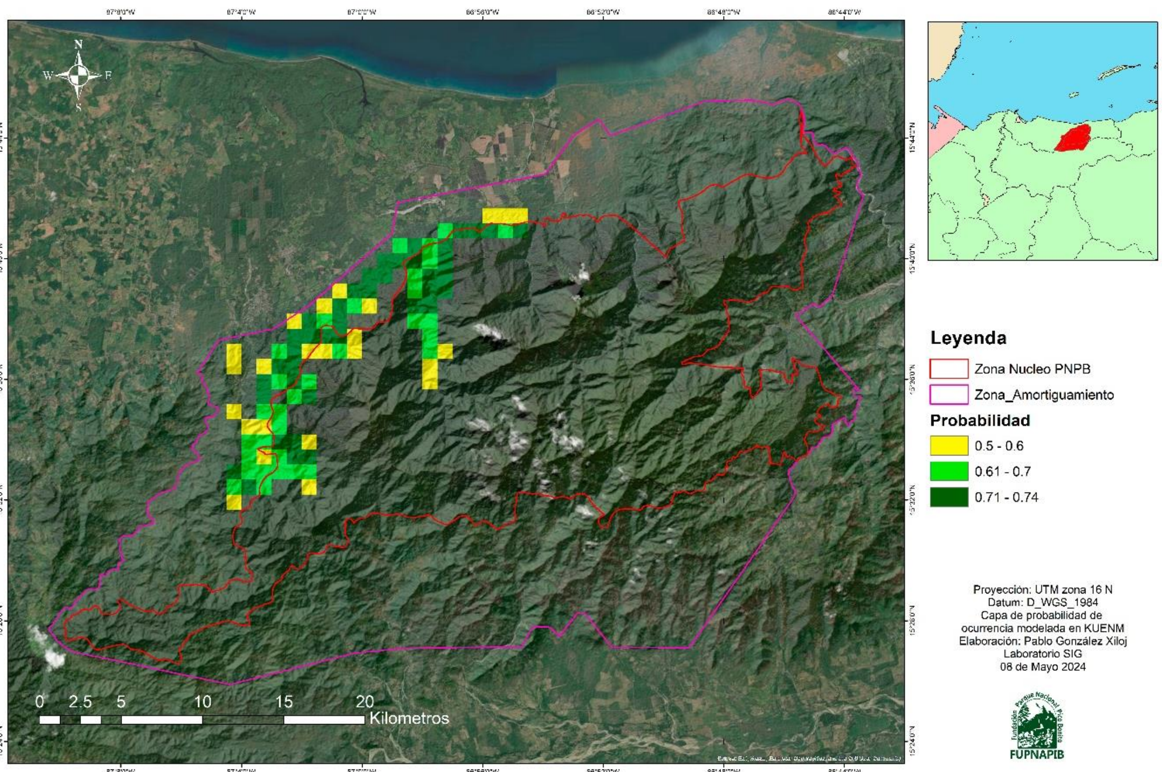


Figure 67. *Map of probability of occurrence to 2040 realistic scenario Magnolia ciroorum.*

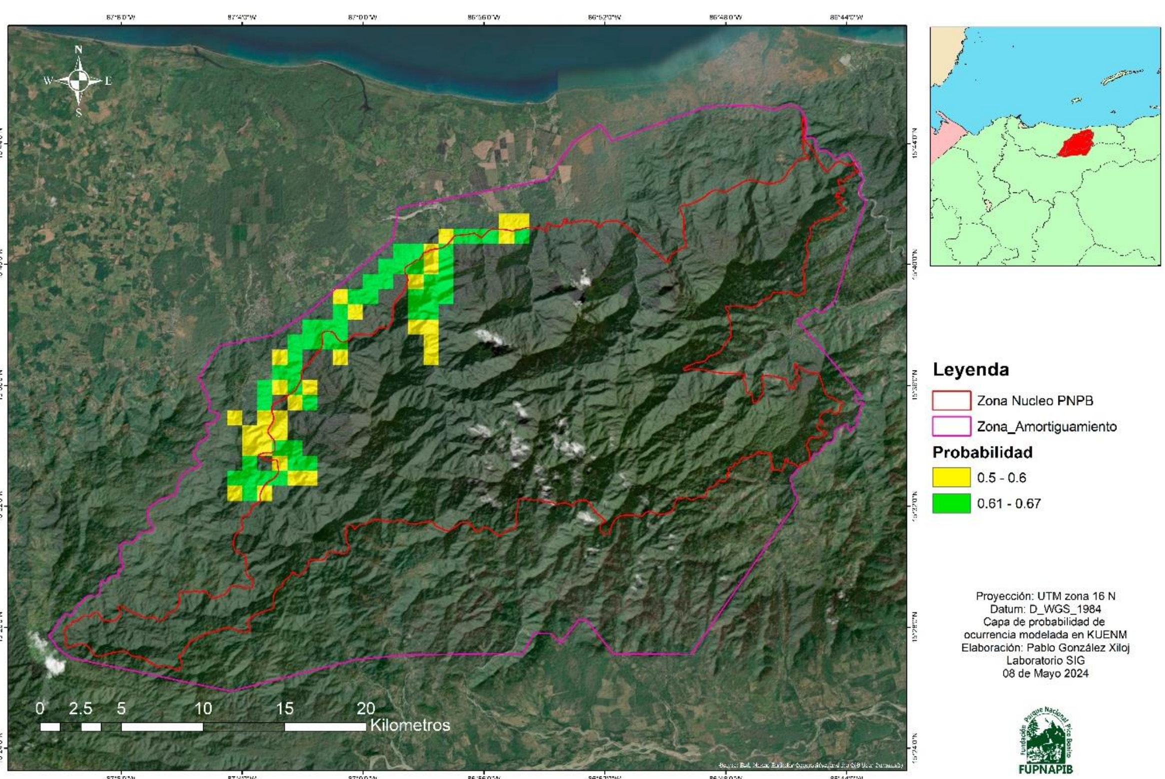


Figure 68. *Map of probability of occurrence to 2060 realistic scenario Magnolia ciroorum.*

