THE POTENTIAL NICHE OF *Guaiacum coulteri* IN PROTECTED NATURAL AREAS OF SONORA TO OAXACA, MEXICO

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SUMMARY

The genus Guaiacum *belongs to the family* Zigophyllaceae*, encompassing six species of evergreen trees and shrubs. The geographical distribution model allows designing and creating probabilistic maps of sites where species are distributed. The Maxent program projects patterns of geographic distributions by using ecological niche models. In Mexico, several studies indicate that the distribution of* G. coulteri *covers 11 Protected Natural Areas (ANP, for their name in Spanish) covering 2,777km^2; of this area, 75% corresponds to the states of Oaxaca, Sonora and Sinaloa, data which matches that of the present study. The result of ecological niche modeling for* G. coulteri *has a coverage of 24,908.238 km^2 and the surface of the ANPs is 13,545.76 km^2; when overlaying them, the niche area within these is 1,104.42 km^2, which corresponds to a coverage of 9.21%. The results suggest that modeling of the potential* G. coulteri *niche matches the current distribution of the species; although there are areas of modeling that are not found within the ANP, the resulting modeling can be used as a basis for proposing specific fieldwork sites.*

Introduction

The countries with the greatest biodiversity are tropical countries, and such is the case of Mexico, where many species are endemic (Grow and Schwartzman, 2001) or listed as rare (Contreras-Medina *et al*., 2010). The genus *Guaiacum* belongs to the Zigophyllaceae family, which consists of six species of evergreen trees and shrubs distributed throughout Latin America (Maryland-Report, 2000; Grow and Schwartzman, 2001). Some of the species of the genus *Guaiacum* are in a risk category due to loss of their habitat (ARW, 1998; CITES, 2002; Gordon *et al*., 2005).

Guaiacum coulteri is a small evergreen tree of slow growth, with a maximum height of 4m (Maryland-Report, 2000). The bud of flowers is blue-violet and grow in clusters or isolated; blooming occurring during the months of April and September (Mielke, 1993). It can be considered as an endemic species to Mexico, since it is distributed naturally from Sonora to Oaxaca (Porter, 1972; Mielke, 1993; CITES, 2000; Grow and Schwartzman, 2001; Martínez and Galindo-Leal 2002, Dertien and Duval 2009). The species is exploited locally, and its natural populations are under pressure due to land use changes that become a threat to their survival (Grow and Schwartzman, 2001). It is considered a food source for insects and larvae in various plant associations, such as in deciduous chaparral forests (Maryland-Report, 2000); an example being the females of *Kricogonia lyside*, which prefer to lay their eggs on the leaves of *G. coulteri*, considered as a food source plant for butterflies in Sonora (Honcoop, 1997).

Some medicinal uses are attributed to this plant, as expectorant and blood purifying element (Grow and Schwartzman, 2001), as well as laxative, diuretic and in the treatment of joint rheumatism (Maryland-Report, 2000). *G. coulteri* and *G. sanctum* share other medicinal properties such as anti-cancer, diuretic and anti-inflammatory (CITE, 2000). In the case of *G. coulteri*, resin extraction is used in the manufacture of special devices for the detection of gastrointestinal bleeding (Barsch *et al*., 2002). The flower of *G. coulteri* is used in the production of an intense organic blue '*matlali*' dye named after the Aztecs (Haude, 1998). At present, Sonoran inhabitants use a mixture of green organic resin of *G. coulteri*, clay and water to produce the coloring agent '*Antezj kóil*' (Haude,1998).

The population size of *G. coulteri* for the Mexican territory is unknown, although in the Maryland-Report (2000) it is mentioned that this is a locally abundant species with isolated specimens and grows at low densities. Because there are no recent studies, natural populations are likely to have decreased, as the distributions of *G. sanctum* and *G. officinale* have been reduced due to land use changes for agricultural purposes, urbanization, and for the tourism sector.

