DOI: 10.29298/rmcf.v13i72.1224

Article

Distribución natural de *Taxodium huegelii* C. Lawson en el estado de Hidalgo

Taxodium huegelii C. Lawson natural distribution in the state of *Hidalgo*

Rafael Canales-Perez[1], Sergio Hernández-León[1]*, Abraham Palacios-Romero[2], Adriana Hernández Lazcano[1], Rodrigo Rodríguez-Laguna[1], Alfonso Suárez-Islas[1], José González-Ávalos[1], Oscar Arce-Cervantes[1]

Fecha de recepción/Reception date: 12 de octubre de 2021
Fecha de aceptación/Acceptance date: 16 de mayo del 2022

[1]Área Académica de Ciencias Agrícolas y Forestales, Instituto de Ciencias Agropecuarias, Universidad Autónoma del Estado de Hidalgo. México.
[2]Tecnológico de Monterrey, Escuela de Ingeniería y Ciencias. México.

*Autor para correspondencia; correo-e: sergio_hernandez@uaeh.edu.mx
*Corresponding author; e-mail: sergio_hernandez@uaeh.edu.mx

Abstract

Taxodium huegelii (synonym: *Taxodium mucronatum*) is a tree that inhabits gallery forests; its common names are *ahuehuete*, Tule tree, *Montezuma* cypress or *sabino*. The objective of this research was to generate current and potential distribution maps for the species in the state of *Hidalgo*. The 56 records, obtained from field collections and a database search were used to prepare them. Records were pre-analyzed to avoid provenance errors and repeated data. The documented distribution map was generated with ArcGIS® version 10.3 and the potential distribution map with Maxent version 3.4.1. The biogeographic provinces (Zacatecan-Potosin) Southern Highlands, Eastern Sierra Madre, and the Gulf of Mexico were the only ones with records of presence, located in 23 of the 84 municipalities of *Hidalgo*; however, according to the results, there is 46 % suitability for the species to be distributed in 63 municipalities in the state. The potential distribution model is satisfactory, as it has a prediction of 92 %. The distribution of *T. huegelii* is favored in areas where the minimum temperature of the coldest month is not less than 3 °C, and in places with a precipitation range of 100 to 500 mm. The actual and potential distribution maps generated constitute the basis for future research on this emblematic taxon of Mexico.

Key words: *Ahuehuete*, Tule tree, known distribution, potential distribution, riparian vegetation, *Taxodium mucronatum* Ten.

Resumen

Taxodium huegelii (sinónimo: *Taxodium mucronatum*) es un árbol que habita en bosques de galería; sus nombres comunes son ahuehuete, árbol de Tule, ciprés de Montezuma o sabino. El objetivo de esta investigación fue generar mapas de distribución actual y potencial para la especie en el estado de Hidalgo. Para elaborarlos se emplearon 56 registros, obtenidos de colectas en campo y una búsqueda en bases de datos. Los registros se analizaron previamente para evitar errores de procedencia y datos repetidos. El mapa de distribución documentada se generó con *ArcGIS*® versión 10.3 y el mapa de distribución potencial mediante

Maxent versión 3.4.1. Las provincias biogeográficas Altiplano Sur (Zacatecano-Potosino), Sierra Madre Oriental y el Golfo de México fueron las únicas que tuvieron registros de presencia, los cuales se localizaron en 23 de los 84 municipios de Hidalgo; sin embargo, de acuerdo con los resultados, existe 46 % de idoneidad para que la especie se distribuya en 63 municipios del estado. El modelo de distribución potencial es satisfactorio, ya que tiene una predicción de 92 %. La distribución de *T. huegelii se favorece* en zonas donde la temperatura mínima del mes más frío no es menor a 3 °C, y en lugares con un intervalo de precipitación de 100 a 500 mm. Los mapas de distribución real y potencial generados constituyen la base para futuras investigaciones sobre este taxon emblemático de México.

Palabras clave: Ahuehuete, árbol de Tule, distribución conocida, distribución potencial, vegetación riparia, *Taxodium mucronatum* Ten.

Introduction

Taxodium huegelii C. Lawson is the valid name for the species known as *Taxodium mucronatum* Ten., belonging to the Cupressaceae family (Turland *et al.*, 2018; Tropicos, 2022). Common names include: *Montezuma* bald cypress, *Montezuma* cypress, or Tule tree in English, and *ahuehuete*, *ciprés de río*, *ciprés de Montezuma* or *sabino* in Spanish (Eckenwalder, 2009). The word *ahuehuete* comes from the *Nahuatl* language and means "old man of the water" (Villanueva *et al*., 2010). This taxon is distributed in Guatemala, most of Mexico, and the southern tip of Texas in the United States of America (Martínez, 1963; Little, 1971; Carranza-González, 1992). It inhabits gallery forests or is part of the riparian vegetation (Villanueva *et al*., 2010; Enríquez-Peña and Suzán-Azpiri, 2011).

Taxodium huegelii is the National Tree of Mexico, elected by popular vote held in 1921 and convened by the National Forest School (Luque, 1921; Martínez, 1963; Zanoni, 1982; Villanueva *et al*., 2010); the 100^{th} anniversary of this election was celebrated in 2021.

Ahuehuete is one of the most interesting species in the national territory due to its scenic beauty, corpulence, and longevity of up to 1 650 years (Villanueva *et al*., 2003). In pre-Columbian times, it was considered a rain-attracting tree, besides having diverse uses (Eckenwalder, 2009; Farjon, 2017), some of which are associated with its medicinal properties (Cortés-Arroyo *et al*., 2011; De La Cruz *et al*., 2012; Luján-Hidalgo *et al*., 2012). In the Valley of Mexico, the *Mexicas* planted avenues, gardens and plazas that have survived to the present day (Farjon, 2017).

In Mexico, *T. huegelii* is not under threat, although in the state of Texas it appears on a state list of endangered species, while its conservation status in Guatemala is unknown (Farjon, 2017). However, it faces numerous threats, including land use change, dam construction, aquifers pollution, water diversion for agriculture, disease, fire, population growth, pest, and illegal logging (Ceccon, 2003; Mora-Córdova, 2012; Martínez-Meyer *et al.*, 2014; Villanueva *et al*., 2014; Badii *et al*., 2015).