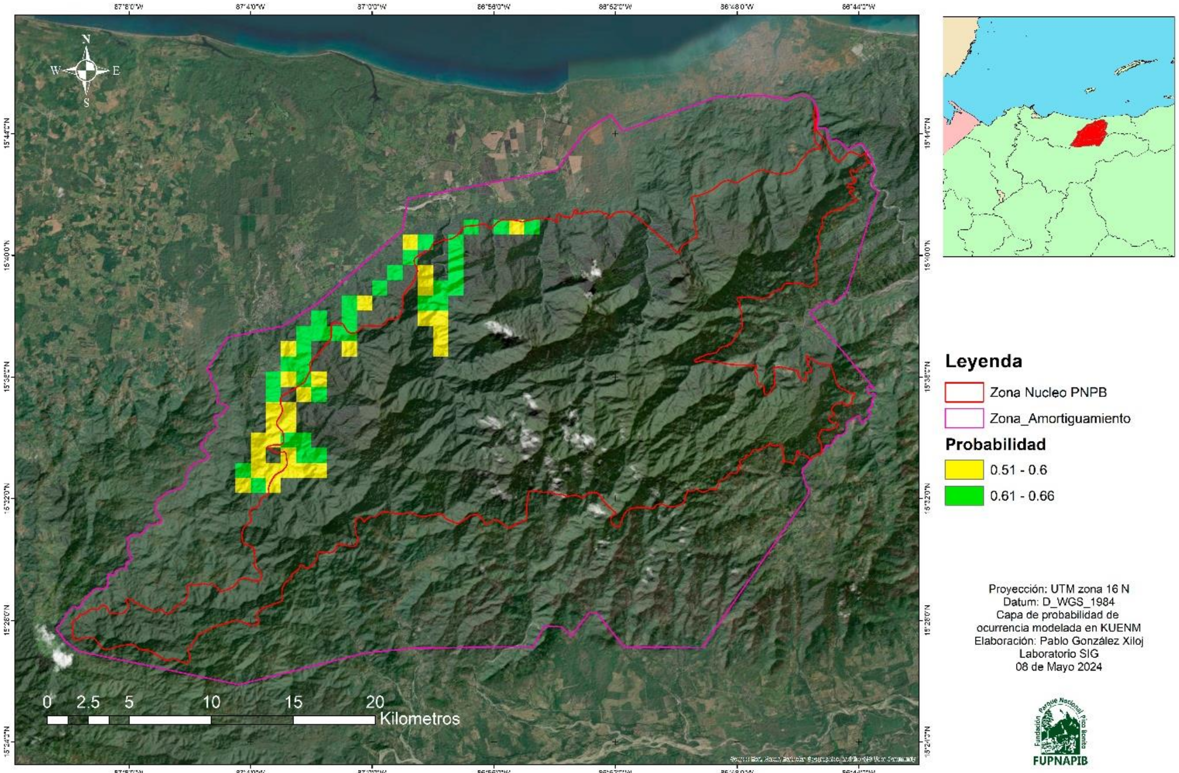
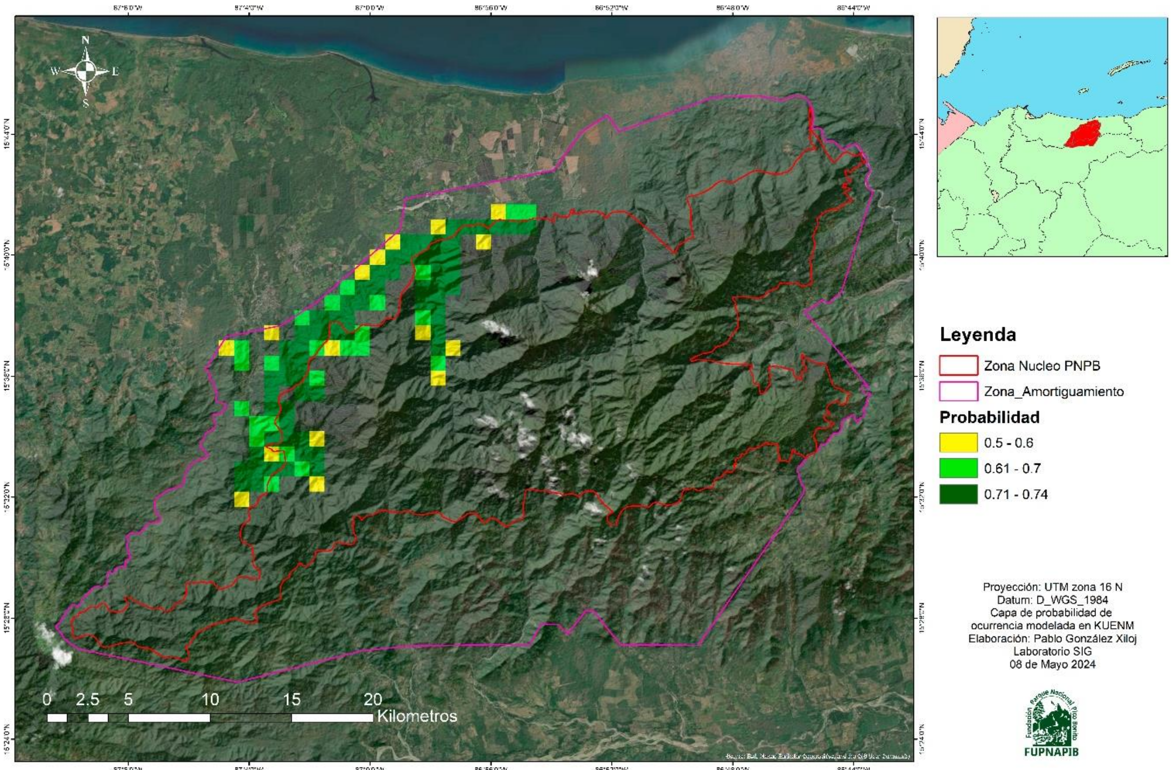


Figure 69. *Map of probability of occurrence at 2080 realistic scenario Magnolia ciroorum.*



Map of probability of occurrence in 2040 pessimistic scenario Magnolia ciroorum.

