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Translated from the original in spanish **Original article**

Proyection of potencial habitats of *Magnolia cubensis* urb. subsp. *cubensis* in the eastern Cuba

Proyección del hábitat potencial de *Magnolia cubensis* urb. subsp. *cubensis* en el oriente de Cuba

Projeção de habitats potenciais da *Magnólia cubensis* urb. subsp. *cubensis* no oriente de Cuba

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ABSTRACT

Species distribution models are an important tool in conservation studies of threatened species. *Magnolia cubensis* subsp. *cubensis* is an endemic species categorized as vulnerable in mountain rainforests of eastern Cuba. The present study aimed to determine the current potential distribution of *M. cubensis* subsp. *cubensis* in eastern Cuba, as a basis for climate change impact studies and identification of sites for conservation. The actual distribution of the subspecies showed a fragmented distribution pattern for the Sierra Maestra mountain range, which is located between 702 and 1396 m a.s.l. and occupies an area of 0.02 km². The modeling of potential habitats shows a fragmented behavior with a suitability area of 12,428.62 ha. The variables that most influenced the potential distribution of the species were those related to the thermal regime, especially the minimum temperature of the coldest period and altitude.

Keywords: *Magnolia cubensis* subsp. *cubensis*; Modeling; Spatial distribution.

RESUMEN

Los modelos de distribución de especies son una herramienta importante en estudios de conservación de especies amenazadas. *Magnolia cubensis* subsp. *cubensis* es una especie endémica categorizada como vulnerable de bosques pluvisilvas de montaña del oriente de Cuba. El presente estudio tuvo como objetivo determinar la distribución potencial actual de *M. cubensis* subsp. *cubensis* en el oriente de Cuba, como base para estudios de impacto de cambio climático e identificación de sitios para la conservación. La distribución real de la subespecie mostró un patrón de distribución fragmentado para el macizo montañoso Sierra Maestra que se ubica entre los 702 a 1 396 m s.n.m y ocupa un área de 0,02 km². La modelación de los hábitats potencial muestra un comportamiento de fragmentado con un área de idoneidad de 12 428,62 ha. Las variables que más influyeron en la distribución potencial de la especie fueron las relacionadas el régimen térmico, especialmente temperatura mínima del período más frío y la altitud.

Palabras clave: *Magnolia cubensis* subsp. *cubensis*; Modelación; Distribución espacial.

RESUMO

Os modelos de distribuição das espécies são um instrumento importante nos estudos de conservação de espécies ameaçadas. *Magnólia cubensis* subsp. cubensis é uma espécie endémica classificada como vulnerável nas florestas tropicais de montanha do oriente de Cuba. O presente estudo visava determinar a atual distribuição potencial de *M. cubensis* subsp. cubensis no oriente de Cuba, como base para estudos de impacto das alterações climáticas e identificação de sítios para conservação. A distribuição real da subespécie mostrou um padrão de distribuição fragmentado para a Serra Maestra, que varia de 702 a 1 396 m a.s.l. e ocupa uma área de 0,02 km². A modelação dos habitats potenciais mostra um comportamento fragmentado com uma área de aptidão de 12 428,62 ha. As variáveis que mais influenciaram a distribuição potencial da espécie foram as relacionadas com o regime térmico, especialmente a temperatura mínima do período mais frio e a altitude.

Palavras chave: *Magnólia cubensis* subsp. *cubensis*; Modelação; Distribuição espacial.

INTRODUCTION

Currently, one of the greatest challenges for the conservation and sustainable management of biodiversity is to maintain viable populations in their natural environments (Aitken *et al*., 2008). Biodiversity conservation likewise requires reasonable knowledge about the distribution of species and their populations (Margules and Sarkar 2007; Rehfeldt *et al.,* 2015). However, the lack of detailed information on the geographic distribution of these species constitutes a limitation to this demand (Pinkard *et al*., 2015).

The information available to carry out conservation initiatives in degraded sites or those composed of rare or poorly studied species can often be made up of incomplete background information (Rehfeldt *et al.,* 2015). This difficulty in obtaining information from the site can be particularly relevant when trying to work with species or ecosystems circumscribed to small fragments immersed within a matrix altered by humans. The lack of information limits the capacity to generate large-scale programs, and as a consequence the proposed initiatives, in many cases, have limited success. Therefore, a relevant issue in this matter is to be able to predict which species or groups of species could obtain better results to be used in site-specific conservation projects (ContrerasMedina *et al*., 2010; Morales 2012).