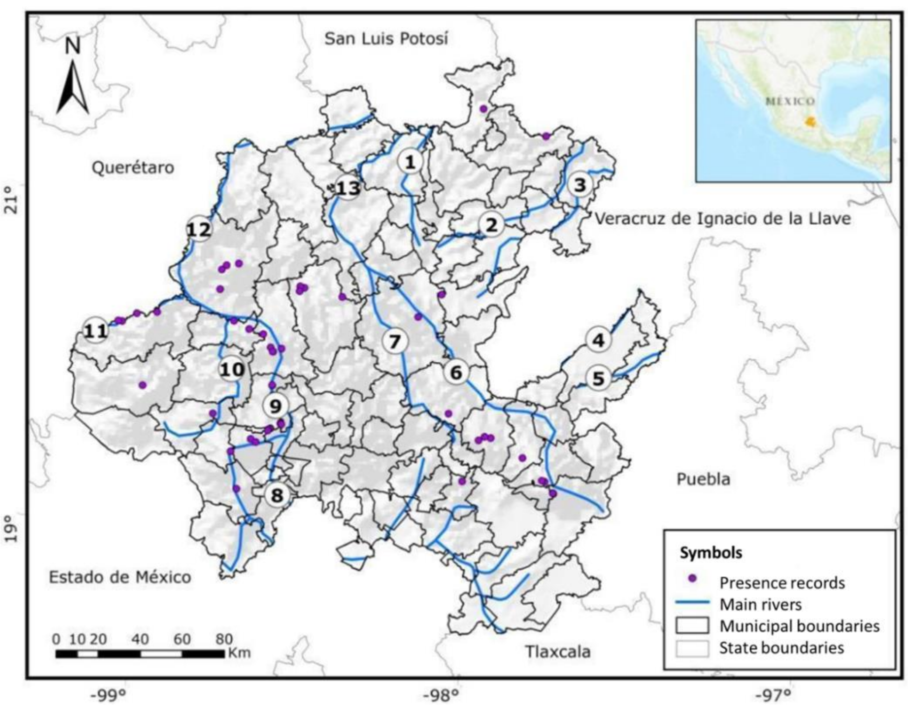
Despite its importance, there is no concrete information on its distribution at the local scale so far, and in the red list of the International Union for Conservation of Nature (IUCN), there is a lack of mapped data on the species (IUCN, 2021). However, records and geo-references are available in herbaria and online databases, which can be used to know their distribution data and estimate their potential distribution.

Identifying the location of a species is very important for the development of future research. In this sense, tools such as ecological niche modeling contribute to the protection of biodiversity, currently considered the most appropriate method to assess the potential distribution of species (Hutchinson, 1944; Guisan and Zimmermann, 2000; Guisan and Thuiller, 2005). Therefore, the objective of this research was to generate current and potential distribution maps for *T. huegelii* in the state of *Hidalgo*.

Materials and Methods

Study area

The state of *Hidalgo* is located in central Mexico and has a surface area of 20 905.12 km^2 (INEGI, 2016) (Figure 1). The relief and climate favor the development of ecosystems such as coniferous and oak forests, gallery forests, mountain mesophyll forests, scrubland, pastureland, rainforest and dry forest (Inegi, 2017).



1.- *Claro* river, 2.- *Calnali* river, 3.- *Calabozo* river, 4.- *Beltrán* river, 5.- *Blanco* river, 6.- *Venados river* (Grande-*Tulancingo* river), 7.- *Amajaque* river, 8.- *Salado* river, 9.- *Tula* river, 10.- *Acayuca* river, 11.- *San Juan* river, 12.- *Moctezuma* river, 13.- *Amajac* river.

Figure 1. *Taxodium huegelii* C. Lawson records and main rivers of the state of Hidalgo.

Presence database

Records of occurrence for the species were documented from field collections and a search of herbaria of public institutions, including: *Facultad de Ciencias*, *Universidad Nacional Autónoma de México* (*FC-UNAM*); *Facultad de Ciencias Naturales*, *Universidad Autónoma de Querétaro* (*FCN-UAQ*); *Escuela de Biología*, *Benemérita Universidad Autónoma de Puebla* (*EB-BUAP*); *Instituto de Biología*, *Universidad Nacional Autónoma de México* (*IB-UNAM*); *Departamento de Botánica*, *Escuela Nacional de Ciencias Biológicas*, *Instituto Politécnico Nacional* (*ENCB-IPN*) and the *Instituto de Ciencias Agropecuarias*, *Universidad Autónoma del Estado de Hidalgo* (*ICAp-UAEH*). Online records were also obtained (The New York Botanical Garden; The United States National Herbarium; University of South Florida) from databases (SEInet) and from the Global Biodiversity Information Facility (GBIF, 2020), *i*Naturalist (Ueda, 2017), *Enciclovida* (Conabio, 2020a) and the Global Biodiversity Information Network (*Red Mundial de Información sobre Biodiversidad*, REMIB) (Conabio, 2020b).

Presence quality control

Data cleaning was carried out by type of error, based on the methods proposed by Cobos *et al.* (2018). The species was searched for in the databases as both *T. mucronatum* and *T. huegelii* in order to consider the change of the scientific name. The potential existence of synonyms, different names, or old names was analyzed.

Naturalista's records were validated by analyzing photographic evidence and by remote verification using Google Earth Pro to corroborate that the altitude and geographic coordinates recorded corresponded with the description of the locality.

Geographic distribution modeling

The 19 monthly bioclimatic variables were drawn from the algorithm BIOCLIM (Busby, 1991) (Table 1) of the database of WorldClim version 2.1 (Fick and Hijmans, 2017), representing data for the 1970−2000 period based on precipitation and minimum and maximum temperature. The topographic variable of elevation from the Shuttle Radar Topography Mission (SRTM) was also used (Farr *et al.,* 2007). The above layers are in generic digital Grid format, made up of pixels with a spatial resolution of 30 seconds (equivalent to ~1 km^2). The layers were clipped and standardized to the state boundary and converted to ASCII Grid format using the software ArcGIS® version 10.3. (Environmental Systems Research Institute [ESRI], 2016).

Table 1. Variables of the BIOCLIM algorithm utilized for modeling the potential distribution of *Taxodium huegelii* C. Lawson.

Bioclimatic variables	**Description**
Bio1	Mean anual temperature
Bio2	Average diurnal range (Monthly mean [Max Temp.-Min Temp.])
Bio3	Isothermality (Bio2/Bio7) (* 100)
Bio4	Seasonality of temperature (standard deviation *100)
Bio5	Maximum temperature of the warmest month
Bio6	Minimum temperature in the coldest month
Bio7	Annual temperature range (Bio5-Bio6)
Bio8	Mean temperature during the wettest four-month period
Bio9	Mean temperature of the driest four-month period
Bio10	Mean temperature of the warmest four-month period
Bio11	Mean temperature of the coldest four-month period
Bio12	Annual precipitation
Bio13	Precipitation of the wettest month
Bio14	Precipitation in the driest month
Bio15	Seasonality of precipitation (Coefficient of variation)
Bio16	Precipitation during the wettest four-month period
Bio17	Precipitation during the driest four-month period
Bio18	Precipitation in the warmest four-month period
Bio19	Precipitation of the coldest four-month period

The MaxEnt or Maximum Entropy algorithm (Maximum Entropy Distribution Modeling) (Phillips *et al.*, 2006) version 3.4.1 (Phillips *et al.*, 2022), was used to model the potential distribution; this is considered to be the best modeling approach, because it generates greater value of the Area Under the Curve (*AUC*) from the analysis of the Receiver Operating Characteristic Curve (*ROC*), that is, it indicates better discrimination of favorable areas versus unsuitable ones for the species, even with few records. It is an adjustment statistic that estimates the probability of occurrence of species, based on environmental requirements and varies between 0 and -1 (Phillips *et al*., 2006; Hernández *et al*., 2006; Pearson *et al*., 2007; Kumar and Stohlgren, 2009). *AUC* values ≥0.75 represent good model discrimination of surfaces with and without the presence of the taxon of interest (Elith *et al.*, 2006). The logistic model was used with 500 iterations, and the Do Clamping option was deactivated to avoid extrapolating the extreme values of the variables.

Of the total records, 75 % were randomly used for training, and 25 %, for testing (validation); they were resampled by bootstrap, so that the independent covariates were adjusted to the largest number of samples. This technique allows estimating an empirical distribution function by resampling the observed data, and the selected model is not affected by autocorrelation (Austin and Tu, 2004).

The response curves of each variable and their contributions to the habitat model of *T. huegelii* were calculated using the Jackknife test (Phillips *et al.*, 2006) and Maxent's *ROC* analysis to evaluate the model.