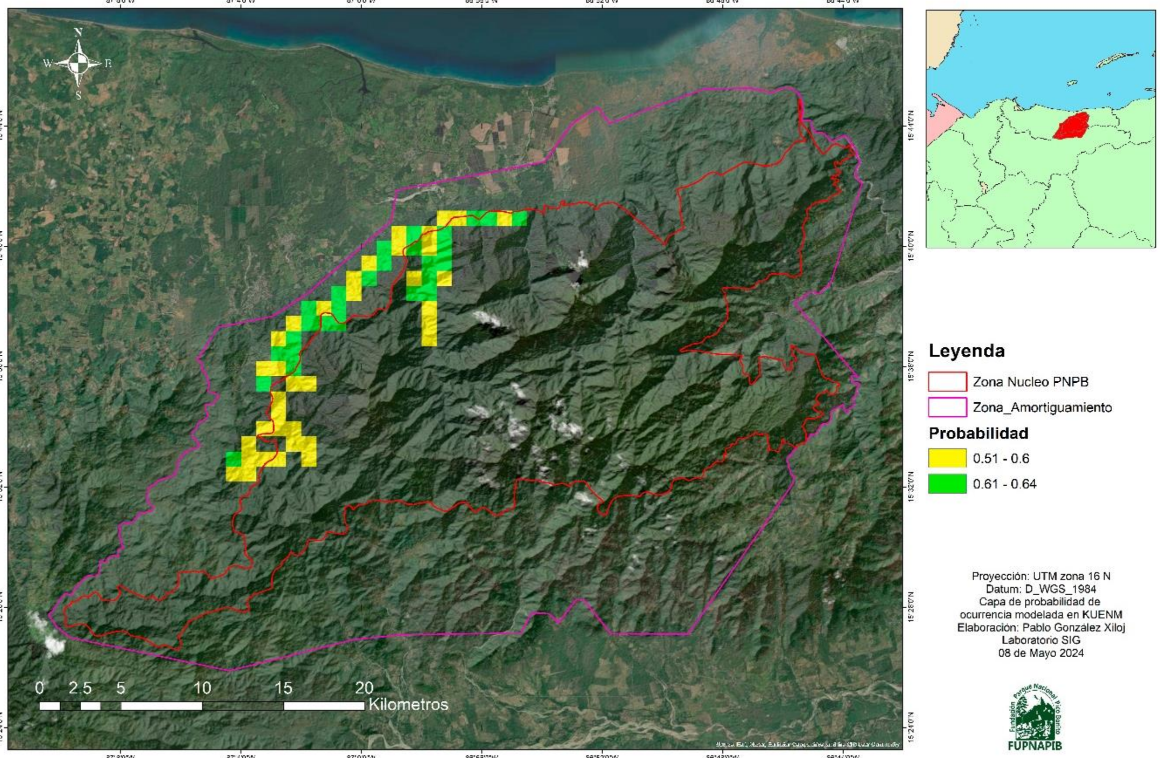


Figure 71. *Map of probability of occurrence to 2060 pessimistic scenario Magnolia ciroorum.*

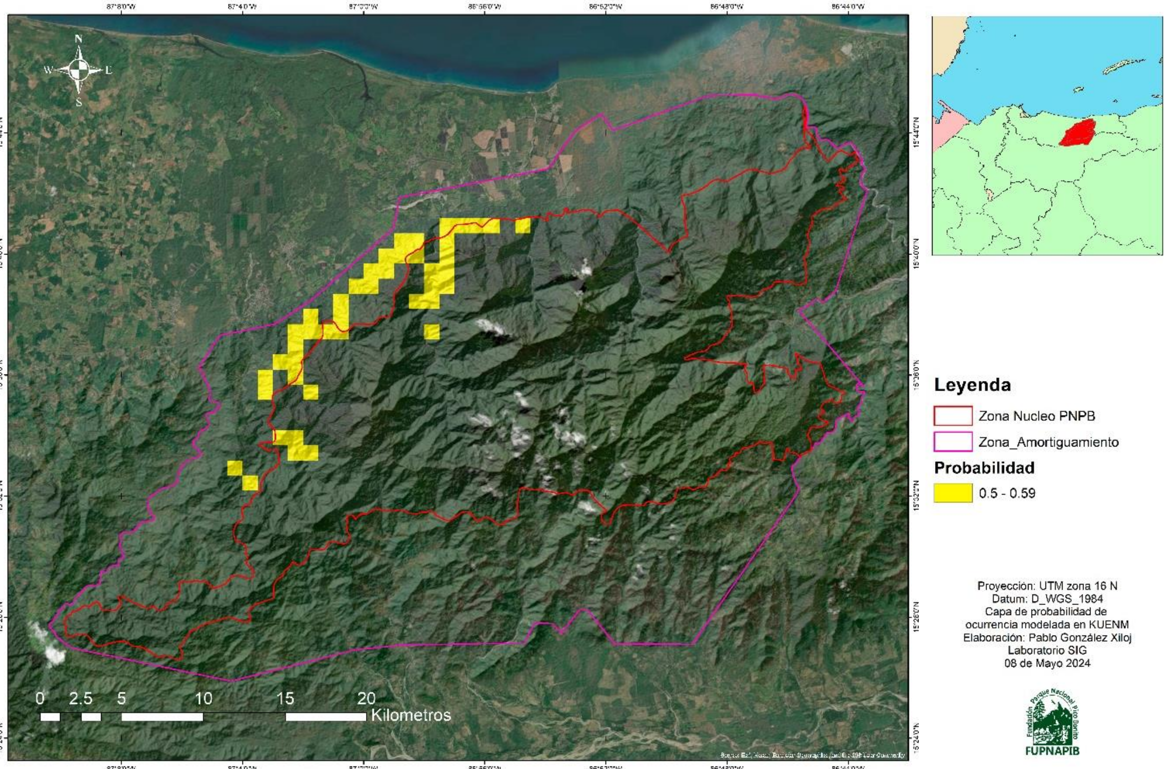
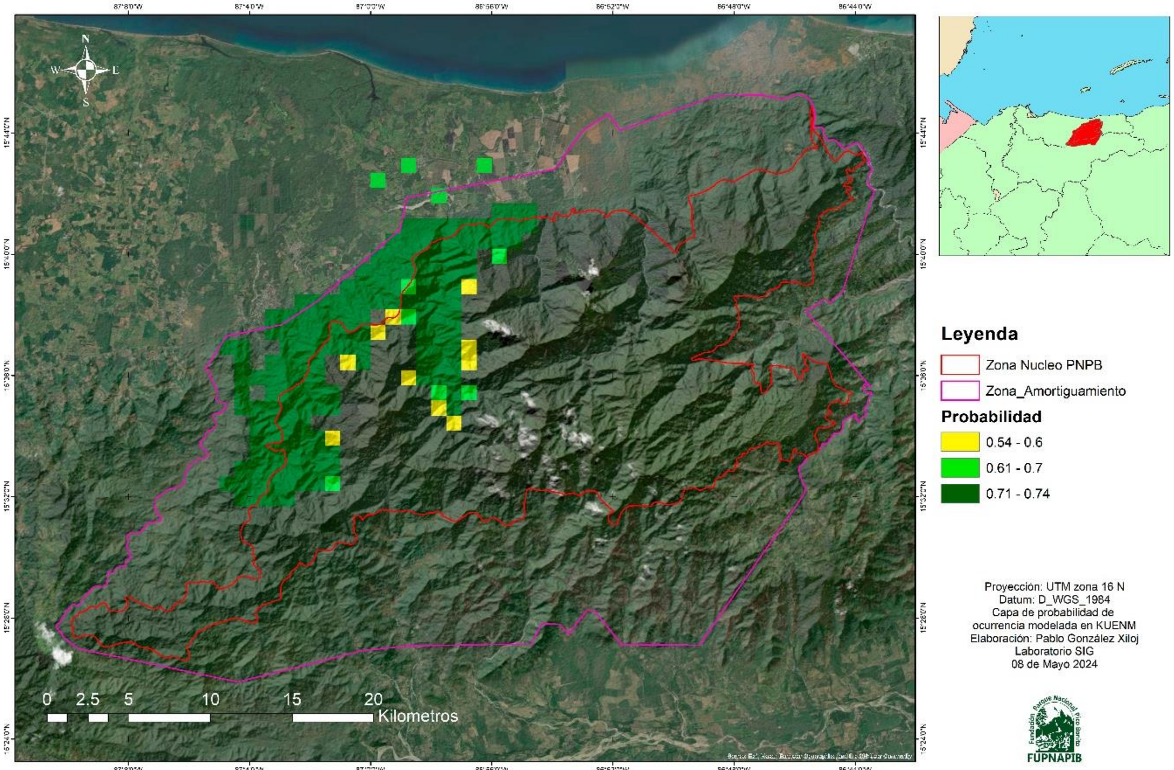