To overcome these information barriers, species distribution models are a valuable tool to determine the distribution of poorly studied species and can be of great help in generating unavailable baseline biological information. Species distribution models are an empirical, robust, repeatable and easy-to-use tool that can help identify potential areas to conserve and/or restore (Phillips and Dunik, 2008 and Arribas *et al*., 2012). The value of these studies in conservation is based on the fact that 1) they indicate potential sites for intervention in case direct explorations are needed, 2) they provide guidelines to determine the behavior of species in the face of exogenous alterations, mainly anthropogenic, and 3) they provide information on the sites to be conserved (Hernández *et al*., 2008 and Arribas *et al*., 2012).

Species distribution modeling algorithms take the collection locations of a species and identify the values of a set of explanatory environmental variables that impact those sites (Eliht *et al*., 2011) and return projected probabilities of occurrence for that species across a predefined study area, dependent on the knowledge variables. Provided that the geographic distribution of the species is well represented by the sites sampled, models should accurately identify the ecological niche for the species of interest.

Magnolia cubensis Urb. subsp. *cubensis* is an endemic taxon of the montane rainforest in eastern Cuba, it grows above 800 m a.s.l. in the Sierra Maestra and Sierra de Gran Piedra (Testé *et al*., 2019). Within the genus *Magnolia* it is one of the most widely distributed taxa (Palmarola *et al*., 2015; 2016), but with fragmented populations within the mountain massif, it is considered among the Cuban precious wood species (MolinaPelegrín *et al*., 2014) In recent years, its natural populations have been seriously affected by timber harvesting, other anthropogenic activities and meteorological events (Palmarola *et al*. 2015) so the species is categorized as vulnerable (González-Torres *et al*., 2016). Currently, a series of activities have been initiated to strengthen its conservation and sustainable use, as well as basic studies of its population structure in the Sierra de Gran Piedra (Testé *et al.*, 2019).

This subspecies is subject to risk levels due to potential reductions in its populations due to the lack of natural areas and poor management. Hence, the important role played by protected areas, since a large part of their populations is found in these areas. Actions to be taken range from knowledge of the area's resources and management of endangered species, to environmental education and community integration in conservation tasks.

All of the above indicates the importance of carrying out modeling studies of the spatial distribution of *M. cubensis* subsp. *cubensis* that contribute to the conservation of this taxon in the eastern region of Cuba. The present research aims to determine the current potential distribution of *M. cubensis* subsp. *cubensis* in eastern Cuba, as a basis for climate change impact studies and identification of sites for conservation.

MATERIALS AND METHODS

Characterization of the study area

The subspecies has its natural distribution in the Sierra Maestra, comprising five protected areas: La Bayamesa National Park (PNLB) and Turquino National Park (PNT), protected areas of national significance, Gran Piedra Protected Natural Landscape, as well as the Pico Caracas and El Gigante Ecological Reserves. They make up the mountainous block above 1,200 meters above sea level with the largest area in Cuba.

The climate of the territory is not very varied, although there are differences between the northern part and the southern border. Precipitation is high, ranging between 1 800 and 2 300 mm per year. The average annual evaporation is low. The mean annual temperature varies between 16°C and 20°C. The absolute minimum temperatures vary between 12°C and 16°C, the mean absolute maximum temperatures are 26°C to 30°C, while the mean absolute minimum temperatures are 4°C to 8°C (Montenegro, 1991).

In the Sierra Maestra, there is a great diversity of plant formations: cloud forest, cloud scrub, mountain rainforest, natural pine forests, mesophytic evergreen forest, gallery grassland and anthropogenic vegetation. These depend fundamentally on ecological differences, which are mainly conditioned by altitude and sometimes edaphic conditions (Maceira *et al*., 2005). *Magnolia cubensis* subsp. *cubensis,* inhabits the mountain rainforest vegetation formation, which predominates in sites between 800 and 1 400 m a.s.l. In the upper areas it transitions with cloud forest, and in the lower areas with mesophytic evergreen forest. The relief is abrupt, often with slopes of more than 30 degrees on very poor and acidic leached red ferrallitic soils (Testé *et al.,* 2019).

Geographic distribution

Current distribution

The actual distribution area of *M. cubensis* subsp. *cubensis* was determined from the coordinates of each individual recorded with Gramin GPS. The adult individuals registered range in age from 12 to 60 years of age estimated according to phenotype. The period of collection of the points of presence includes the years between 2008 and 2017. With these data, the actual distribution map of the subspecies was generated using ArcGis software version 10.3. The actual area of occupation of the population was calculated by multiplying the number of cells with presence of at least one individual by the area of the grid (400 m^2).