Maps

In order to prepare the current and potential distribution maps, as well as the calculation of the potential surface area, we used the *ArcGIS*® software, version 10.3. (ESRI, 2016).

Results

56 records were documented based on field work and database searches (Figure 1, Table 2), in addition to vegetation associated with *T. huegelii*, both native and introduced, represented by species such as: *Cupressus lusitanica* Mill., *Fraxinus uhdei* (Wenz.) Lingelsh, *Salix humboldtiana* Willd., *Schinus molle* L., and *Quercus* sp.

Table 2. Localities with occurrence records for *Taxodium huegelii* C. Lawson in the state of *Hidalgo*

No.	Locality	Altitude (masl)	North Latitude	West Longitude
1	*Acatlán*. Dam 1.5 km north of *Acatlán*, *Acatlán-Huasca* highway. Growing on the margin of the dam. GBIF: 1895049679	2 145	20.147778	-98.4386944
2	*Atotonilco el Grande*. On a pier	2 095	20.28650	-98.67068
3	*Cardonal*. 8 km N of *San Miguel Tlazintla*. Year 1976. Deep soil, abundant moisture, high altitude 25-30 m. EncicloVida: ID SNIB: ec956dc4e4893ab06c616c452d670f92	2 340	20.679167	-99.12278
4	*Cardonal*. In a river in the caves of *Tolantongo*. Growing on the river bank. GBIF: 1895049683.	1 296	20.651044	-99.003994
5	*Cardonal*. *Mapethe Santuario Ejido*, Gallery forest, associated species *Quercus* sp.	2 219	20.683833	-99.13542
6	*Cardonal*. iNaturalist: https://www.inaturalist.org/observations/31663438. GBIF: https://www.gbif.org/occurrence/2397593300	2 342	20.668753	-99.137727
7	*Chapantongo*. *El Tanque* water park	2 120	20.287576	-99.41035
8	*Chilcuautla*. *Tlacotlapilco*	1 794	20.37483	-99.22336
9	*Chilcuautla*. *Tunititlán*	1 927	20.240565	-99.229401
10	*Chilcuautla*. iNaturalist: https://www.inaturalist.org/observations/303669	1 796	20.37501	-99.223973
11	*Chilcuautla*. iNaturalist: https://www.inaturalist.org/observations/30366906. GBIF: https://www.gbif.org/occurrence/2331947435	1 793	20.3763083	-99.2244083
12	*Epazoyucan*. *Xolostitla de Morelos*. On the bank of a dry river, but growing 15 m downstream from a spring	2 472	20.075263	-98.62806
13	*Huasca*. Garden in Downtown *Huasca*, in front of the church	2 112	20.203183	-98.576567
14	*Huasca*. Small stream on the *Huasca-Tulancingo* highway, between farmlands	2 131	20.210617	-98.538183
15	*Huasca de Ocampo*. iNaturalist: https://www.naturalista.mx/observations/40061534	2 082	20.214581	-98.557549

16	*Huichapan*. *El calvario*. iNaturalist: https://www.naturalista.mx/observations/4987574	2 112	20.375326	-99.63035
17	*Huichapan*. iNaturalist: https://www.naturalista.mx/observations/12131001	2 112	20.375293	-99.63033
18	*Ixmiquilpan*. Growing in a flooded area. GBIF: 1895049657	1 707	20.480139	-99.22075
19	*Ixmiquilpan*. 2 km N of *Ixmiquilpan*, on the *Tula* river. Abundant. Large tree. GBIF:1419216930	1 694	20.493255	-99.228820
20	*Ixmiquilpan*. Gallery forest, vegetation associated with *Fraxinus uhdei* (Wenz.) Lingelsh., *Schinus molle* L.	1 704	20.4805	-99.22192
21	*Ixmiquilpan*. *El Nith*. GBIF: 1893897681	1 751	20.489444	-99.19444
22	*Ixmiquilpan*. iNaturalist: https://www.inaturalist.org/observations/28574742	1 674	20.534803	-99.2519
23	*Metztitlán*. 500 m south of the town of *Metztitlán*, near the food market. Vascular aquatic flora of the state of *Hidalgo*: *Moctezuma* River hydrological basin, Mexico. Evergreen and deciduous riparian forests. Growing in a flooded area. GBIF: a2486035c9ead34dbeaab4a32528bdb4	1 275	20.5883333	-98.7655278
24	*Metztitlán*. *Zoquizoquipan*. There are only two trees, stem 7m, circumf. 12.40m. Hillside, western exposure, near a spring and *maguey* crops, disturbed vegetation. GBIF: 1893393761	2 235	20.6583333	-98.6916667
25	*Santiago Tulantepec de Lugo Guerrero*. *Ventoquipa*. Near a spring	2 207	20.03847	-98.34353
26	*Santiago Tulantepec de Lugo Guerrero*. *Ventoquipa*. Near a spring	2 207	20.0382	-98.34311
27	*Santiago Tulantepec de Lugo Guerrero*. *Ventoquipa*. Near a spring	2 206	20.0374	-98.34216
28	*Santiago Tulantepec de Lugo Guerrero*. *Ventoquipa*. Near a spring	2 208	20.03672	-98.34188
29	*Santiago Tulantepec de Lugo Guerrero*. *Ventoquipa*. Near a spring	2 205	20.03799	-98.3427
30	*Santiago Tulantepec de Lugo Guerrero*. Near a spring	2 205	20.038000	-98.342658

31	*Santiago Tulantepec de Lugo Guerrero*. iNaturalist: https://www.naturalista.mx/observations/8502735. Near a spring	2 204	20.037742	-98.342812
32	*Tasquillo*. iNaturalist: https://www.inaturalist.org/observations/44075347	1 640	20.551056	-99.296091
33	*Tecozautla*. 500 m E of the *Taxhido* spring. Xerophytic scrub. Enciclovida ID: 97d16d8091da90d6a74bac94927cf0bc	1 604	20.6005555	-99.6481666
34	*Tecozautla*. The Geyser, on the banks of the *Moctezuma* River. Enciclovida	1 647	20.575833	-99.69417
35	*Tecozautla*. *La Sabina*. Aquatic and underwater vegetation. River bank, forest. Enciclovida: ace30aa2dd066f59d417c8a72b6cc513	1 647	20.60389	-99.58472
36	*Tecozautla*. iNaturalist: https://www.inaturalist.org/observations/16220700	1 670	20.577873	-99.70684
37	*Tasquillo*. *Puente de Fierro*	1 610	20.57628	-99.34317
38	*Tezontepec de Aldama*. *Río Tezontepec*. Enciclovida. ID SNIB: 95627084b5792cfa5fab5563bd0b45f0	2 021	20.207817	-99.291640
39	*Tezontepec de Aldama*. *Avenida Allende*. iNaturalist: https://www.inaturalist.org/observations/24389679	1 968	20.197992	-99.275825
40	*Tula de Allende*. *Río Tula*. *Moctezuma* River watershed, Mexico. Environment / Lotic. Growing on the river bank. GBIF: 1895049697	2 042	20.052389	-99.335972
41	*Tulancingo de Bravo*. *Río Grande*. By the *Tulancingo* University bridge	2 163	20.074161	-98.36882
42	*Tulancingo de Bravo*. *Río Grande*. Next to the *Bicentennial* Boulevard, *Tulancingo*	2 160	20.077573	-98.3783
43	*Zimapán*. *La Tinaja*, at a distance of 6.2 km from *Zimapán*. Evergreen and deciduous riparian forests. Growing on the margin of a flooded area. GBIF: https://www.gbif.org/occurrence/1895049694	1 825	20.6754167	-99.3868888
44	*Zimapán*. *Venustiano Carranza*, 6 km NE of *Zimapán*. ID, SNIB: e57aa2e5debc8cf1de463a58e1a36da8 Enciclovida.	1 914	20.755	-99.32833
45	*Zimapán*. On church grounds. Very old tree over 40 m high. The fruits fall when green, fragmenting upon impact with the ground. GBIF: 574801155	1 816	20.750000	-99.36667
46	*Zimapán*. In a park. Enciclovida: ID SNIB: 087782963c555af80d4f50f55c301a96	1 774	20.736944	-99.38194

