



Geographic Information Systems for Forest Species Distribution and Habitat Suitability

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Abstract. The reach and descriptive capabilities of geographic information systems are displayed using a pair of examples modeling distribution range and habitat suitability for big-leaf mahogany *Swietenia macrophylla* King from the Yucatan Peninsula of Mexico based on the National Forest and Soils Inventory database. Big-leaf mahogany is an economically important species in the Neotropics. For over three centuries, it has been selectively extracted from tropical forest, threatening its populations. These examples show that this region contains, and it will continue to hold large areas suitable for big-leaf mahogany. Although models predict a decrease in the extent of the regional big-leaf mahogany natural distribution, suitable habitat is expected to be abundant in Quintana Roo, Mexico. These studies have taken full advantage of GIS capabilities to integrate georeferenced data with explanatory environmental factors. Models of these relationships have turned out to be effective tools that generate valuable information for decision making and scientific understanding of the issues and concerns regarding big-leaf mahogany.

Keywords: Big-leaf mahogany · MaxEnt · Species distribution model (SDM)

1 Introduction

Geographic information systems (GIS) comprise a category of software tools with ample usage potential for managing spatially explicit data. GIS applications provide means to display species distribution ranges and suitability habitat for valuable timber species such as big- leaf mahogany *Swietenia macrophylla* King [1]. Species distribution and suitability habitat are two issues that can be addressed as mathematical models that relate locations where the species occurs

to environmental features in those places. GIS software such as ArcGIS, ArcMap, QGIS, DIVA-GIS, and gvSIG make it possible to integrate species distribution with ecological factors (climate, soil, land use) [2]. Recent GIS applications that portray species distribution include Navarro-Martínez et al., in 2018. On the other hand, a habitat suitability model was developed by Ramírez et al. (in press). GIS models are built on two tiers: 1. Primary data on species presence as shown in forest inventories and herbarium metadata, and 2. Secondary data about climate and physical environment (soil, topography and such). Secondary data usually comes from repositories such as WorldClim¹ [3]. WorldClim offers global climatic data with a one-kilometer spatial resolution at the Equator. Other data sources for Mexico include Instituto Nacional de Estadística y Geografía (INEGI)², Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO)³, and Comisión Nacional Forestal (CONAFOR)⁴.

The two models presented here will showcase the reach and modeling capabilities of GIS. The cases model big-leaf mahogany distribution and habitat suitability. Big leaf mahogany is a highly appreciated fine timber that is an economically important and emblematic of the Neotropics. This species grows as an emerging tree in humid and dry forests of diverse soil and climate characteristics [4–6]. Big-leaf mahogany also grows among secondary vegetation after catastrophic disturbances and after traditional Maya slash and burn agriculture [7–9].

The natural distribution of big-leaf mahogany covers around 8 000 km², encompassing from southern Mexico down to the northern regions of Brazil and Bolivia [10]. Lamb in 1966 considers that the best big-leaf mahogany is the one from tropical dry forests [11]. In Mexico, big-leaf mahogany is found in six southeastern states [12]. One of the largest Mexican populations is the one in the Yucatan Peninsula [13]. This population is considered one of the best remaining in Mexico (Fig. 1). On the Yucatan Peninsula, many forest communities depend on big-leaf mahogany harvests to obtain suitable profits from their forest management operations [14].

Historic records of big-leaf mahogany logging span for over three centuries [15–17]. Current forest structure is dominated by juvenile pole size trees in dense stands, old growth and regeneration spots are rare [18]. However, land development and commercial logging in the Yucatan Peninsula for the last twenty years appear to have not encroached on the natural mahogany forests, as they have in other regions [1].

Currently, big-leaf mahogany is listed in Mexico as vulnerable and prone to extinction [19–21]. Since 1998 big-leaf mahogany was labeled as vulnerable in the CITES list of endangered internationally traded species [22]. It was known that at the end of the 20th Century mahogany was present in an estimated 36% of its potential area [23]. In the case of Mexico, the loss of mahogany forests

¹ <http://www.worldclim.org/>.