Transformation and conversion of bioclimatic and topographic variables

Nineteen bioclimatic variables were used for the study: (bio01) mean annual temperature, (bio02) mean diurnal range of temperature, (bio03) isothermality, (bio04) seasonality of temperature, (bio05) maximum temperature of the warmest period, (bio6) minimum temperature of the coldest period, (bio07) annual temperature variation (bio05-bio06), (bio08) mean temperature of the rainiest quarter, (bio09) mean temperature of the driest quarter, (bio10) mean temperature of the warmest quarter, (bio11) mean temperature of the coldest quarter, (bio12) annual precipitation, (bio13) precipitation of the rainiest period, (bio14) precipitation of the driest period, (bio15) precipitation seasonality, (bio16) precipitation in the wettest quarter, (bio17) precipitation of the driest quarter, (bio18) precipitation of the warmest quarter and (bio19) precipitation of the coldest quarter, obtained from the WorldClim global climate surface database, (http: //www. worldclim.org). In addition, altitude was used as a variable, from the digital elevation model available in the WordClim collection based on SRTM (Shuttle Radar Topography Mission) radar records.

First, the raster files of the bioclimatic variables were cropped to take the study area. For this, a mask from a shapefile of the eastern region of Cuba was used, the shapefile had to be reprojected to the WGS 84 UTM Zone 18N coordinate system, once reprojected, and it constituted the support for the transformation of the rest of the bioclimatic variables and altitude.

The environmental raster configuration was carried out with the Environmental Environments tool, which allows all the environmental layers to have the same extension, cell size and coordinate system; these are indispensable requirements for the files to be processed by the MaxEnt program. Once the raster files were configured, they were converted to ASCII format so that they could be executed by MaxEnt, the conversion process was carried out using the ArcGis 10.3 program.

Distribution model

Model of the current potential distribution

The distribution of *M. cubensis* subsp. *cubensis* was modeled using MaxEnt v. 3.3.3 (Phillips *et al*., 2006). The result of the MaxEnt modeling reveals the relative probability of distribution of a species in all grids or cells in the defined geographic space, in which a high probability value associated with a particular grid indicates the probability of having favorable environmental conditions for the modeled species (Elith and Leathwick, 2009).

The modeling was based on the coordinates of the 589 points of presence, points generated during the census of the individuals of *M. cubensis* subsp. *cubensis*, which comprise the entire natural distribution areal. The variables used in this first modeling were the 19 environmental variables and altitude as a topographic variable.

The predictive robustness of the model was determined through the technique of evaluation of the operational curve (ROC) through the area under the ROC curve (AUC) generating a sensitivity vs. specificity analysis (Phillips *et al*., 2006), for which 75 % of the training accessions and 25 % of the test accessions were used in the random test percentage option, which tells the program to randomly choose and set aside 25 % of the sample records to be used in the test for the verification of the resulting models. The AUC can then be interpreted as the higher probability that a randomly selected presence point is located in a raster cell with a high probability value for the presence of the species compared to that of a randomly generated point (Elith *et al.,* 2011 and AvilaCoria *et al*., 2014). The highest predictive ability of a MaxEnt-generated model is achieved when the AUC has a value of 1 (Araújo and Guisan, 2006).

In the configuration, a maximum of 500 interactions was specified with a convergence limit prefixed at 0.00001 that guarantees the convergence of the algorithm, i.e. it maintains stability in its analyses (Elith *et al*., 2011). The definition of these convergence limit parameters are usually those employed (Ávila *et al*., 2014). In order to avoid presence data with duplicate records, deleting duplicates was activated, which allowed reducing sampling biases.

To validate and train at the same time without overfitting the neural network, the crossvalidate option was used. The logistic function was established as the output format, as it is the simplest to conceptualize, since it provides an estimate between zero and one of the probabilities of presence (Phillips and Dudik, 2010). This represents the estimated probability of presence of the species, given the constraints imposed by the predictor variables. With this format, grids with low values (close to zero) are considered inappropriate for the species given its ecological niche (Phillips and Dudik, 2010; Elith *et al.,* 2011). The final model of the potential distribution was taken from the ASCII format map generated by the program; this map was converted to raster format using the ArcGis 10.3 program. The area covered by the current potential distribution was determined by creating polygons and determining the area it occupies within the territory, using ArcMap tools.

The Jackknife resampling method was used to evaluate the contribution of the bioclimatic variables within the model. This test analyzes the contribution of each variable in isolation and additionally generates another with all the variables, indicating the gain of each one of them. In order to analyze the influence of each climatic variable on the presence of the species, response curves were generated, since they express how each of these affects the prediction of MaxEnt.

Evaluation of conservation zones for the subspecies

The determination of potential and critical zones for the conservation of the subspecies was proposed by joining the geographic distribution maps generated by the MaxEnt program (points of presence and potential distribution) with the zoning of the National System of Protected Areas (SNAP) according to CNAP (2014). For this purpose, the digital version of the map of the National Center for Protected Areas (CNAP) for the period 2014-2020 was used. The area of the zones of high suitability for the presence of the subspecies in each of the protected areas under study was quantified with the ArGis 10.3 program.