47	*Progreso de Obregón*. Gallery forest. On the *Tula* River (On the border of *Chilcuautla*)	1 900	20.258973	-99.19692
48	*Progreso de Obregón*. Gallery forest. On the *Tula* River (On the border of *Chilcuautla*)	1 896	20.256098	-99.19817
49	*Progreso de Obregón*. Gallery forest. On the *Tula* River (On the border of *Chilcuautla*)	1 904	20.253129	-99.19519
50	*Mixquiahuala*. Gallery forest. On the *Tula* River (On the border of *Chilcuautla*)	1 925	20.240381	-99.22988
51	*Mixquiahuala*. Gallery forest. On the *Tula* River	1 935	20.237907	-99.23552
52	*Mixquiahuala*. Gallery forest. On the *Tula* River	1 932	20.234271	-99.23769
53	*Tepetitlán*. On the *Tula* River. At a distance of 1.55 km from the *Endhó* dam	1 994	20.168849	-99.35482
54	*Huejutla de Reyes*. On a river	112	21.151944	-98.36472
55	*Huejutla de Reyes*. On a river	113	21.152777	-98.36416
56	*San Felipe Orizatlán*. On a river	129	21.237778	-98.560556

Quality control of occurrence records

Of the total number of records, nine (16.36 %) were excluded from the analysis because they did not meet the inclusion criteria. Records for the species were located in 23 of the 84 municipalities of the state (Figure 1). According to the recovered data, *Taxodium huegelii* is distributed at an altitudinal range of 112-2 472 masl. The documented records are associated with or close to the banks of the *Acayuca*, *Amajaque*, *San Juan*, *Tula* and *Venados* rivers (*Grande* river) (Figure 1).

The potential distribution map (Figure 2) reflects that *T. huegelii* can be established in 63 municipalities of the state (suitability interval: 0.11-0.92) that coincide with the banks of the rivers: *Acayuca*, *Amajaque*, *Amajac*, *Moctezuma*, *San Juan*, *Tula* and *Venados* (*Grande* river).

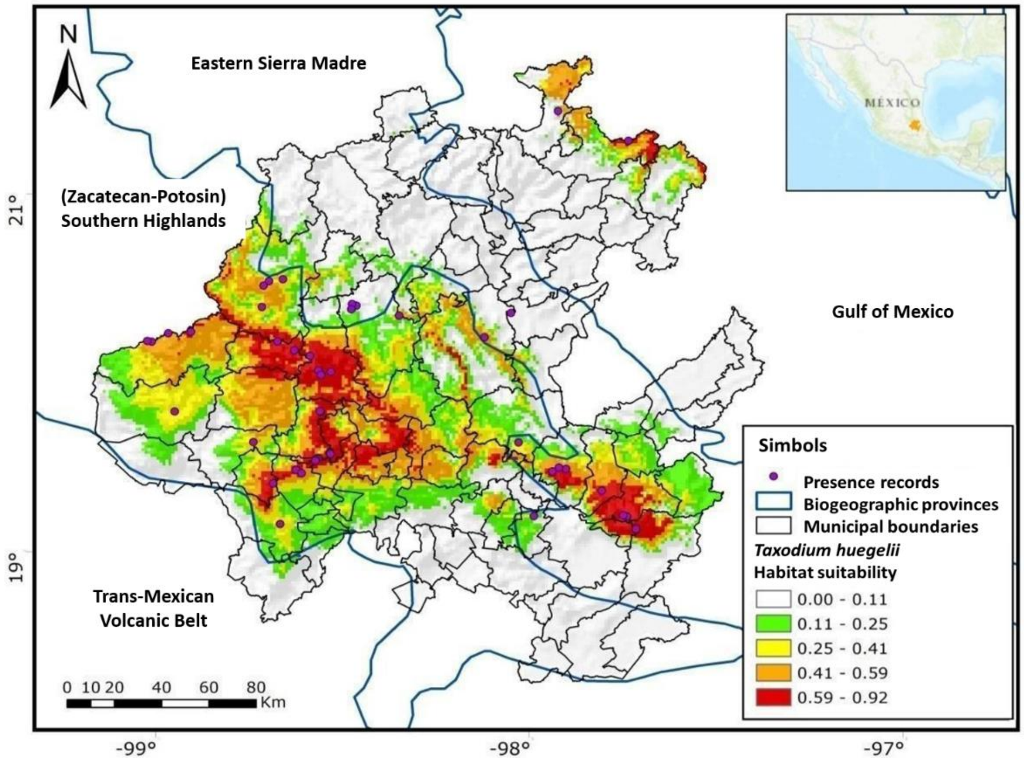


Figure 2. Potential distribution map of *Taxodium huegelii* C. Lawson and biogeographic provinces of the state of *Hidalgo*.

Estimation of the potential surface area

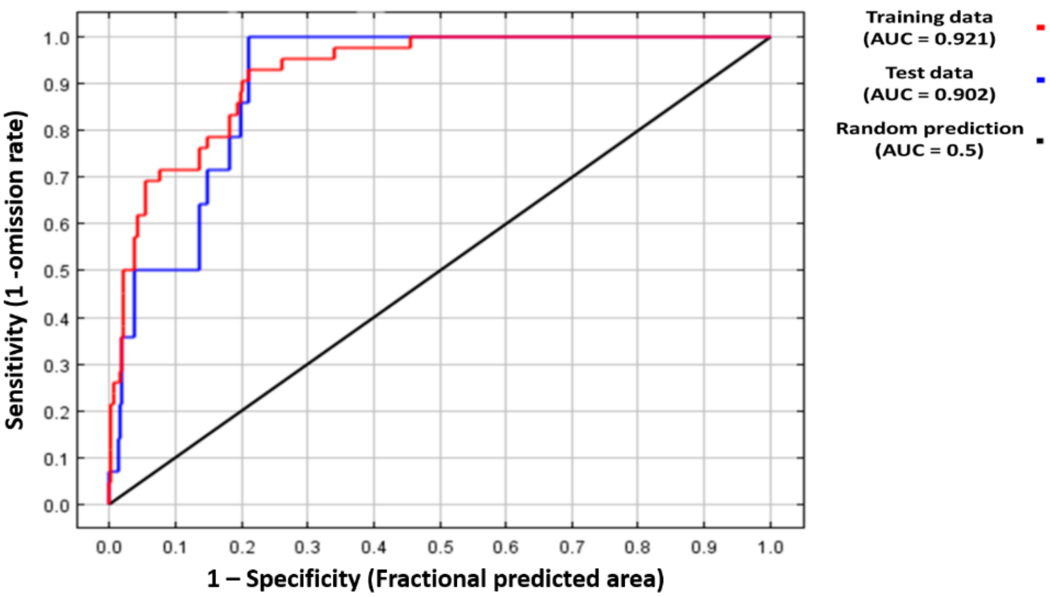
The potential distribution map (Figure 2) indicated that suitable conditions for the establishment of the species may be present in 1 254.3 km^2 (6 %) of the total area of the state of *Hidalgo*, while acceptable conditions exist in 8 362 km^2 (40 %) (Figure 2).