² <https://www.inegi.org.mx>.

³ <https://www.gob.mx/conabio>.

⁴ <https://www.gob.mx/conafor>.

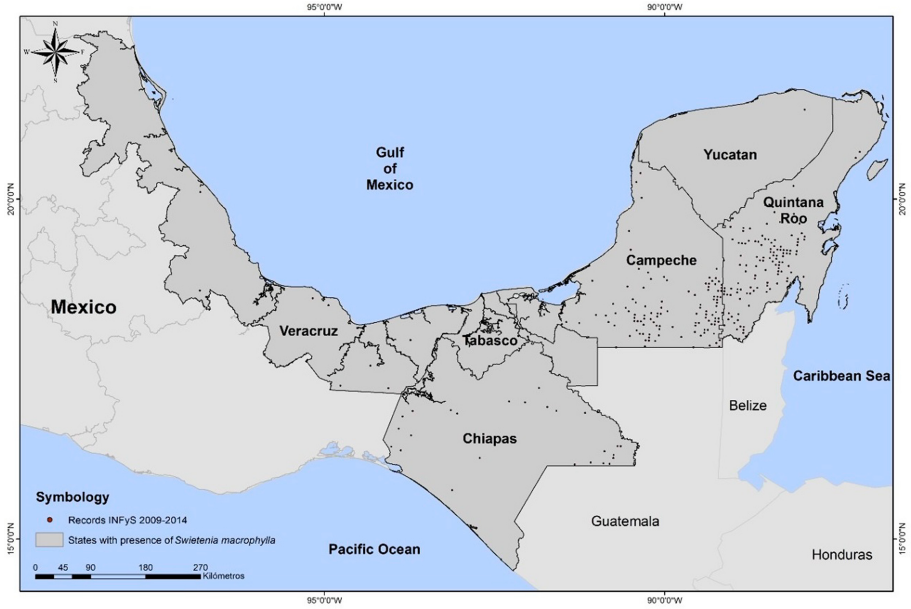


Fig. 1. Field reports of presence of big-leaf mahogany (*Swietenia macrophylla*) King in Mexico. Source: National Forest and Soils Inventory database.

adds up to an estimated 76% [24]. As a caveat, it should be stated that some researchers consider these figures speculative [25].

An array of modeling approaches has been developed to link bioclimatic variables to the presence of species on the ground. Most models assume that climate regulates the distribution of species [26,27]. These models make it possible to forecast changes in the future distribution of diverse species and ecosystems [28–33]. This paper presents the results of two studies that model potential distribution and habitat suitability of *Swietenia macrophylla* King in the Yucatan Peninsula of Mexico. These models convey ecological information for the management of this species and its habitat, since mahogany is associated to over 200 other tree species and many other life forms.

2 Potential Distribution of Big-Leaf Mahogany in Mexico

In a previous study from 2018, a model was produced to represent the potential area of distribution of *S. macrophylla* (Fig. 2) [1]. This model was developed using MaxEnt version 3.3.3 [34]. Input data was made up of 393 field plots where the species was present based on the National Forest and Soils Inventory database (INFyS) in 2004–2009. Climatic variables were provided by WorldClim. Ancillary information was added to include vegetation and land use patterns. This explanatory information was provided by CONAFOR (scale 1:

250,000) [12]. INEGI's elevation model (30 by 30 m resolution) was also used. CONAFOR's national forest inventory in the study region comprises of 248 conglomerates. Each conglomerate is made up of four rectangular subplots 400 m² each. Conglomerates are systematically placed on the ground. These samples contain 566 instances of mahogany presence.

MaxEnt software follows the statistical concept of maximum entropy. The software allows estimates of potential distribution probabilities [35]. All coordinate values are coded as Mercator **WGS84** geodesic projection. Results are displayed using ArcGIS 9.2 software. The MaxEnt software provides an AUC value to assess the model. Model performance means efficacy in discriminating among sites with and without mahogany [36]. An AUC value greater than 0.5 indicates an acceptable model performance [34].