KEYWORDS / Distribution / Ecological Niche / Modeling / Protected Natural Areas /

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EL NICHO POTENCIAL DE *Guaiacum coulteri* EN ÁREAS NATURALES PROTEGIDAS DE SONORA A OAXACA, MÉXICO

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RESUMEN

El género Guaiacum *pertenece a la familia* Zigophyllaceae *y abarca seis especies de árboles y arbustos siempre verdes. El modelo de distribución geográfica permite diseñar y crear mapas probabilísticos de sitios donde se distribuyen las especies. El programa Maxent proyecta patrones de distribuciones geográficos mediante el empleo de modelos de nicho ecológico. En México, diversos estudios registran 11 Áreas Nacionales Protegidas (ANP) donde se distribuye la especie en estudio, con una cobertura de 2.777km^2; un 75% del área corresponde a los estados de Oaxaca, Sonora y Sinaloa, datos que coinciden con el presente estudio. El resultado del modelaje del nicho ecológico de* G.coulteri *tiene una cobertura de 24.908,238km^2 y la superficie de las ANP es de 13.545,76km^2, que al ser sobrepuestas revelan un área de nicho dentro de 1.104,42km^2, la cual corresponde a una cobertura de 9,21%. Los resultados sugieren que el modelaje de nicho potencial de* G. coulteri *coincide con la distribución actual de la especie; aunque hay áreas del modelaje que no se encuentran dentro de las ANP, el modelaje resultante puede usarse como base para proponer trabajo de campo en sitios específicos.*

O NICHO POTENCIAL DE *Guaiacum coulteri* EM ÁREAS NATURAIS PROTEGIDAS DE SONORA A OAXACA, NO MÉXICO

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RESUMO

O gênero Guaiacum *pertence à família* Zigophyllaceae *e abrange seis espécies de árvores e arbustos sempre-verdes. O modelo de distribuição geográfica permite desenhar e criar mapas probabilísticos de locais onde estão distribuídas as espécies. O programa Maxent projeta padrões de distribuição geográfica mediante a modelagem de nicho ecológico. No México, diversos estudos registram 11 Áreas Nacionais Protegidas (ANP) onde está distribuída a espécie em estudo, com uma cobertura de 2.777km^2; 75% da área corresponde aos estados de Oaxaca, Sonora e Sinaloa, dados que coincidem com o presente estudo. O resultado da modelagem do nicho ecológico de* G. coulteri *tem uma cobertura de 24.908,238km^2 e a superfície das ANP é de 13.545,76km^2, que quando sobrepostas revelam uma área de nicho dentro de 1.104,42km^2, que corresponde a uma cobertura de 9,21%. Os resultados sugerem que a modelagem de nicho potencial de* G. coulteri *coincide com a distribuição atual da espécie; embora existam áreas da modelagem que não se encontram dentro das ANP, a modelagem resultante pode ser usada como base para propor trabalho de campo em locais específicos.*

The geographic distribution modelling of plant species is considered a vitally important tool, since it allows to design and create probabilistic maps of sites where species are distributed (Martínez-Meyer, 2005). In turn, it is complemented by the provision of computer programs to obtain biogeographic information and is also an advantage that can be analyzed with a number of existing records. For these models, the Maxent program stands out, allowing to project patterns of geographical distributions through the use of ecological niche models, built on the basis of specific records of collection locations (Phillips *et al*., 2004, 2006; Hernández *et al*., 2006; Phillips and Dudík, 2008; Illoldi-Rangel and Escalante, 2008).

Natural Protected Areas (ANP, for their name in Spanish) are sites that contribute to the conservation of species, although they are often established for political purposes, and the species do not have real protection (Paredes-García *et al*., 2011). The present study focused on modeling the potential ecological niche of *Guaiacum coulteri* in ANPs in the Mexican states of Sonora, Sinaloa, Nayarit, Jalisco, Colima, Michoacán, Guerrero and Oaxaca.

Methodology

Obtaining species data

The data for this study were collected from scientific collections (Soberon and Nakamura, 2009; Soberon, 2012), since these serve as a first contact with the species and provide information such as taxonomic characteristics and geographical features that are in turn rooted in websites such as the portal of the Global Fund for Biodiversity Information (GBIF). The latter includes collections of the National Herbarium of Mexico, Instituto de Biología, UNAM (MEXU); the Herbarium of the National School of Biological Sciences, Instituto Politécnico Nacional (ENCB); the Herbarium of the Instituto de Ecología in Xalapa (XAL); and the Herbarium of the Instituto de Ecología in El Bajío (IEB), as well as biological collections abroad as, for example, the New York Botanical Garden (NY); the Missouri Botanical Garden (MO) and the U.S. National Herbarium (US). Four hundred and two records were obtained from the GBIF portal. Afterwards, a database with taxonomic and geographical attributes was developed and a duplicate data elimination was carried out, leaving a total of 139 locations. The requirement of having a minimum of 50 locations was met, so that the modeling of the potential distribution is not overestimated or, in its absence, underestimated (Scheldeman and Zonneveld, 2011). Google Earth was used for geo-referencing of the model following the methodology of Pérez-García and Liria (2013).