Biogeographic provinces

According to the map in Figure 2, the presence records and the area where the conditions of suitability for *T. huegelii* exist are located in the biogeographic provinces of the (Zacatecan-Potosin) Southern Highlands, the Gulf of Mexico, and the Eastern *Sierra Madre*. In the first, the greatest number of presence records (29) was obtained. In contrast, the biogeographic province of the Trans-Mexican Volcanic Belt lacked records and suitable environmental conditions for the development of the species.

Model evaluation

The model presented an *AUC* value of 0.921 for the training, and of 0.902 for the test (Figure 3). The environmental variables that contributed most to the prediction (Table 3) were the precipitation of the wettest four-month period (Bio_16), with 24.2 %, precipitation for the coldest four-month period (Bio_19), with 20.5 %, and the minimum temperature of the coldest month (Bio_6), with 20.3 %, followed by the precipitation during the wettest month (Bio_13), with 10.4 %. Altitude (Elev) had little contribution (4.5 %). The results of the Jackknife test indicated that the minimum temperature of the coldest month (Bio_6) was the bioclimatic variable with the highest gain (>0.4) when used independently, followed by the precipitation of the wettest four-month period (Bio_16), the precipitation of the wettest month (Bio_13), and the annual precipitation (Bio_12).



The red line represents the fit of the model to the training data. The blue line represents the fit of the model to the test data, being the actual test of predictive power, and the black line is the expected value if the model were no better than a random one.

Figure 3. *ROC* analysis.

Table 3. Variables that contribute the most to the potential distribution model of *Taxodium huegelii* C. Lawson in Maxent.

Variable	Percentage contribution (%)
Precipitation during the wettest four-month period (Bio 16)	24.2
Precipitation of the coldest four-month period (Bio 19)	20.5
Minimum temperature of the coldest month (Bio 6)	20.3
Precipitation of the wettest month (Bio 13)	8.5
Average temperature during the wettest four-month period (Bio 8)	7.7
Elevation (Elev)	4.5
Average temperature of the driest four-month period (Bio 9)	4
Annual precipitation (Bio 12)	3.7
Average diurnal range (Monthly mean [Max Temp.-Min Temp. Min) (Bio 2)	2.3
Seasonality of the precipitation (Coefficient of variation) (Bio 15)	2
Average temperature of the coldest four-month period (Bio 11)	0.8
Precipitation in the driest month (Bio 14)	0.7
Precipitation during the warmest four-month period (Bio 18)	0.6
Precipitation during the driest four-month period (Bio 17)	0.1
Maximum temperature of the warmest month (Bio 5)	0
Annual temperature range (Bio 5-Bio 6) (Bio 7)	0
Seasonality of temperature (standard deviation *100) (Bio 4)	0
Isothermality (Bio 2/Bio 7) * 100 (Bio 3)	0

Average temperature of the warmest four-month period (Bio 10)	0
Mean annual temperature (Bio 1)	0

The response curves indicated that the habitat suitability of *T. huegelii* in the state of Hidalgo is high in regions where the minimum temperature of the coldest month (Bio_6) is not lower than 3 °C, and the precipitation of the wettest four-month period (Bio_16), the precipitation of the wettest month (Bio_13), and the annual precipitation (Bio_12) is less than 250 mm, 100 mm and 500 mm, respectively.

Discussion

Field work made it possible to document the vegetation associated with *T. huegelii*: *Cupressus lusitanica*, *Fraxinus uhdei, Salix humboldtiana*, *Quercus* sp., and *Schinus molle*. Previous research cites the following associated taxa: *Carya illinoinensis* (Wangenh.) K. Koch, *Cephalanthus occidentalis* L., *Platanus glabrata* Fernald, and *Salix gooddingii* C. R. Ball (Villanueva *et al*., 2014), as well as certain genera of trees at low altitudes, such as *Ficus* and *Inga*; however, other taxa still need to be documented, particularly in the southern part of its distribution range (Farjon, 2017).

Presence record maps

Most of the records and conditions of suitability for the species were concentrated in the biogeographic provinces of the (Zacatecan-Potosin) Southern Highlands and the Eastern *Sierra Madre*, mainly along the *San Juan* and *Tula* rivers; few such records exist in the northern portion, and none in the south of the state despite the presence of rivers (Gulf of Mexico and Trans-Mexican Volcanic Belt biogeographic provinces).

Potential distribution maps

According to the potential distribution map (Figure 2), 23 municipalities have records of the presence of the species, and 31 municipalities have areas of high suitability for its potential distribution (0.59-0.92); of these, 12 have no previous records. There are also suitable conditions for the development of the species along the *Amajaque* river and other localities; however, no records exist, and therefore it is crucial to carry out more fieldwork in order to verify the veracity of the modeling. The presence of *T. huegelii* has not been documented along the *Beltrán*, *Blanco*, and *Claro* rivers, consistently with the obtained results, as these areas offer no suitable environmental conditions for the species despite the presence of bodies of water (Figure 2).

The potential distribution of *T. huegelii* is within the limits of the Eastern *Sierra Madre*, (Zacatecan-Potosin) Southern Highlands, and Gulf of Mexico biogeographic provinces. The prevailing climate types are Warm humid, Dry warm semi-dry, Dry temperate, Semi-cold semi-dry, and Temperate sub-humid. It has previously been pointed out that *T. huegelii* is a typical tree of low and semi-warm places, being uncommon in very warm places, at altitudes below 300 m, and at temperatures equal to or above 25 °C (Martínez, 1963), consistently with the results of the present study.

To the north of its distribution in the state, it forms green strips along rivers in dry regions with an arid to semi-arid landscape (Farjon, 2017). In addition to the environmental conditions evaluated in this research, other biotic factors associated with the types of climates in which the species is absent may restrict its geographic distribution.

Evaluation of the *AUC* model

The model is satisfactory according to the training and test data set (Figure 3), since fit values of 0.921 and 0.902, respectively, were obtained; this implies that the closer the curves are placed, the smaller the error of omission is, and the more appropriate the fit (Elith *et al*., 2006; Phillips, 2006). The work of Yi *et al.* (2016) cites *AUC* values of 0.899 for training and 0.840 for testing in *Homonoia riparia* Lour., a riparian species.

Variables independent contribution to the model

Three of the environmental variables that contributed the most to the prediction are related to precipitation (Bio_16, 24.2 %; Bio_19, 20.5 %, and Bio_13, 10.4 %). Likewise, the response curves indicate that the habitat suitability of *T. huegelii* in the state of *Hidalgo* is high in regions where the precipitation of the wettest four-month period (Bio_16), the precipitation of the wettest month (Bio_13), and the annual precipitation (Bio_12) are less than 250, 100 and 500 mm, respectively.