The Fig. 2 was produced by MaxEnt output, and it can be considered as the potential distribution of *S. macrophylla*. This model resembles the species known actual distribution (Fig. 1), except for an overly elevated probability in the south-southwest portion of the Yucatan Peninsula, particularly in the states of Quintana Roo and Campeche. This zone seems to have in a wide geographic area with a high-quality habitat. The model identifies the best conditions for mahogany in the largest forestry ejidos as Petcacab and Noh Bec in the center of the state and Tres Garantias and Caoba in the southern part of Quintana Roo. In Campeche, the best habitat for mahogany was found in the Calakmul region [1]. Community forestry has been developed in this area since the early 1980s, proving to be a good strategy for forest conservation [14].

The example model reached an AUC value of 0.9. Vegetation was the variable with the highest contribution to the model, and high and medium tropical forest covers were closely related. Vegetation was also important. A model for the same species in Veracruz, Mexico [37] arrived at the same outcome. Elevation too was an important factor. Climatic variables explained a minor part of the model projections.

3 Habitat Suitability of Big-Leaf Mahogany in Mexico

Distribution models can include trends of change in climatic variables [38–40]. This capability invites inquiries into the effect of the current problem of accelerated global climatic change. Effects of climatic change are expected to show as variations of forest structure and composition, as well as changes in species distribution patterns [41, 42]. Models based upon the idea of habitat suitability have shown the likelihood of diminishing the range of distribution for some species. This topic has been addressed by several researchers [43–48]; their work improves the understanding of those changes, their size and trend [49].

Ramírez-Magil et al. in print used models to assess the habitat suitability distribution of *Swietenia macrophylla* King in the Yucatan Peninsula of Mexico, and to forecast future distribution under two scenarios of climatic change [50]. The second model in this paper drew its input data from INFyS 2009–2014, WorldClim, and CONABIO's biogeographic provinces [51]. Data was input into MaxEnt and ArcGIS for processing.

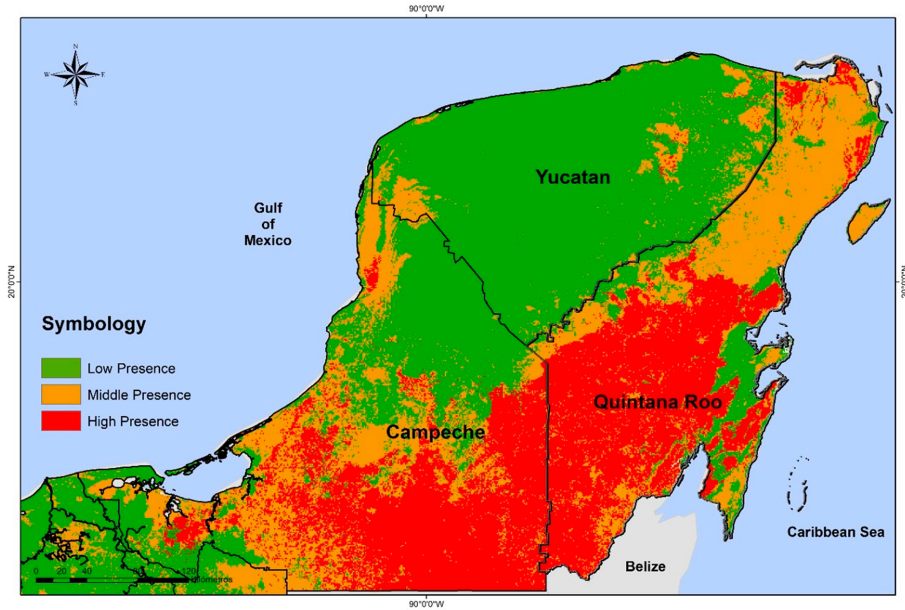


Fig. 2. Potential distribution of *Swietenia macrophylla* King in the Yucatan Peninsula, Mexico.

Raster files for each of 19 bio-climatic variables were produced for the study area using options in the environment settings menu of ArcMap 10.4.1. Raster data were trimmed using the extract by mask tool from the same software.