Figure 72. *Map of probability of occurrence to 2100 pessimistic scenario Magnolia ciroorum.*



Magnolia atlantida

Regarding the geographic projection of the models for this species, it is observed that in both scenarios there is a decrease in the area and probability of occurrence within the park. By 2100, in the pessimistic scenario, the ecological niche of the species in the PNPB is almost completely extirpated. The points of presence used in the modelling are also shown to show the variability of climates used in the modelling (Figure 73-80).

Figure 73. *Points of presence of Magnolia atlantida.*

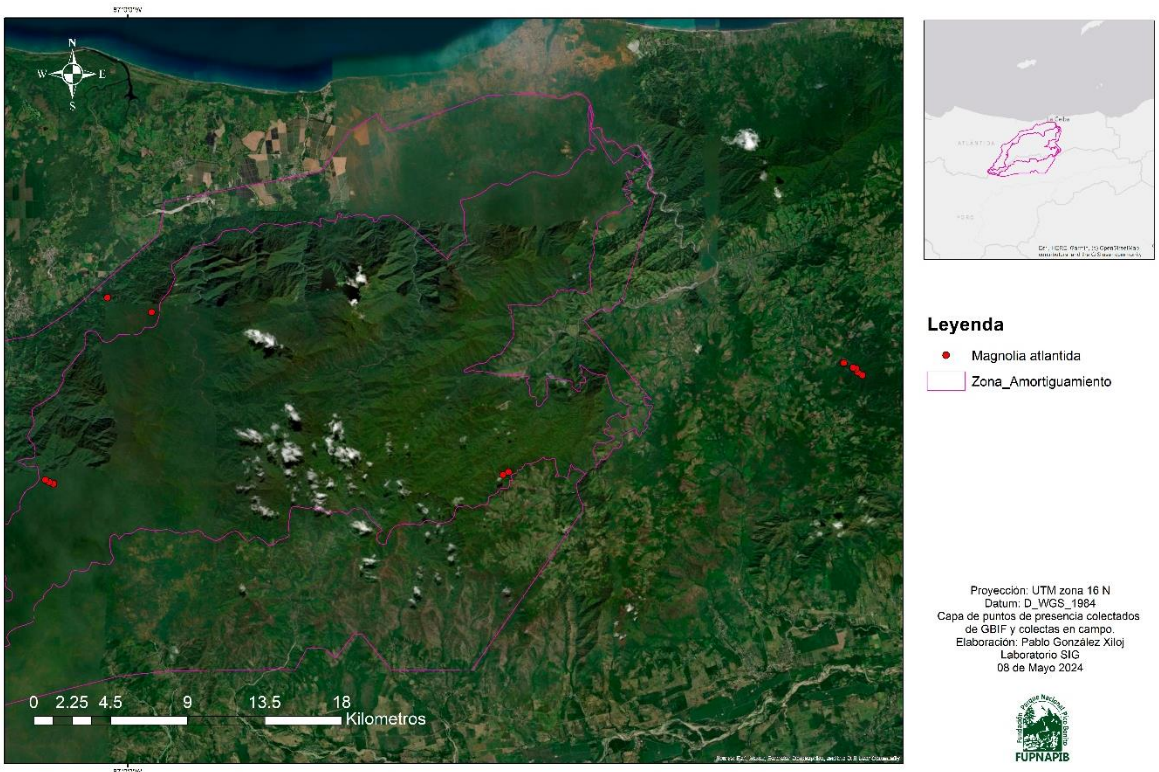
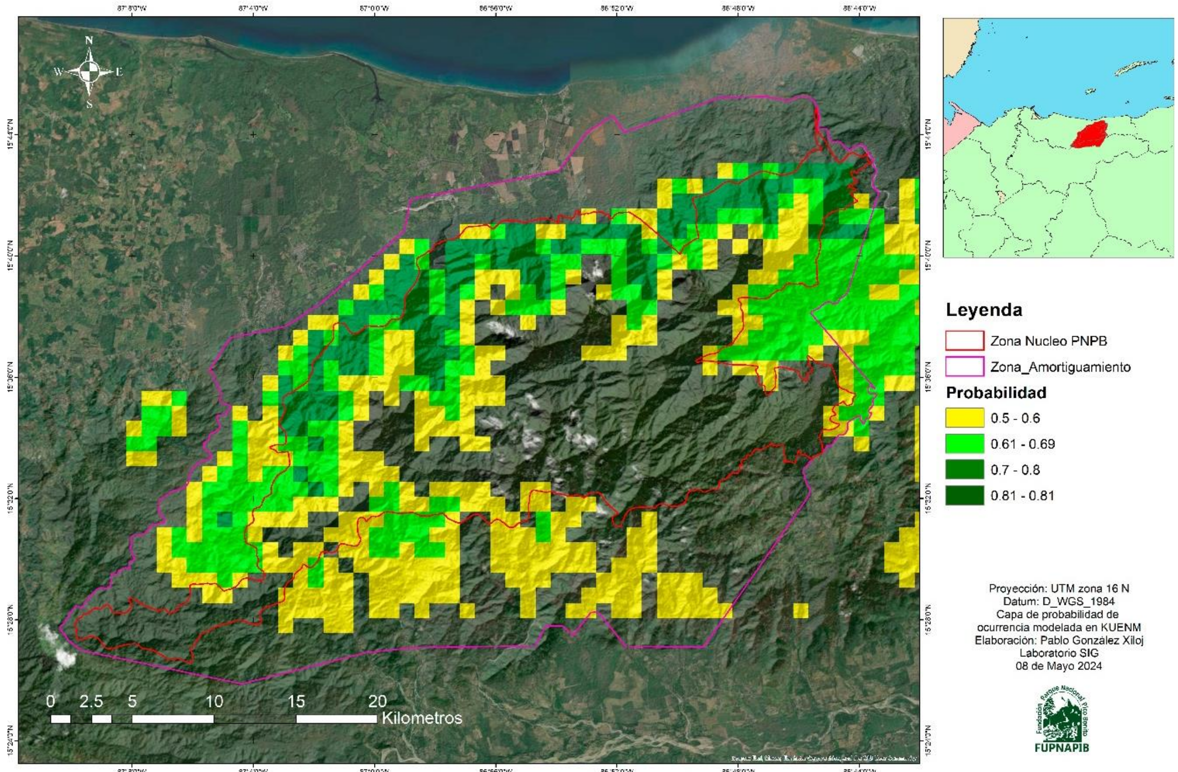


Figure 74. *Map of probability of current occurrence Magnolia atlantida.*



Map of probability of occurrence to 2040 realistic scenario Magnolia atlantida.