RESULTS AND DISCUSSION

Geographical distribution

Actual distribution

Magnolia cubensis subsp. *cubensis* occupies an area of 0.02 km², of which 0.0184 km² corresponds to the subpopulation located in Granma province and 0.0016 km² to the subpopulation in Santiago de Cuba province (Figure 1). From the biological point of view, the distribution could be related to favorable ecological conditions for its development only in the Sierra Maestra mountains (Testé *et al*., 2019).

The current arrangement of its distribution in small and geographically separated areas may be due to habitat fragmentation as a consequence of the exploitation of the taxon, the low availability of reproductive individuals and problems related to the seed bank; however, studies that focus on these aspects are very scarce (Molina-Pelegrín, 2014). So far, there is only one study available on the impact of habitat fragmentation on the population and genetic structure of *M. cubensis* subsp. *acunae t*hrough spatial and molecular analysis, which concluded that this is the main cause of the reduction of its natural distribution and that it also increases the risk of climate change scenarios (Hernández *et al*., 2020). Therefore, molecular and autoecology studies in the subspecies *cubensis* are necessary.

This distribution pattern in *M. cubensis* subsp. *cubensis* and the population structure of diameter and height classes evaluated by Molina-Pelegrín *et al.,* (2014) and by Testé *et al*., (2019) for Gran Piedra, revealed the aging of these populations, which could explain the reduced area of current occupation.

The geographic distribution of individuals of the subspecies ranges from 1958' 10.2'' N and 7700'29.6'' W to 200'46.0'' N and 7537'50.1'' W. The altitudinal range is between 702 and 1 396 m a.s.l., although most individuals are found in the range of 1 000 to 1 200 m a.s.l.

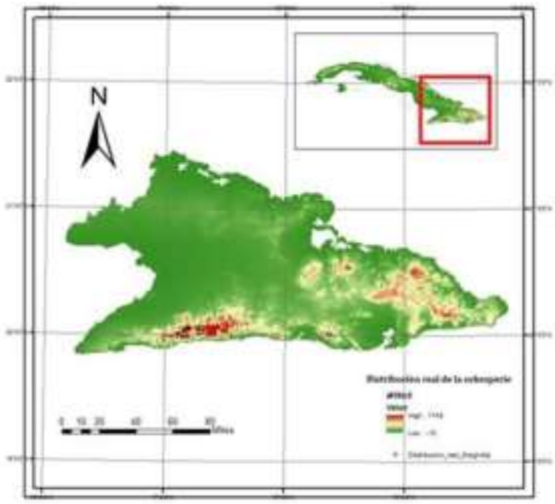

Figure 1. - Distribution of the actual area occupied by *Magnolia cubensis* subsp. *cubensis*, based on the georeferencing of the 587 individuals

Current potential distribution model

There is a good fit for predicting the presence of the species, since the value of the area under the ROC curve was 0.996 (Figure 2), values above 0.9 are considered as indicators of good predictive robustness of the model (Phillips *et al.,* 2008 and Elith *et al*., 2011). This result was similar in potential habitat prediction studies of conifers (Contreras-
Medina *et al*., 2010; García-Aranda *et al*., 2012, Ávila-Coria *et al*., 2014 and MirandaSierra 2017) and other species of forest interest (Smith *et al*., 2012). However, in animal species, lower AUC values are reported in modeling with climatic variables, apparently due to the influence of other environmental variables in the definition of their climatic niche (Azor-Hernández and Barro-Cañamero 2014; Cobos-Cobos, 2016).

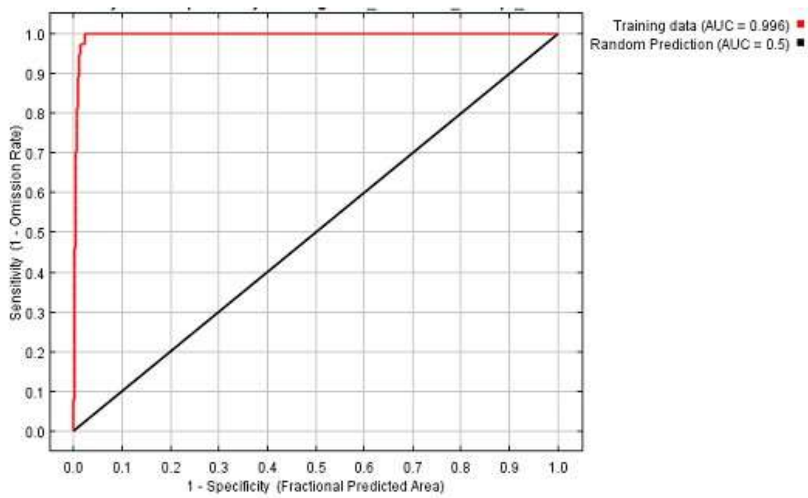

Figure 2. - Operational response curve (ROC) of the current potential distribution model of *Magnolia cubensis* subsp. *cubensis* in eastern Cuba.
Note: in red the average ROC curve for the training data. The black line represents the random prediction (AUC=0.5)