Modeling of the potential niche of the species

The program used to display the potential distribution was

Maxent, since it is one of the best algorithms for modeling the potential species niche (Ortega and Peterson, 2008). It is considered an artificial intelligence method that applies the principle of maximum entropy to calculate the most suitable geographical distribution of a species. This method estimates the probability of occurrence of the species looking for the distribution of maximum entropy (as uniform as possible) subject to the condition that the expected value of each environmental variable according to this distribution coincides with the empirical mean. For modeling, the Contreras-Medina *et al*. (2010) methodology was followed, performing a total of 100 repetitions to avoid modeling biases, accounting 70% of the records for modeling and 30% for their evaluation. The cross-validation option was included, which consists of replicating the data for the elaboration of the models and the same data used to evaluate the next model. The parameters used to obtain these models were: regularization multiplier= 1, maximum number of background points= 10000, convergence limit= 0.00001, and maximum iterations= 500. A set of 19 bioclimatic layers were obtained from the WorldClim portal, as proposed by Hijmans *et al*. (2005). Additionally, the digital elevation model of INEGI (1985) was used.

Bioclimatic layer correlation analysis

Given that bioclimatic layers can be correlated among them, a bivariate correlation analysis was performed with the SPSS version 18 software (SPSS, 2009). If two variables shared a correlation coefficient >0.8, that one was selected as most significant layer at the biological level for each species or those simplest layers of interpretation.

Distribution of the potential niche within the ANPs

Upon completing modeling of the potential distribution, the model was selected and in turn extrapolated to ArcGis 9.3.1 software (ESRI, 2008), and placed at the ANP locations in order to calculate the potential distribution on them and estimate the percentage of distribution.

Biodiversity in ANPs

Zicuirán-Infiernillo: The Zicuirán-Infiernillo Biosphere Reserve was established in November 2007. It is located in the municipalities of Arteaga, Churumuco, La Huacana and Tumbiscatío, 103km southwest of the city of Morelia, Michoacán, Mexico. Its extension is just over 265,117ha. The predominating vegetation in the area is a low deciduous and subcaducifolia forest, with no degree of disturbance, covering about 75% of the territory of the ANP. Due to the size of the area, this percentage makes it the most extensive area, nationwide, for the protection of this type of vegetation. Vertebrates have an important presence in the region; of the 161 species of mammals described for Michoacán, 86 species have been registered in the ANP, which implies that Zicuirán-Infiernillo is a refuge for more than 53% of species. On the other hand, 253 species of birds have been registered, representing almost 47% of the 539 species registered for the state and about 25% of the species registered for all of Mexico. Of them, 101 birds are migratory. Regarding the herpetofauna, 69 species have been registered, representing 37% of the state amphibian and reptile species (CONANP, 2007).

Islas Marías: Located 132km from San Blas, Nayarit, the archipelago called 'Islas Marías' is made up of four islands, enlisted from larger to smaller as María Madre, María Magdalena, María Cleofás and San Juanito Islands. It has a subtropical climate with rains in the summer, and encompasses different ecosystems such as mangroves, low deciduous forests and medium sub-deciduous forests, with numerous endemic species of flora and fauna. It has three core areas that comprise the islands of María Magdalena, María Cleofás and San Juanito, as well as the adjacent marine portion. María Madre Island is the largest island, the only one with a human population and has been home to a Federal Criminal Colony since 1905. The Islas Marías Biosphere Reserve was created on November 27, 2000, with an area of 641,285ha and a depth of up to 200m. The Federal Criminal Colony is a penitentiary center of the Federal Government of Mexico, established on May 12, 1905 by Porfirio Díaz. At a given time, the worst criminals were held there; subsequently, prisoners that were not related to the government or who had fought against the state were allowed to leave. On December 30, 1939, former President Lázaro Cárdenas authorized that those prisoners, called there settlers, could live with their families (CONANP, 2007).

Gulf islands of California: Located in the states of Baja California Sur, Sonora and Sinaloa, with an area of 418,910ha, it was established as a reserve and refuge area for migratory birds and wildlife in 1978. The origin of these islands is attributed to processes linked to tectonic and volcanic activity. There are 2,700 plant species in the islands (Wiggins, 1980; Case and Cody, 1983).