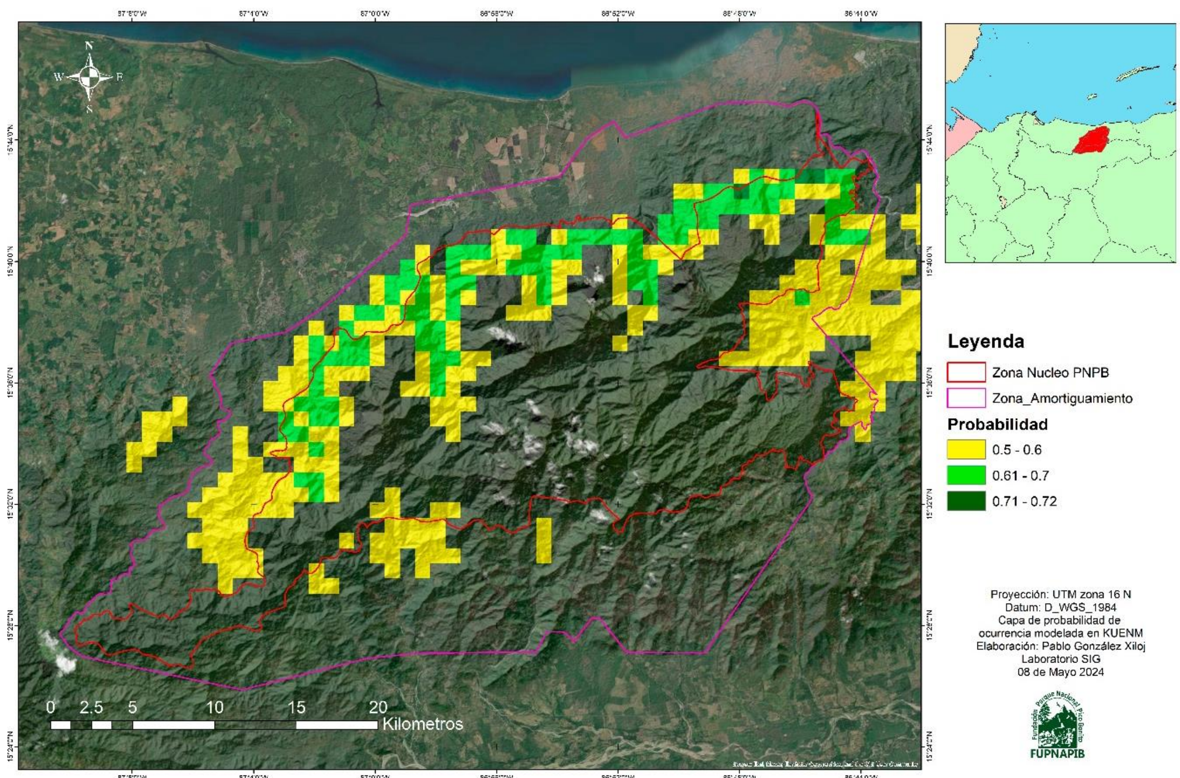


Figure 76. *Map of probability of occurrence to 2060 realistic scenario Magnolia atlantida.*

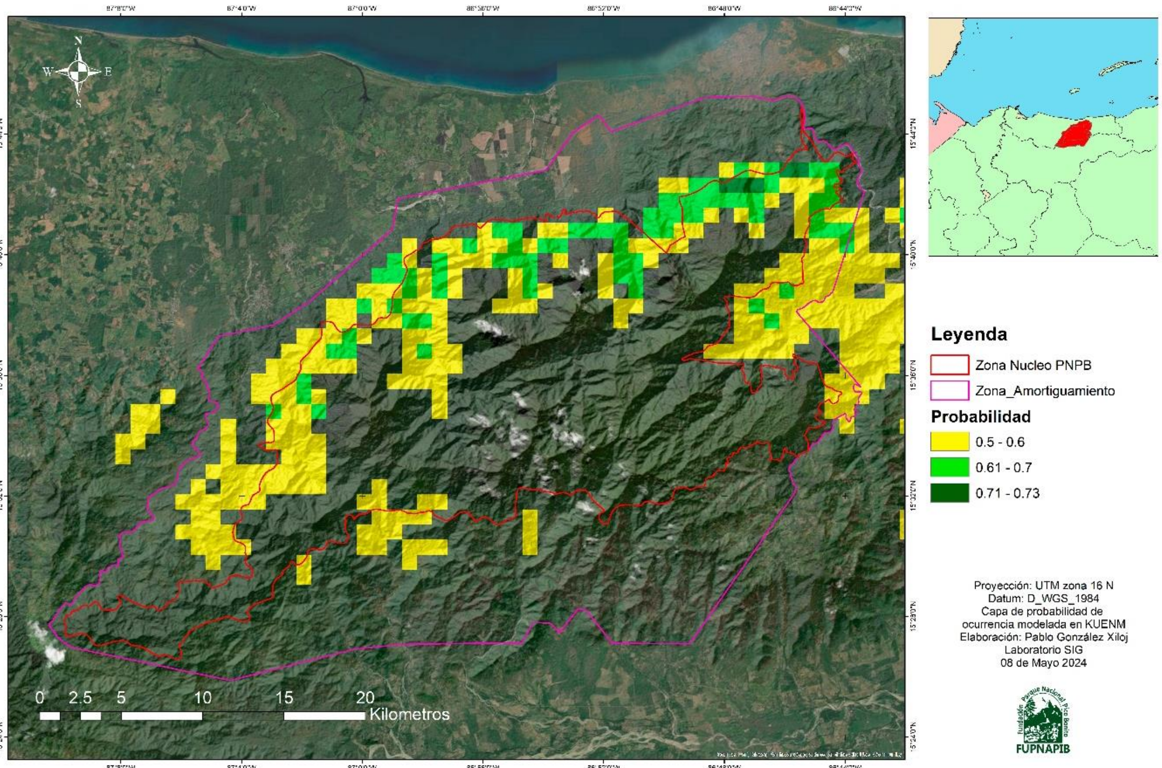


Figure 77. *Map of probability of occurrence to 2080 realistic scenario Magnolia atlantida.*