According to the results of this research, most of the documented records are located on the banks of rivers and localities associated with springs in the municipalities of *Chapantongo* in the *El Tanque* spa, *Epazoyucan* in *Xolostitla de Morelos*, *Metztitlán* in *Zoquizoquipan*, *Santiago Tulantepec de Lugo Guerrero* in *Ventoquipa*, and *Tecozautla* in the springs of *Taxhido*. This is evidence of the close relationship between the development of the species and water sources. The presence of few or only one individual far from water bodies is the result of planting for ornamental purposes.

Since pre-Hispanic times, *T. huegelii* has been introduced and planted in many locations far from water sources in Mexico and Guatemala; however, all of these places have (or had) water tables that are reached by the deep root system of the trees. Most specimens correspond to planted trees (Farjon, 2017).

Villanueva *et al.* (2010) point out that the *ahuehuetes* of *Barranca de Amealco*, in *Querétaro*, are very sensitive to the precipitation that occurs in summer and is related to the increase in flow rates that cause an increase in oxygenation and finally greater growth. In addition, seasonal changes of 80 to 90 cm in the water table depth result in temporary reductions in water potential and a maximum net photosynthetic rate of the foliage (Campos-Ángeles *et al.*, 2005).

The distribution of *T. huegelii* along riverbanks is indicative of riparian vegetation or gallery forest, which is important for maintaining biodiversity (Naiman and Decamps, 1997). During floods, this species traps nutrients and pollutants, in addition to stabilizing sediments, whereby it prevents soil erosion and improves water quality, this is of crucial importance, considering that the *Tula* river is one of the most polluted rivers in the country (Arredondo *et al.*, 2017). It also reduces the speed of water flow by keeping a sinuous course that favors the recharge of water in the groundwater table at a high level (Patten, 1998); however, when the flow increases, due to prolonged flooding, it can affect regeneration by seeds and shoots (Gecy and Wilson, 1990). Other key factors in the decline of riparian vegetation include soil compaction (Kozlowski, 1985), lack of water, soil infertility, contamination, water scarcity (Kozlowski and Pallardy, 1997), the construction of river terraces (Enríquez-Peña and Suzán-Azpiri, 2011), and climate change.

The suitability of the habitat of *T. huegelii* in *Hidalgo* is high in regions where the minimum temperature of the coldest month (Bio_6) is not below 3 °C, consistently with what is cited in the literature in the sense that it is a frost-sensitive species, unlike *T. distichum* (L.) Rich. which withstands extremely low temperatures (Farjon, 2017), its optimum development interval is between 16 and 22 °C (Conafor and Conabio, 2019). In northern and central Mexico, high temperatures at the end of winter favor its growth during spring (Villanueva *et al.*, 2013). The climatic variables of precipitation and temperature are closely related to the ecophysiology of *T. huegelii* (Fritts, 1976; Correa *et al.*, 2014).

Altitude (Elev) contributes 4.5 % to prediction. In this research, the altitudinal range for *T. huegelii* in the state of *Hidalgo* was determined to be 112 to 2 472 m, consistently with the previously cited records (Martínez, 1963; Eckenwalder, 2009; Villanueva *et al*., 2010; Farjon, 2017, Martínez-Sifuentes *et al*., 2021).

Martínez-Sifuentes *et al.* (2021) predict a reduction in the distribution of *T. huegelii* in Mexico for future climate change scenarios (2050, 2070) under the riparian ecosystem criterion. In *Hidalgo*, there is no protected natural area that guarantees the conservation of genetic diversity for the species; therefore, the creation of at least one Ecological Conservation Area for the entity should be considered based on future studies of genotypic and phenotypic diversity.

As a riparian species, *ahuehuete* has a close relationship with bodies of water, which implies that its dispersal maybe much more difficult under climate change scenarios, compared to tree species whose survival does not strictly depend on the presence of bodies of water, therefore, *in situ* conservation is particularly important for this species.

The location of long-lived organisms is paramount and supports the continuation of efforts for the protection, restoration, formulation of ecotourism projects and conservation of the large extension of unique riparian ecosystems in Mexico in which *T. huegelii* is distributed (Villanueva *et al.*, 2010; Villanueva *et al.*, 2012). In Mexico City, it is used as an indicator of surface aquifers (Martínez and Chacalo, 1994). In the case of *ahuehuetes*, historical records allow to determine the seasonal variation of precipitation based on dendrochronology (Cortés *et al*., 2010; Correa-Díaz *et al.*, 2014); such is the case of the climatic conditions prevailing during the establishment, flourishing, and decline of pre-Hispanic civilizations (Villanueva *et al*., 2010).

The ages of *ahuehuete* trees in gallery forests in *Hidalgo* have been little studied (Correa-Díaz *et al.*, 2014) and remain virtually unknown. Among the states in which such data for *T. huegelii* individuals are available, the following can be cited: *Aguascalientes*, *Chiapas*, *Coahuila*, *Guanajuato*, *Jalisco*, *Michoacán*, *Nuevo León*, *Oaxaca*, *Querétaro*, *Tamaulipas* and *Zacatecas* (Suzán-Azpiri *et al.*, 2007; Villanueva *et al*., 2010).

Conclusions

This research contributes to solve one of the challenges in distributional ecology which consists in the incomplete knowledge of the distribution of the species, since it provides additional records of localities for *T. huegelii* that present a more current picture of its distribution in the state of *Hidalgo*. This information is the basis for carrying out phenotypic and genotypic characterization research at the population level, estimating the age of the individuals, performing dendrochronological analysis, ecotourism, and protection and restoration projects, as well as locating new superficial aquifers.

According to the distribution maps generated, future field work will allow to know in detail the geographical distribution of the species in the state. These maps are relevant as a tool for decision-making in terms of management plans, sustainable use, and the establishment of areas, locally, for the conservation of this emblematic species of Mexico.

Acknowledgments

The authors wish to express their gratitude to Isaías González Ángeles, Rubén Luna León, Christian de Jesús García Valdez and José Clemente Martínez Becerril, for providing georeferences and photographic evidence of specimens in the field.

Conflict of interest

The authors declare no conflict of interest.

Contribution by author

Rafael Canales-Pérez, Sergio Hernández-León, Abraham Palacios-Romero, Adriana Hernández Lazcano, Rodrigo Rodríguez-Laguna, Alfonso Suárez-Islas, José González-Ávalos and Oscar Arce-Cervantes: information search, field work, drafting and review of the manuscript.

References

Austin, P. C. and J. V. Tu. 2004. Automated variable selection methods for logistic regression produced unstable models for predicting acute myocardial infarction mortality. Journal of Clinical Epidemiology 57(11):1138-1146. Doi: 10.1016/j.jclinepi.2004.04.003.

Ramírez A., A., L. J. Sánchez R. y A. García M. 2017. Por un Tula mejor y más limpio. Centro Educativo Cruz Azul. Tula, Hidalgo, México. 13 p. http://vinculacion.dgire.unam.mx/vinculacion-1/Memoria-Congreso-2017/trabajos-ciencias-biologicas/medio-ambiente/23.pdf. (17 de noviembre de 2021).

Badii, M. H., A. Guillen, C. E. Rodríguez, O. Lugo, J. Aguilar y M. Acuña. 2015. Pérdida de Biodiversidad: Causas y Efectos. Revista Daena: International Journal of Good Conscience 10(2):156-174. https://agua.org.mx/wp-content/uploads/2019/05/biodiversidad.pdf. (17 de noviembre de 2021).

Busby, J. R. 1991. Bioclim, a bioclimate analysis and prediction system. In: Margules, C. R. and M. P. Austin (eds.). Nature conservation: cost effective biological surveys and data analysis. Commonwealth Scientific and Industrial Research Organisation (CSIRO). Canberra, Commonwealth of Australia. pp. 64-68.