The resulting model (Fig. 3), used 270 locations of species reports (80%), soil type, and six bioclimatic variables as input for MaxEnt. The 20% of unused field registers were set apart for later use in independently validate the model. Validation was carried using Partial Roc software [52].

Future scenarios estimates required alternative climatic parameters. These were taken from the general circulation model MRI-CGCM3. This climate change model assumes that global emissions will peak in 2040. The rendering of projected scenarios was possible using ArcMap 10.4.1. In this process, maximum sensibility and specificity of 0.254, 0.238, 0.275 (2020, 2050, 2070, respectively), were the thresholds for reclassification of the species presence or absence. This screening produced a map for each scenario, and from them, it was possible to tally pixels that changed their value of presence or absence of mahogany. The tally was then converted to area estimates.

The resulting MaxEnt model exhibits a great influence of soil type (32.4%), precipitation season (14.7%), and diurnal temperature spread (8.5%). A total of 7 017 106.68 ha were deemed suitable habitat for *S. macrophylla* (Fig. 3A). Campeche (41%) and Quintana Roo (32%) were the states with the largest area suitable for mahogany. These figures are close to the current occupation area.

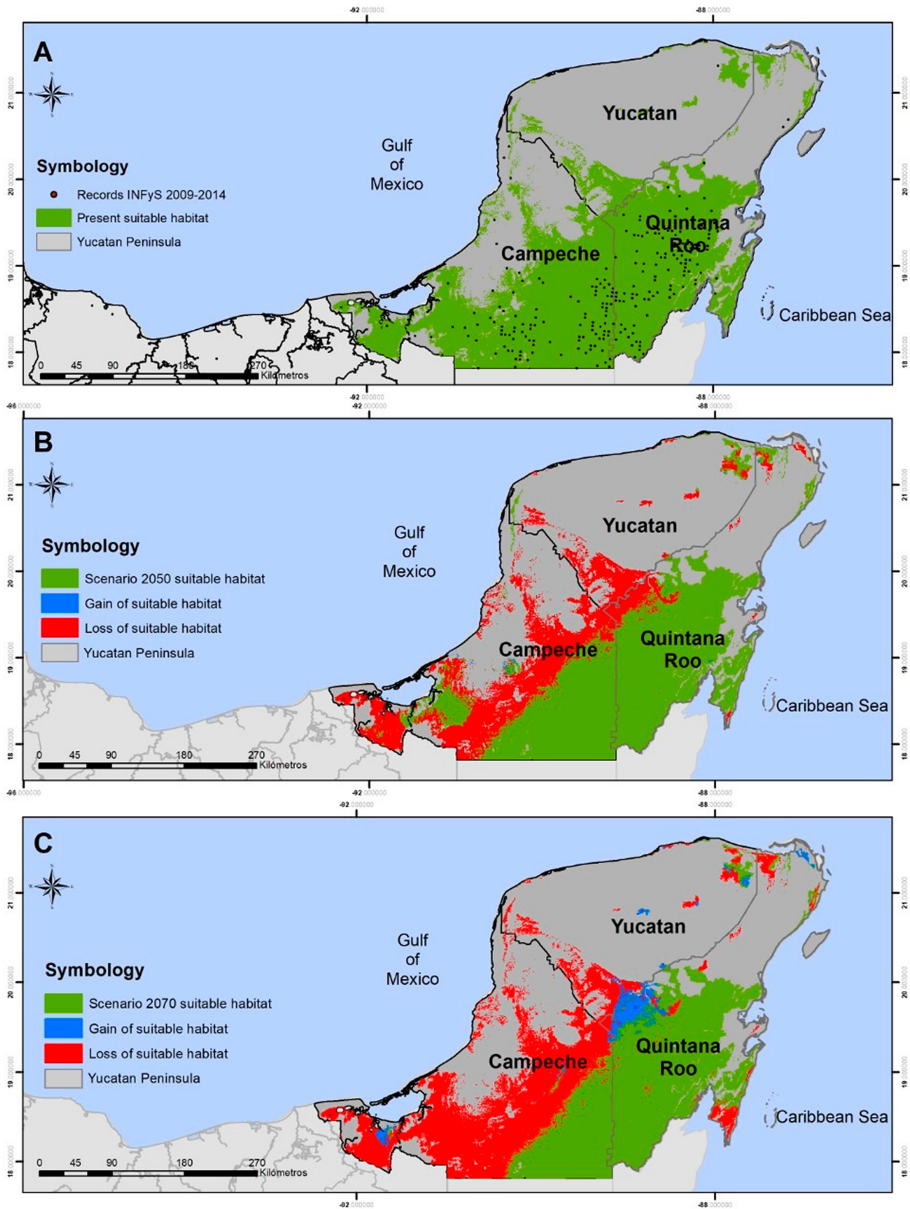


Fig. 3. Suitable habitat for *Swietenia macrophylla* King in the Yucatan Peninsula, Mexico.

Navarro-Martínez et al. in 2018 findings are about the same amount, hence suggesting that there is a significant area of mahogany habitat in the Yucatan Peninsula today (2020).

The 2050 scenario expects 4 714 137.45 ha of suitable habitat, this is equivalent to a 32.8% decline respect to 2020 (Fig. 3B). In this scenario, Campeche would still retain some 37% of lands with suitable habitat, while Quintana Roo would be holding 48.6% of the 2020 suitable habitat.

The expectation for the year 2070 is to have 3 964 615.11 ha, or a loss of 56.5% of the present habitat, equivalent to a 15.9% decrease relative to the 2050 scenario. At this later time, Quintana Roo will be highly relevant in preserving the species and its habitat in México (Fig. 3C).

The reduced suitable habitat expected in 2070 might be explained because of the emissions peak in 2040, and subsequent subsiding running up to 2070. Habitat suitability estimated for 2050 could be related to precipitation reductions and increases in temperature those years. The habitat losses could possibly be larger than expected according to Calvo y Rivera in 2000.