The map of probability of potential presence, according to the chosen threshold, indicated absences of the subspecies below 0.15. The model highlighted two main geographical cores: Sierra Maestra (Granma province) and Gran Piedra, also belonging to the same mountain massif, but the latter located in Santiago de Cuba province. Although there are six small population nuclei in the Sagua - Nipe - Baracoa Mountain massif, with possibilities of presence of the taxon. In general, there is an area with a medium probability (0.38-0.69) of presence and a disjunct pattern was reflected in the distribution of the subspecies (Figure 3). The Sierra Maestra region, in the western part (Granma province), comprises the largest area of potential occupation with 54 081.48 ha (92.80 %), while Gran Piedra (east) comprises 4 168.36 ha (7.15 %), for a total of 58 249.83 ha.

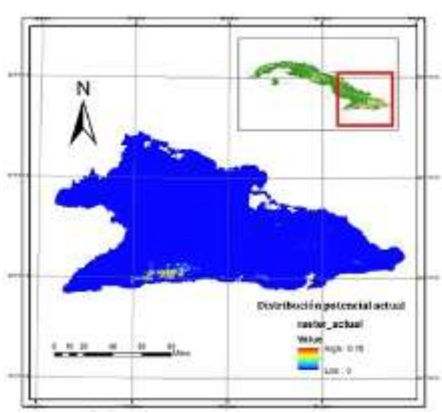

Figure 3. - Map of current potential distribution of *Magnolia cubensis* subsp. *cubensis* in eastern Cuba

The analysis of the importance of each variable by means of the jackknife test (Figure 4), shows that the variables that most influence the presence of the species are those related to temperatures (bio01, bio05, bio06, bio08, bio09 and bio10) and altitude. These results allow us to identify the climatic requirements of the species and their ranges that determine the probability of their presence. Therefore, this constitutes a first approach to the evaluation of the influence of climatic variables on the distribution of the species. Likewise, this has been an alternative used by several authors for some endemic or endangered species and thus facilitate conservation decision-making, such as: *Cedrela odorata* (Gómez-Díaz *et al*., 2007); *Taxus globosa* (García-Aranda *et al*., 2012); *Pinus strobus* (Joyce and Rehfeldt, 2013); *Pinus herrerae* (Ávila-Coria *et al.,* 2014); *Magnolia schiedeana* (Vásquez-Morales *et al.,* 2014) and others (see review Gray and Hamann 2012).

In this case, it is explained that the variables related to the thermal regime are those that affect, in the first order, the potential distribution of the taxon. Therefore, if there are abrupt and prolonged changes in the ranges for one or several climatic variables, then the favorable climatic conditions for the presence of the taxon would be affected. In this regard, McLean (2015) projects a drier climate and increased temperatures in the Caribbean area, particularly in eastern Cuba; this could affect the species' physiological processes, biomass production and even flowering and seed production (Álvarez-Brito, 2017 and Sáenz-Romero, 2014). This will make these sensitive as a result of alterations in their climatic niche.

Studies of the influence of climate changes on physiological and reproductive processes have been studied in several conifers and broadleaf species with wide distribution (Aitken *et al.,* 2008), but in tropical and island species are very scarce (Álvarez-Brito *et al*., 2014 and Álvarez-Brito, 2018) and these also supported by genetic studies of the species and their populations are the basis for promoting resilience and adaptive management. In Cuba, such studies, although incipient, information is available on alterations of vegetative and reproductive phenophases in three forest species (Hechavarría-Kindelán *et al.,* 2008; Hechavarría-Kindelán 2012 and Álvarez-Brito and Mercadet-Portillo, 2014). Therefore, research on the phenology and reproductive biology of tree species and their changes due to the effect of variations in climate, together with these, but based on the simulation of changes in climatic variables in nursery conditions, *in situ* conservation areas are crucial in understanding the impact of changes in the demographic structure of the species.