Chamela-Cuixmala and Teopa beach: The establishment of the UNAM biology station in Chamela took place in 1971. The beaches of Cuixmala and Teopa, located within the reserve, were established as sanctuaries for the protection of sea turtles on October 29, 1986. Since 1988, the Ecological Foundation of Cuixmala, A.C., and UNAM conducted studies for the establishment of a biosphere reserve in the region, the decree of which was published on December 30, 1993. The reserve protects aquatic and terrestrial environments, where eight types of vegetation have been identified (Ceballos and Miranda, 1986; Castillo and Gómez-Pompa, 1991; Ceballos, 1991; Ceballos *et al*., 1994). In the coastal plain of the Cuitzmala River, of ~800ha, there are numerous types of vegetation such as mangrove, riparian vegetation, carrizal, aquatic vegetation, vegetation of coastal dunes and grasslands. In the 'lomeríos' the low deciduous forest dominates, although there are other types of vegetation that are more localized, such as the medium-sized sub-deciduous forest.

Huatulco: A deciduous forest is located in the polygon of the Huatulco National Park, which presents a good state of conservation and a high biodiversity of flora and fauna. There are 430 species of flora, 15 species of amphibians, 291 species of birds, 130 species of mammals and 72 species of reptiles in the area. Of the total, 146 species are under a protection status according to NOM-059-SEMARNAT-2010 (CONANP, 2003).

Cacaxtla Meseta: Located in the municipalities of San Ignacio and Mazatlan, in the state of Sinaloa, covers an area of 50,862ha. The ANP was decreed in 2000, as a protection of flora and fauna area under the name of 'Cacaxtla Meseta'. It has a floristic list of more than 200 species of vascular plants. Among the representative fauna species is the gila monster *Heloderma horrridum* (Lavín *et al*., 2002), and six existing feline species from Mexico have been registered for the ANP (Ceballos and Oliva, 2005).

Chamela Bay islands: Located off the coast of the Municipality of La Huerta, Jalisco, they constitute the first sanctuary in Mexico established as an ANP on June 13, 2002. The only nesting colonies on the entire Jalisco coast for seabird species such as the brown pelican (*Pelecanus occidentalis*), the yellow-footed booby (*Sula leucogaster*) and the blue-footed booby (*S.*

nebouxii) occur on these islands. Other species that nest or take refuge in the islands are the common frigate (*Fregata magnificens*), cormorants (*Phalancrocorax olivaceus*), night heron (*Nycticorax nycticorax*), heron cinder (*Ardea herodias*), white heron (*A. alba*), golden-eared heron (*Egretta thula*), ladle heron (*Cochlearius cochlearius*), pijije duck (*Dendrocygna autumnalis*), white ibis (*Eudocimus albus*), pink spatula (*Platalea ajaja*), dark ibis (*Plegadis chihi*), common buzzards (*Coragyps atratus*), auras (*Cathartes aura*), as well as several species of passerine birds and some migratory ones (CONANP, 2008).

Escobilla beach: The ecosystems that are protected in this ANP are mangrove, medium-sized deciduous forest, thorny thicket, coastal dune vegetation, tular, floating and submerged vegetation, palm groves, halophyte plant clusters, low deciduous forest, and grassland. The main species of fauna to be protected is the golf turtle (*Lepidochelys olivacea*), since this beach is the most important nationwide for the number of females that annually lay their eggs, although there are also birds such as the blue hummingbird (*Eupherusa cyanophrys*) that is endemic to the region and considered threatened, as well as the green toucan (*Aulacorhynchus prasinus*) and hawks considered under special protection. Marine mammals such as the false killer whale and several species of dolphins have been registered in the sea. Meanwhile, regarding the flora, there is black mangrove (*Avicennia germinans*), red mangrove (*Rhizophora mangle*), white mangrove (*Laguncularia racemosa*) and button mangrove (*Conocarpus erectus*) (CONAN, 2009).

Maruata and Colola beach: Maruata beach corresponds to the bay of the same name; it is a marine and coastal wetland where there are three beaches. The main beach located to the east, with an extension of 2.4km where most of the sea turtles nest; to the center of the Maruata coast line is a small beach of 90m and at the west end is a beach of ~150m. The average width of the beaches is 40m. On the main beach, where the bay is located, the site ends abruptly with vegetation composed mainly of shrubs of the *Acacia* genus, which marks the limit of the beach and the beginning of a rocky edge. The beach is bare of vegetation, although only *Ipomea pescaprae* patches are found, which are oriented towards the sea. In the eastern limit, there is a strip of vegetation of ~100m formed by shrubs of deciduous forest, mainly from the *Prosopis*, *Acacia*, *Glirisidia*, *Phitocellobium* and *Solanum* genera. Across this strip of vegetation is the coastal road (INEGI, 1985).