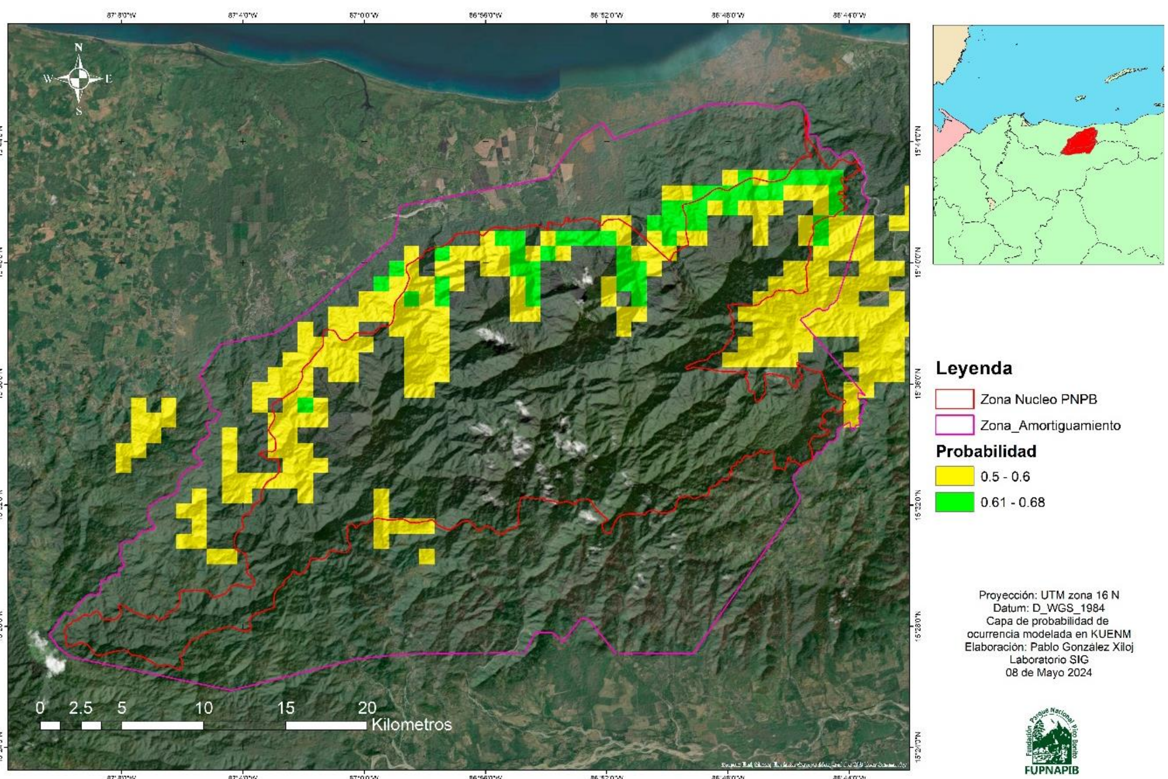


Figure 78. *Map of probability of occurrence to 2040 pessimistic scenario Magnolia atlantida.*