Campos-Ángeles, G. V., J. J. Vargas-Hernández, C. Trejo-López, J. López-Upton y J. Velázquez-Mendoza. 2005. Variación estacional del potencial hídrico, tasa de fotosíntesis y conductancia estomática en el árbol del tule. Terra Latinoamericana

23(4):515-522. https://www.redalyc.org/pdf/573/57311146010.pdf. (2 de diciembre de 2020).

Carranza-González, E. 1992. Familia Taxodiaceae. Flora Del Bajío y de Regiones Adyacentes. Fascículo, 4. Instituto de Ecología, A. C. Centro Regional del Bajío. Pátzcuaro, Mich., México. 12 p. Doi: 10.21829/fb.131.1992.4.

Ceccon, E. 2003. Los bosques ribereños y la restauración y conservación de las cuencas hidrográficas. Ciencia 72:46-53. http://revistas.unam.mx/index.php/cns/article/viewFile/11921/11243. (6 de agosto de 2020).

Cobos, M. E., L. Jiménez, C. Nuñez-Penichet, D. Romero-Alvarez and M. Simòes. 2018. Sample data and training modules for cleaning biodiversity information. Biodiversity Informatics 13:49-50. Doi: 10.17161/bi.v13i0.7600.

Comisión Nacional Forestal (Conafor) y Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (Conabio). 2019. Paquetes tecnológicos *Taxodium mucronatum* Ten. Ciudad de México, México. http://www.conafor.gob.mx:8080/documentos/docs/13/1011Taxodium%20mucronatum.pdf. (6 de agosto de 2020).

Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (Conabio). 2020a. Enciclovida (en línea). www.enciclovida.mx/. (6 de agosto de 2020).

Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (Conabio). 2020b. REMIB Red mundial de información sobre biodiversidad (en línea). http://www.conabio.gob.mx/remib/doctos/remib_esp.html. (6 de agosto de 2020).

Correa-Díaz, A., A. Gómez-Guerrero, J. Villanueva-Díaz, L. U. Castruita-Esparza, T. Martínez-Trinidad y R. Cervantes-Martínez. 2014. Análisis dendroclimático de ahuehuete (*Taxodium mucronatum* Ten.) en el centro de México. Agrociencia 48(5): 537-551. https://agrociencia-colpos.mx/index.php/agrociencia/article/view/1101/1101. (14 de noviembre de 2021).

Cortés-Arroyo, A. R., A. M. Domínguez-Ramírez, M. Gómez-Hernández, J. R. Medina L., M. Hurtado y de la Peña and F. J. Lopez-Muñoz. 2011. Antispasmodic and bronchodilator activities of *Taxodium mucronatum* Ten. leaf extract. African Journal of Biotechnology 10(1):54-64. Doi: 10.5897/AJB10.1018.

Cortés B., E. N., J. Villanueva D., J. Estrada Á., C. Nieto de Pascual P., V. Guerra de la C. y O. Vázquez C. 2010. Utilización de *Taxodium mucronatum* Ten. para determinar la variación estacional de la precipitación en Guanajuato. Revista Mexicana de Ciencias Forestales 1(1):113–121. Doi: 10.29298/rmcf.v1i1.659.

De la Cruz, S., E. Rodríguez, H. N. Dávalos and A. Astudillo-Vázquez. 2012. Acute toxicity and decreased peristalsis in mice caused by *Taxodium mucronatum* and *Acacia farnesiana* extracts. Revista Latinoamericana de Química 40(1):19–25. http://www.scielo.org.mx/pdf/rlq/v40n1/v40n1a3.pdf. (17 de noviembre de 2021).

Eckenwalder, J. E. 2009. Conifers of the world: the complete reference. Timber Press. Portland, OR, USA. 720 p.

Elith, J., C. H. Graham, R. P. Anderson, M. Dudík, … and N. E. Zimmermann. 2006. Novel methods improve prediction of species distributions from occurrence data. Ecography 29(2):129-151. Doi: 10.1111/j.2006.0906-7590.04596.x.

Enríquez-Peña, E. G. y H. Suzán-Azpiri. 2011. Estructura poblacional de *Taxodium mucronatum* en condiciones contrastantes de perturbación en el estado de

Querétaro, México. Revista Mexicana de Biodiversidad 82(1):153–167. Doi: 10.22201/ib.20078706e.2011.1.380.

Environmental Systems Research Institute (ESRI) Inc. 2016. ArcGIS (Version 10.3.1.). ESRI, Inc. Redlands, CA, USA. https://support.esri.com/es/products/desktop/arcgis-desktop/arcmap/10-3-1. (17 de noviembre de 2021).

Farjon, A. 2017. A Handbook of the World's Conifers. Revised and Updated Edition. Brill Academic Publisher. Leiden, Netherlands and Boston, USA. 1112 p.

Farr, T. G., P. A. Rosen, E. Caro, R. Crippen, … and D. Alsdorf. 2007. The shuttle radar topography mission. Reviews of Geophysics 45(2):1-33. Doi: 10.1029/2005RG000183.

Fick, S. E. and R. J. Hijmans. 2017. WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. International Journal of Climatology 37(12):4302-4315. Doi: 10.1002/joc.5086.

Fritts, H. C. 1976. Tree rings and climate. Academic Press. New York, NY, USA. 567 p.

Gecy, J. L. and M. V. Wilson. 1990. Initial establishment of riparian vegetation after disturbance by debris flows in Oregon. The American Midland Naturalist 123(2):282-291. Doi: 10.2307/2426556.

Global Biodiversity Information Facility (GBIF). 2020. GBIF Home Page. https://www.gbif.org. (5 de agosto de 2020).

Guisan, A. and N. E. Zimmermann. 2000. Predictive habitat distribution models in ecology. Ecological Modelling 135(2-3):147-186. Doi: 10.1016/S0304-3800(00)00354-9.

Guisan, A. and W. Thuiller. 2005. Predicting species distribution: offering more than simple habitat models. Ecology Letters 8(9):993–1009. Doi: 10.1111/j.1461-0248.2005.00792.x.

Hernández, P. A., C. H. Graham, L. L. Master and D. L. Albert. 2006. The effect of sample size and species characteristics on performance of different species distribution modeling methods. Ecography 29(5):773–785. Doi: 10.1111/j.0906-7590.2006.04700.x.

Hutchinson, G. E. 1944. Limnological studies in Connecticut. VII. A critical examination of the supposed relationship between phytoplankton periodicity and chemical changes in lake waters. Ecology 25(1):3-26. Doi: 10.2307/1930759.

Instituto Nacional de Estadística, Geografía e Informática (INEGI). 2016. Marco Geoestadístico Nacional. https://www.inegi.org.mx/temas/mg/ (14 de noviembre de 2021).

Instituto Nacional de Estadística y Geografía (Inegi). 2017. Anuario estadístico y geográfico de Hidalgo 2017. INEGI. Aguascalientes, Ags., México. 674 p.

International Union for Conservation of Nature (IUCN). 2021. The IUCN Red List of Threatened Species. (Version 2021-1). https://www.iucnredlist.org. (27 de mayo de 2021).

Kozlowski, T. T. 1985. Soil aeration, flooding, and tree growth. Journal of Arboriculture 11(3):85-96. Doi: 10.1080/02827588609382405.