It is important to keep into perspective that Quintana Roo and Campeche hold today extensive mahogany populations, even though the species has been harvested for over 300 years. Current populations continue being logged because they are an important resource for Maya communities that practice their traditional management schemes of slash and burn. Traditional community forestry has shown to be successful in securing a continuous renovation of the forest within the constraints and goals of natural resources sustainable management.

4 Conclusion

The use of GIS and their supplementary software have shown effective modeling capabilities to study the distribution and suitability of mahogany habitat. These models generate visions of the future and elicit connections and explanations about the trends in species occupation. These insights are valuable when handed over those in charge of decisions, and they are also important in supporting scientific explanations of the species trends.

The potential distribution of *S. macrophylla* obtained from the MaxEnt software predicted the greatest probability of occurrence as wide and continuous expanses of habitat in the southern and southeastern regions of the Yucatan Peninsula. This outcome is consistent with field reports of presence, although its abundance varies. The spatial potential distribution model was best explained by vegetation cover (medium- and high-stature semievergreen tropical forest), and elevation. In this area are found today and for the future the most suitable habitat conditions for the permanence of the species, particularly in Quintana, which according to the projections of the MaxEnt model tested for the years 2050 and 2070, will conserve around 50% of the current area in the natural distribution range of the species in Mexico; although the general trend between the present scenarios, 2050 and 2070 is a decrease in habitat. This region represents one of the most important and continuous relics of tropical vegetation in Mexico, which implies a challenge for its permanence given the pressure on natural resources by land use change.

Nevertheless, the economic importance of *S. macrophylla*, current evidence suggests changing forest management at the guide species level to management

of all species in the forest to favor their regeneration; also, silvicultural practices should be promoted that favor the rapid growth of seedlings and young individuals in such a way as to favor recruitment and with it, the recovery of harvested individuals.

5 Future Work

Given the importance of big-leaf mahogany in contributing to the economy of the families in the forest communities where it is distributed, it is necessary to complete the knowledge about its ecology by incorporating information about the demographic behavior of the species in the region, and that allows the elaboration of a robust proposal for the management and conservation of the species and the forests of Quintana Roo. This requires the design and establishment of a long-term monitoring network.

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