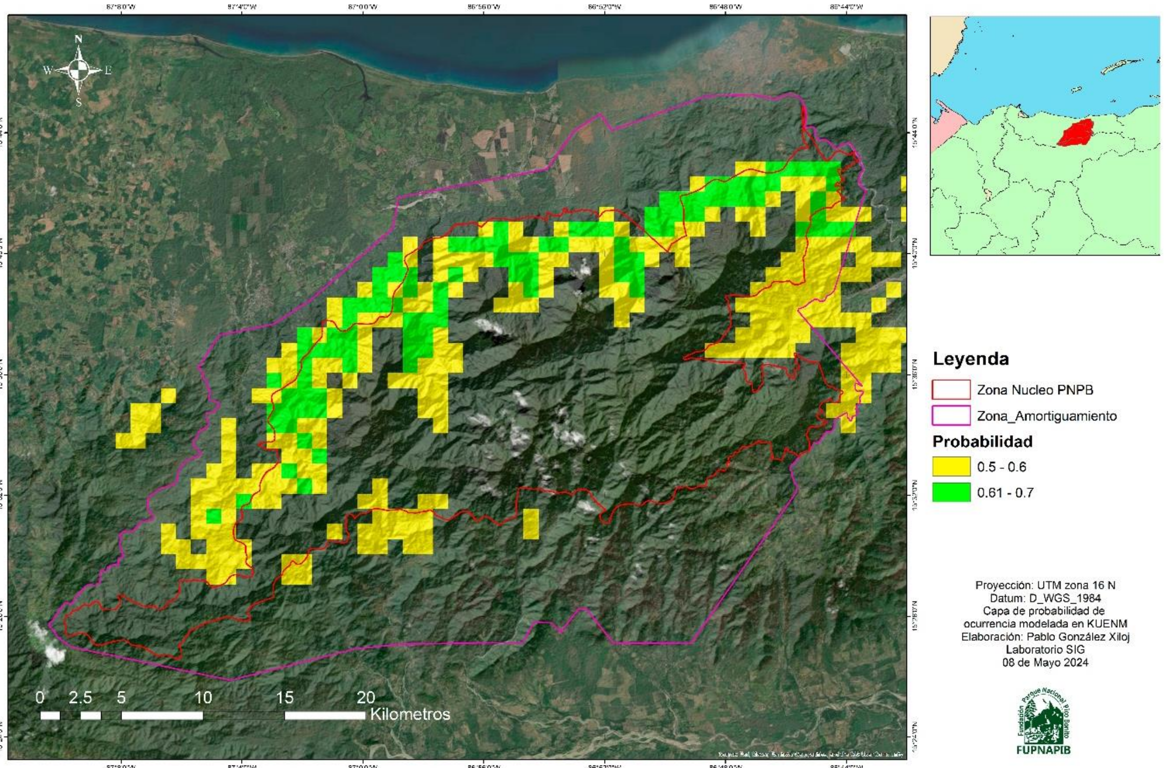
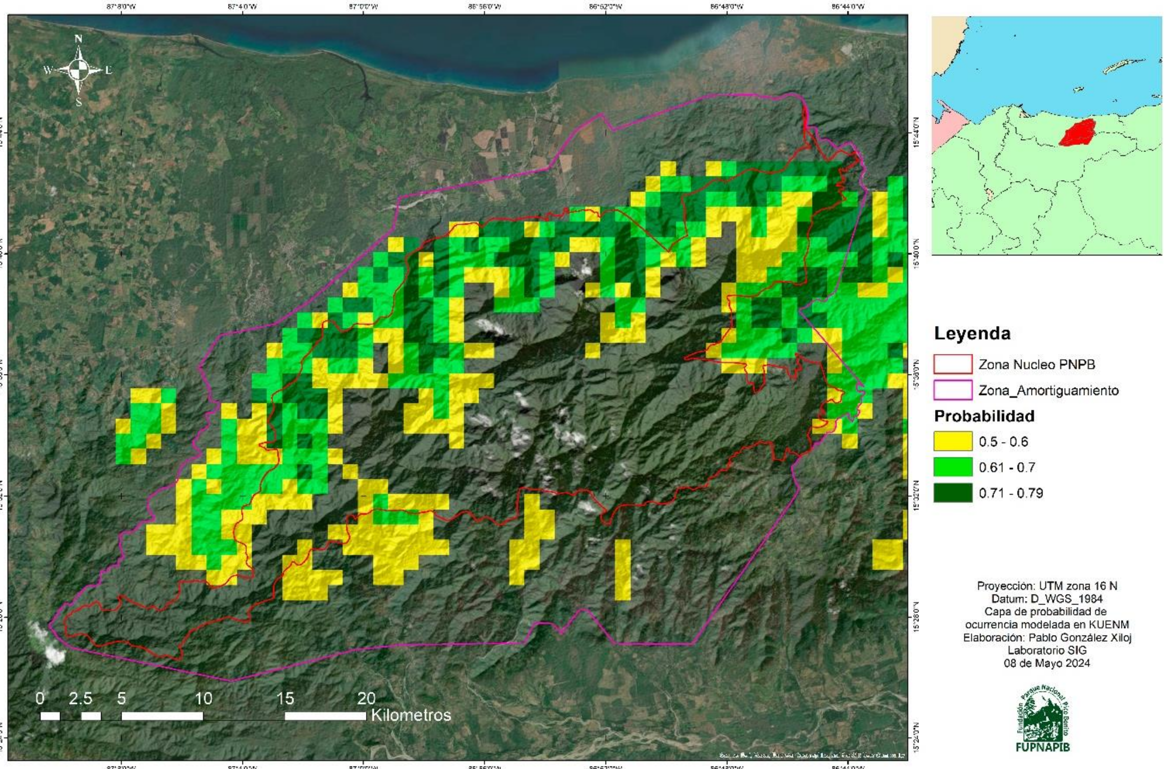
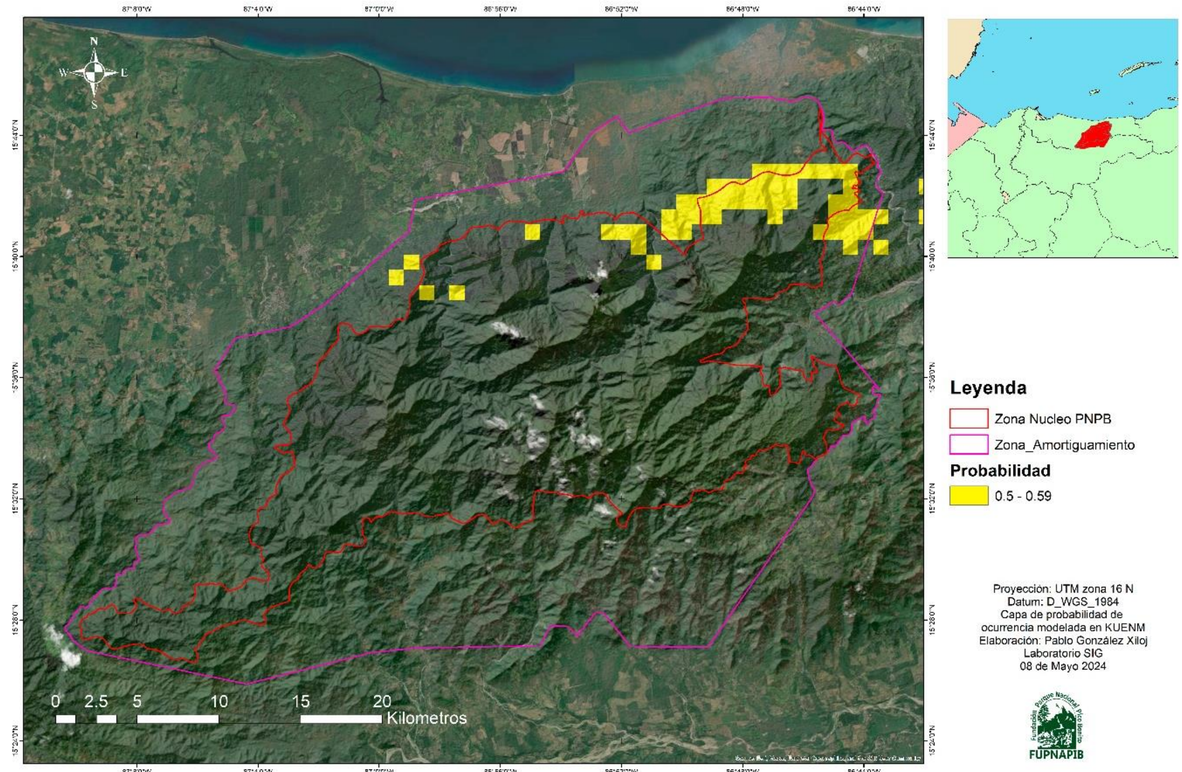


Figure 79. *Map of probability of occurrence to 2060 pessimistic scenario Magnolia atlantida.*



Map of probability of occurrence at 2100 pessimistic scenario Magnolia atlantida.



Discussion of results

Honduras is one of the countries most at risk from climate change in recent years (Eckstein et al., 2020). Locally, little is known about the effects that this phenomenon will cause in various aspects, including diversity. This study provides a novel approach to understanding these impacts. It is evident that each species of the five analysed will perceive an impact in the face of climate change; none is immutable. However, some will benefit and others will be affected.

A general analysis shows that *D. hondurensis* will be the most affected species in this scenario. Its area of possible future distribution decreases and it is the species with the greatest displacement of its centroid in latitude and longitude. One characteristic that may influence this greater vulnerability may be that it is the species with the highest altitude of all those analysed; however, this is not very congruent with other species that tend to be "sheltered" in high regions, since a rugged orography allows them to pursue their niche towards higher elevations to maintain their ideal conditions (La Sorte and Jetz, 2012). The PNPB will present a considerable increase in temperatures in the core area in both scenarios, as well as a considerable decrease in precipitation (Cresto, et. al, 2024), which directly affects the area where the species is currently found. This information is congruent with the average temperature graph, as it is observed that the species decreases its probability of occurrence the higher the temperature is. However, the species seems to prefer less precipitation, suggesting that the variable that most affects the distribution of this species is the temperature variable.