Kozlowski, T. T. y S. G. Pallardy. 1997. Growth control in woody plants. Academic Press. San Diego, CA, USA. 641 p.

Kumar, S. and T. J. Stohlgren. 2009. Maxent modeling for predicting suitable habitat for threatened and endangered tree *Canacomyrica monticola* in New Caledonia. Journal of Ecology and Natural Environment 1(4):94–98. Doi: 10.5897/JENE.9000071.

Little, E. L. 1971. Atlas of United States Trees, vol. 1: Conifers and Important Hardwoods. Series: Miscellaneous Publication 1146. US Department of Agriculture, Forest Service. Washington, DC, USA. 200 p.

Luján-Hidalgo, M. C., F. A. Gutiérrez-Miceli, L. M. C. Ventura-Canseco, L. Dendooven, … y M. Abud-Archila. 2012. Composición química y actividad antimicrobiana de los aceites esenciales de hojas de *Bursera graveolens* y *Taxodium mucronatum* de Chiapas, México. Gayana Botanica 69(número especial):7–14. http://www2.udec.cl/~gvalencia/pdf/GB2012_69_ne_Lujan-Hidalgo_etal.pdf. (17 de noviembre de 2021).

Luque, E. 1921. Voto razonado para elegir el árbol nacional. Sociedad Forestal Mexicana. Revista México Forestal 1(9-10):3.

Martínez G., L. y A. Chacalo H. 1994. Los árboles de la Ciudad de México. Universidad Autónoma de México Unidad Azcapotzalco. México, D. F., México. 351 p.

Martínez, M. 1963. Las pináceas mexicanas. Instituto de Biología y Universidad Nacional Autónoma de México. México, D. F., México. 400 p.

Martínez-Meyer, E., J. E. Sosa-Escalante y F. Álvarez. 2014. El estudio de la biodiversidad en México: ¿una ruta con dirección? Revista Mexicana de Biodiversidad 85:1–9. Doi: 10.7550/rmb.43248.

Martínez-Sifuentes, A. R., J. Villanueva-Díaz, E. Crisantos de la Rosa and D. W. Stahle. 2021. Current and future spatial modeling of habitat suitability of the Mexican baldcypress (*Taxodium mucronatum* Ten.): a proposal for conservation in Mexico. Botanical Sciences 99(4):752-770. Doi: 10.17129/botsci.2772.

Mora-Córdova, C. P. 2012. Manejo in vitro y caracterización molecular de ahuehuete (*Taxodium mucronatum* Ten.). Tesis de Maestría en Ciencias en Horticultura. Departamento de Fitotecnia, Universidad Autónoma de Chapingo. Texcoco, Edo. Méx. México. 208 p.

Naiman, R. J. and H. Décamps. 1997. The ecology of interfaces: riparian zones. Annual Review of Ecology and Systematics 28(1):621-658. Doi: 10.1146/ANNUREV.ECOLSYS.28.1.621.

Patten, D. T. 1998. Riparian ecosytems of semi-arid North America: Diversity and human impacts. Wetlands 18(4):498-512. Doi: 10.1007/BF03161668.

Pearson, R. G., C. J. Raxworthy, M. Nakamura and A. T. Peterson. 2007. Predicting species distributions from small numbers of occurrence records: a test case using cryptic geckos in Madagascar. Journal of Biogeography 34(1):102–117. Doi: 10.1111/j.1365-2699.2006.01594.x.

Phillips, S. J., R. P. Anderson and R. E. Schapire. 2006. Maximum entropy modeling of species geographic distributions. Ecological Modelling 190(3–4):231–259. Doi: 10.1016/j.ecolmodel.2005.03.026.

Phillips, S. J., M. Dudík and R. E. Schapire. 2022. Maxent software for modeling species niches and distributions (Version 3.4.1). American Museum of Natural History. New York, NY, USA. http://biodiversityinformatics.amnh.org/open_source/maxent/. (27 de mayo de 2022).

Suzán-Azpiri, H., G. Enríquez-Peña and G. Malda-Barrera. 2007. Population structure of the Mexican baldcypress (Taxodium mucronatum Ten.) in Querétaro, Mexico. Forest Ecology and Management 242(2-3):243-249. Doi: 10.1016/j.foreco.2007.01.041.

Tropicos. 2022. Tropicos.org. Missouri Botanical Garden (Tropicos v3.3.2). http://www.tropicos.org. (7 de marzo de 2022).

Turland, N. J., J. H. Wiersema, F. R. Barrie, W. Greuter, … and G. F. Smith (eds.). 2018. International Code of Nomenclature for algae, fungi, and plants (Shenzhen Code). Regnum Vegetaible 159. Glashütten, Hesse, Alemania. 254 p. https://koeltz.com/en/international-code-of-nomenclature-for-algae-fungi-and-plants-shenzen-code-2018. (14 de noviembre de 2021).

Ueda, K. 2017. iNaturalist Research-grade Observations. https://www.inaturalist.org/. (14 de noviembre de 2021).

Villanueva D., J., A. Hernández R., F. García S., E. H. Cornejo O., … y M. K. Cleaveland. 2003. Análisis estructural de un rodal de sabino (*Taxodium mucronatum* Ten.) en Los Peroles, San Luis Potosí, México. Revista Mexicana de Ciencias Forestales 28(94):57-79. http://cienciasforestales.inifap.gob.mx/index.php/forestales/article/view/884/2147. (14 de noviembre de 2021).

Villanueva D., J., J. Cerano P., D. W. Stahle, V. Constante G., … y J. de. D. Benavides S. 2010. Árboles longevos de México. Revista Mexicana de Ciencias Forestales 1(2):7-29. Doi: 10.29298/rmcf.v1i2.634.

Villanueva D., J., J. Cerano P., J. de. D. Benavides, D. W. Stahle, … y M. Tostado P. 2012. Reconstrucción de los niveles del lago de Chapala con series dendrocronológicas de *Taxodium mucronatum* Ten. Revista Mexicana de Ciencias Forestales 3(14):55-68. Doi: 10.29298/rmcf.v3i14.474.

Villanueva D., J., V. Constante G., J. Cerano P., A. R. Martínez S., D. W. Stahle y J. Estrada Á. 2013. Fenología y crecimiento radial del sabino (*Taxodium mucronatum* Ten.) en el río San Pedro Mezquital, Durango. Folleto Técnico Núm. 27. INIFAP-Centro Nacional de Investigación Disciplinaria en Relación Agua, Suelo, Planta, Atmósfera. Gómez Palacio, Dgo., México. 33 p.

Villanueva D., J., V. Constante G., J. Cerano P. y A. R. Martínez C. 2014. La cuenca San Martín y situación del ahuehuete (*Taxodium mucronatum* Ten.) en el río sabinas, Coahuila. Folleto Técnico. Centro Nacional de Investigación Disciplinaria Relación Agua-Suelo-Planta–Atmósfera. Gómez Palacio, Dgo., México. 40 p.

Yi, Y.-J., X. Cheng, Z.-F. Yang and S.-H. Zhang. 2016. Maxent modeling for predicting the potential distribution of endangered medicinal plant (*H. riparia* Lour.) in Yunnan, China. Ecological Engineering 92: 260–269. Doi: 10.1016/j.ecoleng.2016.04.010.

Zanoni, T. A. 1982. Flora de Veracruz. Taxodiaceae. Fascículo 25. Instituto Nacional sobre Recursos Biótico INIREB. Xalapa, Ver., México. 18 p.