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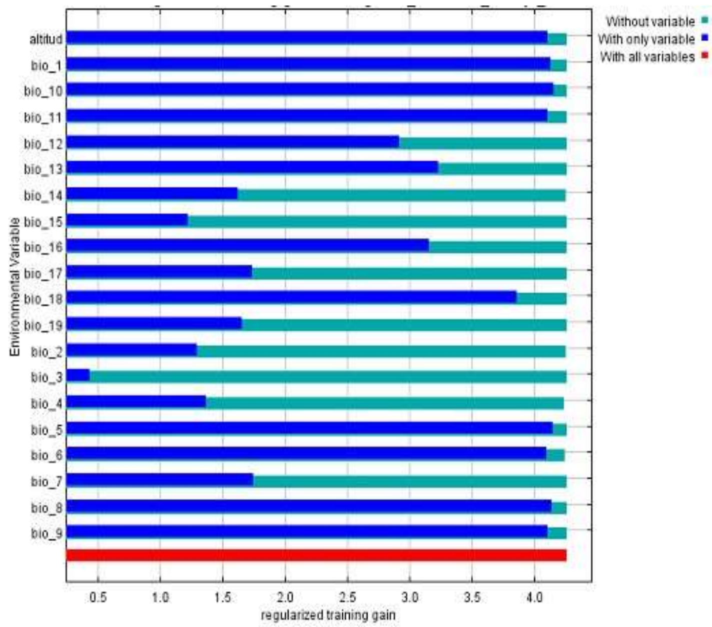

Figure 4. - Contribution of environmental variables to the current potential distribution pattern of *Magnolia cubensis* subsp. *cubensis* in eastern Cuba
The blue bars represent the average gain of the model using only one variable and the green bars represent the gain when each variable was excluded

The analysis of the response of the variables that contribute most to the model revealed that, in particular, the response curve of the variable minimum temperature of the coldest period (˚C) had an inverse exponential form, with lower temperatures corresponding to increases in the probability of presence of the species, i.e., increases in the suitability for the presence of the subspecies (Figure 5A). For the case of the altitude variable, it is shown that the probability of presence of the taxon increased from 700 to around 1 400 m a.s.l., from which point it began to lose relevance (Figure 5B). The implication of altitude as one of the most explanatory variables in the models agrees with that reported by González-Torres *et al*., (2013) and Palmarola *et al*., (2018) for the subspecies *M. cubensis* subsp. *acunae* in the Guamuhaya massif and with studies of *M. schiedeana* in Mexico (Vásquez-Morales *et al*., 2014).

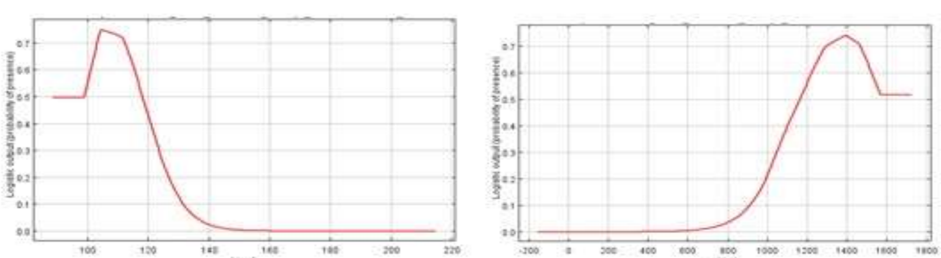

Figure 5. - Average response curves for (A) minimum cold period temperature (BIO 6) and (B) elevation above sea level (Altitude) in the current potential distribution model of *Magnolia cubensis* subsp. *cubensis* in eastern Cuba

Potential and critical zones for the conservation of the subspecies

The 78.58 % of the current potential distribution of *M. cubensis* subsp. *cubensis* is under conservation of areas belonging to the National System of Protected Areas of Cuba (SNAP), with an area of 45 773, 38 ha. Below are the maps of the potential zones for *in situ* conservation of the taxon (Figure 6, 7, 8, 9 and 10), corresponding to each of the protected areas.

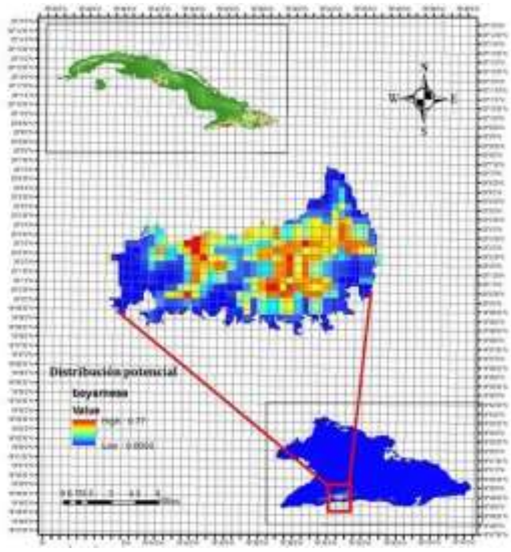

Figure 6. - Map of potential zones for *in situ* conservation of *Magnolia cubensis* subsp.*cubensis* in La Bayamesa National Park, based on potential distribution