E. coyolensis benefits from climate change, increasing its distribution area in both scenarios and increasing its probability of occurrence. What is expected in the southern part of the park, based on the pattern of *E. coyolensis*, is an exchange of species over time, with species from drier conditions beginning to dominate this area. This is congruent when analyzing the graphs of altitude changes presented in the results, where this species increases its average height over time. However, this altitude decreases at 2080, it would be interesting to analyse smaller scale predictions at 2080 and 2100 of temperature and precipitation to see if there is any change in these conditions that would allow the species to decrease again in altitude. All this should be analysed under the magnifying glass that the *E. coyolensis* model has points very close to each other, so it is necessary to collect more dispersed points to improve the analysis.

M. atlantida prefers sites in the northern part of the PNPB. All evidence indicates that it is the second most vulnerable of the species analysed. Evidently it will be affected by the variation in temperature and precipitation predicted for the area (Cresto, et al., 2024). The model does not present the best AUC value (0.801), which indicates that there may be some margin of error in these predictions. However, if the pessimistic 2100 predictions are correct, a reduction of almost 90% of its ecological niche is observed.

Globally, evidence has been found linking climate change with a greater number of extreme weather events (Stott, 2016). *L. yoroensis* is the third most vulnerable of all the species analysed. This species is adapted to the dry corridor of Honduras, preferring higher temperatures and low precipitation. However, it prefers sites where the temperature does not vary so much during the whole day. The species is partially "benefited" by climate change, increasing its distribution area in the park zone; however, in the central plateau of Olanchito there is a decrease or disappearance of its occurrence in future scenarios. This decrease in occurrence in the Olanchito plateau could be due to the increase in extreme climatic events; however, the incidence of these events is unknown for the area.

Finally, *M. ciroorum* presents a number of points very close to each other, which does not allow the ecological niche of the species to be analysed in the best way. There is a slight decrease in the potential area of distribution at 2060 and an increase in the last period analysed. However, it is suggested not to rely on this analysis, at least in the future predictions that generate greater uncertainty. However, the model can suggest probable distribution sites at present.

Conclusions

The northern area of the PNPB is expected to suffer more from the consequences of climate change based on the evidence of the species analysed, since there is a reduction in the suitability of the species found in this part of the park. On the contrary, in the southern area of the park, there is an increase in the potential area of distribution of the species.

D. hondurensis is the most vulnerable species of all, followed by *M. atlantida*, both of which show a considerable reduction in their niche in the pessimistic and realistic scenarios of 2100 and 2080, respectively. *L. yoroensis* shows a slight reduction in the probability of occurrence on the Olanchito plateau, making it the third most vulnerable species. *E. coyolensis* benefits from the changes predicted by the global circulation models in temperature and precipitation variables, as its distribution increases by 2080 and 2100. The models for *M. ciroorum* are very unreliable due to the small number of points and the geographic proximity between them; it is necessary to collect more points to improve this model.

D. hondurensis has the greatest displacement in latitude and longitude of its centroid, followed by *E. coyolensis, L. yoroensis, M. atlantida and M. ciroorum.* In the case of *M. ciroorum*, due to the small amount of data, the displacement was also analysed for a small basin, so these data could increase when analyzing a larger area. In terms of altitudinal displacement, *E. coyolensis* shows the greatest displacement, followed by *D. hondurensis.* Both Magnolias show a decrease in their heights in the realistic scenario.

D. hondurensis is found at an altitude between 921-1887 meters above sea level. Average temperatures of 1426.5-1701 mm and average temperatures between 16.27 and 22.58°C, all these values obtained from the direct extraction of the points of presence. *E. coyolensis* presents uncertain values due to the small amount of data and their proximity, however, it seems to prefer places with rainfall less than 1600 mm per year, temperatures higher than 26°C and altitudes of approximately 247 meters above sea level. For *L. yoroensis* it is observed that it prefers altitudes between 244-682 masl, rainfall between 1116-1300 mm and average temperature between 23.6-26.1 °C. *M. ciroorum* is found between 192-371 masl, average rainfall between 1475-1833 mm and average temperature between 25.27-26.125°C, however, these data will probably vary when more specimens are collected. Finally, *M. atlantida* is found at altitudes between 452-852 masl, average precipitation between 1000-1500 mm and average temperature between 22.67-23.81°C.

Recommendations

It is necessary to increase the number of collection points for all species, especially for *M. ciroorum, E. coyolensis and M. atlantida.*

We recommend modelling more species in the northern area of the park to elucidate in more detail the impact that climate change will have on this region. At the same time, it is suggested that mitigation measures be taken to mitigate the possible climate impact on the area's ecosystems, because if the species assemblage is modified, the ecosystem services provided by this area will surely be affected.

It is suggested to analyse the occurrence of extreme climatic events that will allow us to elucidate the behaviour of *L. yoroensis* in the future, as well as to see the impact of these events on other species.

It is suggested to analyse the impact of climate change on important crops in the region that affect the food security of communities and their local livelihoods using an approach similar to the one used in this research.

It is suggested that this information be disseminated to other protected areas in the country so that other institutions can prepare themselves and seek synergies between institutions, since some of the models were developed for all of Honduras.

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Annexes

Annex 1. FUPNAPIB Training

As part of the consultancy, a third activity was also carried out with the objective of training FUPNAPIB technical staff on the use of tools for modelling ecological niches using MaxEnt and R studio.

To meet this objective, three training sessions were held for all FUPNAPIB personnel, two of them online and one in person. The first online training was provided on Monday, April 8 of this year, and the second was provided on Monday, May 6. In these first two sessions, the methodology for the pre-processing of the models in KUENM was instructed, i.e., it included: downloading GBIF data, downloading climate layers, clipping climate layers, handling of point of presence databases, etc. Subsequently, classroom training was provided during 3 days from 9am to 4pm from Monday May 27 to Wednesday May 29. In this last part, a review of the topics previously covered was provided. An introduction to the R programming language, data processing in KUENM and post-processing analysis were covered.

Similarly, personalized training was provided to a member of FUPNAPIB, which consisted of online sessions, usually lasting an hour and a half. The training sessions were conducted on the zoom platform and the entire modelling process was explained in detail. One difficulty in completing this second activity was the lack of suitable hardware to run the models, as the participant's computer did not have enough RAM. Four classes were held for data pre-processing and the processing in KUENM was done with the rest of the staff in the classroom training. All trainings except the first one were recorded.