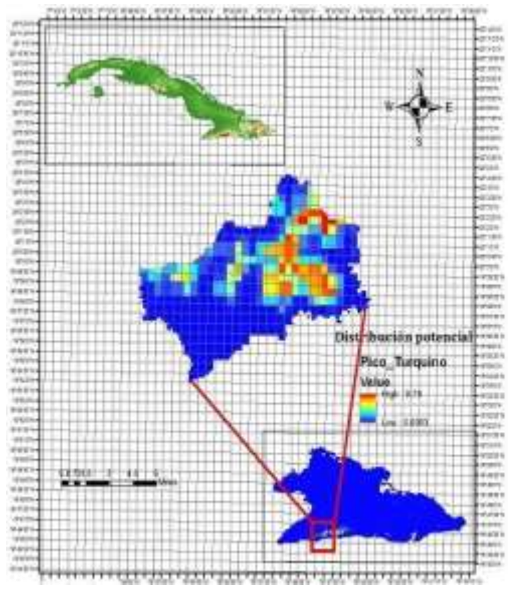

Figure 7. - Map of potential zones for *in situ* conservation of *Magnolia cubensis* subsp. *cubensis* in Turquino National Park, based on potential distribution

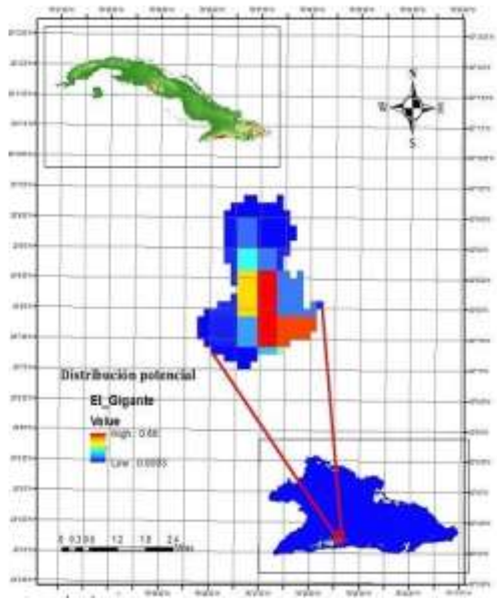

Figure 8. - Map of potential areas for *in situ* conservation of *Magnolia cubensis* subsp. *cubensis* in El Gigante Ecological Reserve, based on potential distribution

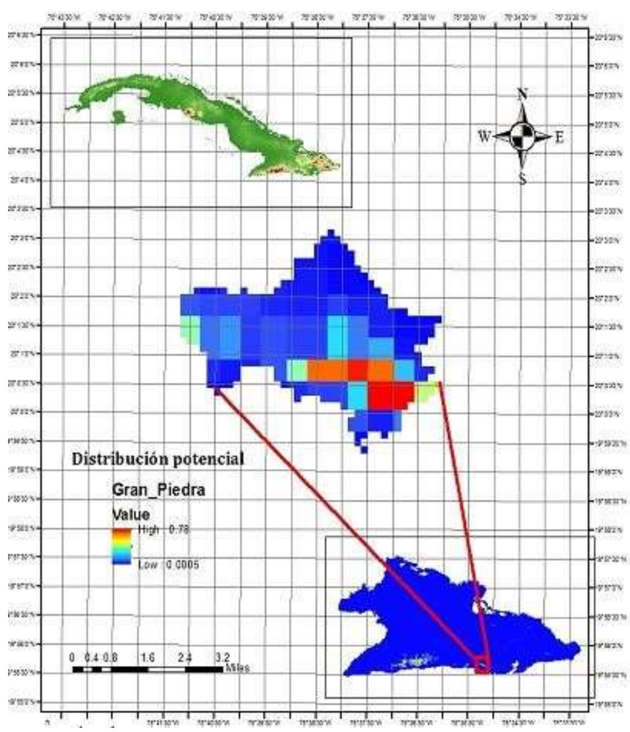

Figure 9. - Map of potential areas for *in situ* conservation of *Magnolia cubensis* subsp. *cubensis* in the Gran Piedra Protected Natural Landscape, based on potential distribution

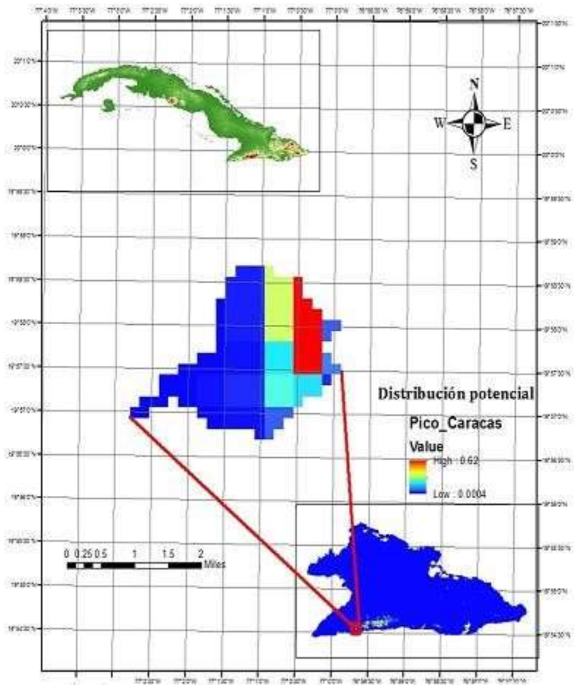

Figure 10. - Map of potential zones for *in situ* conservation of *Magnolia cubensis* subsp. *cubensis* in the Pico Caracas Ecological Reserve, based on potential distribution

A low correspondence of the potential distribution of *M. cubensis* subsp. *cubensis* in the SNAP is shown, which contrasts with a high actual representativeness of the subspecies in the study developed.

There is a low correspondence in the distribution of the taxon registered by the SNAP and the one presented in this study as actual current distribution, which shows that not all of the species is only within protected areas, and that, therefore, there are still individuals that are part of areas where there is no protection. In this sense, Hernández and Estrada (2004) state that the delimitation of protected areas has been established based on logistical reasons, based on anthropocentric or geographic criteria and without taking into account the requirements of the species to be protected. Similarly, in relation to the potential area and its real distribution, in almost all the protected areas there are potential habitats where the species could develop if actions were taken for its propagation.

The critical areas for the conservation of the subspecies are mainly located in the buffer zone of the protected areas; this reinforces the importance of these areas within the conservation strategy for the taxon and the need to combine more interdisciplinary and inter-administrative actions of the protected areas. The existence of 12,428.62 ha that are not part of the subspecies' conservation target and that show sites with probabilities of presence of the taxon was determined (Figure 11). Some of these sites are within the buffer zone of Pico La Bayamesa National Park, where the largest rural settlements are located, a factor that constitutes a risk for the *in-situ* conservation of the subspecies

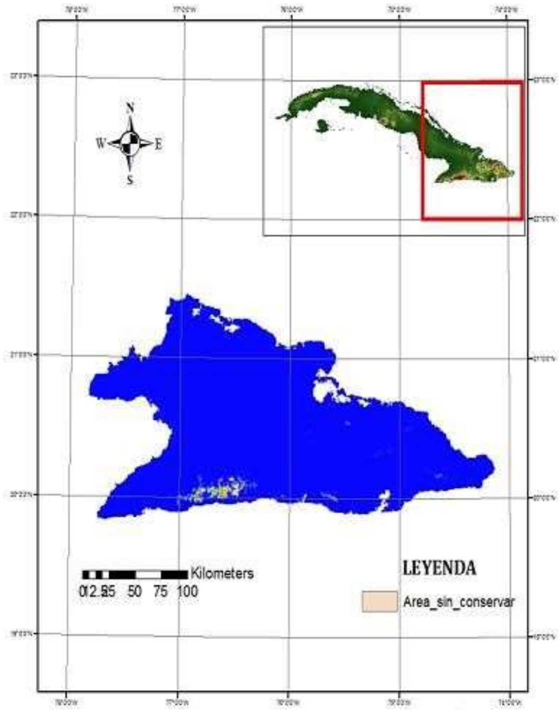

Figure 11. - Map of sites with probabilities for potential habitat *Magnolia cubensis* subsp. *cubensis*, not included in the protected areas in eastern Cuba

CONCLUSIONS

Magnolia cubensis subsp. *cubensis* is distributed in a fragmented way in the Sierra Maestra Mountain massif. Individuals are mostly distributed in the altitudinal range from 1 000 to 1 200 m a.s.l.

The area of current potential distribution, in eastern Cuba, presents a disjunct pattern with an area of total suitability in the Sierra Maestra Mountain massif, conditioned fundamentally by the variables: minimum temperature of the coldest period and elevation above sea level.

The 78.58 % of the current potential distribution of *Magnolia cubensis* subsp. *cubensis* is under conservation by the National System of Protected Areas of Cuba (SNAP).

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Yenia Molina-Pelegrín: Conception of the idea, literature search and review, instrument making, instrument application, preparation of tables, graphs and images, drafting of the original (first version), translation of terms or information obtained, review of the application of the applied bibliographic standard.

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