Veladero: It is an ecological reserve located in the bay of the port of Acapulco, Guerrero, southern Mexico. It has a surface of 3,159ha and within the site, there is a locality that bears the same name as the park. The vegetation includes, as in most of the municipality, forests of medium subcaducifolia type. The oaks *Quercus affinis* and *Q. laurina* predominate, as well as a deciduous forest. The abundant fauna consists of species of carnivorous birds, reptiles such as iguanas and snakes, boa (*Constrictor imperator*), garrobo (*Ctenosaura pectinata*), osprey (*Pandion haliaetus*), scorpion (*Heloderma horridum*) and cojolite (*Penelope purpurascens*) (INE, 2007).

Results and Discussion

Protected natural areas

The distribution of *G. coulteri* covers 11 Natural Protected Areas (APN). These results coincide with López *et al.*, 2011, who also recorded 11 APNs where the species under study is distributed in the Mexican territory, with a coverage of 2,777km². The 75% of this area corresponds to the states of Oaxaca, Sonora and Sinaloa, data that coincide with the present study. Vanclay (2001) and Jackson *et al.* (2009) have suggested that just because a species is found within an ANP, it does not guarantee its conservation; therefore, it is proposed that greater conservation efforts be made.

G. coulteri *surface in ANPs*

The *G. coulteri* ecological niche modeling resulted in a coverage of 24,908,238km². The surface of the ANPs (Chamela-Cuixmala, El Veladero, Chamela Bay Islands, Marías Islands, Cacaxtla Plateau, Maruata Beach and Colola, Teopa Beach, Zicuiran-Infiernillo and Huatulco) was 13,545.76km². When overlaying the ANP polygons, the area of the niche within them was 1,104.42km², which corresponds to a coverage of 9.21% (Figure 1). The ANP with the largest distribution areas were Zicuirán-Infiernillo with 518.33km² and the Marias Islands with 217.69km², while the highest percentage within the ANP is Playa Teopa, with 87.48%, followed by Huatulco with 67.05% (Figure 1).

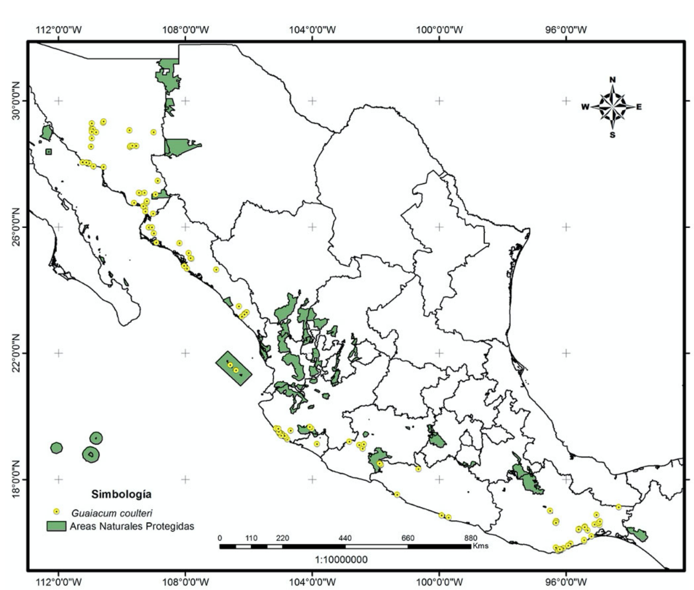

Figure 1. Distribution of localities of *G. coulteri* and Protected Natural Areas near their distribution.

Modeling the ecological niche of G. coulteri

The generated model fits the range of *G. coulteri*. Moreover, it is worth mentioning that this model predicts potential niches in the states of Tamaulipas and Baja California Sur; however, there are no records of this species in the collections. For Tamaulipas, the *G. angustifoluim* record is available, and for Baja that of the species *G. sanctum* Also, when analyzing the records, it was noticed that there were locations in Baja California and Chiapas, and such unconventional records are due to a bad identification of the species or to taxonomic errors. Since there are two other species and a variety: *G. angustifolium*, *G. unijugum* and *G. coulteri* var. *palmeri*, according to McCauley *et al.* (2010) it is likely that the latter has a greater similarity. The bioclimatic layers with greater precision for modeling were the seasonality of precipitation (Bio 15, with a contribution of 28,6) and the annual average temperature (Bio 1, contribution of 31,5), followed by elevation (contribution of 9.6%). Of the 139 unique

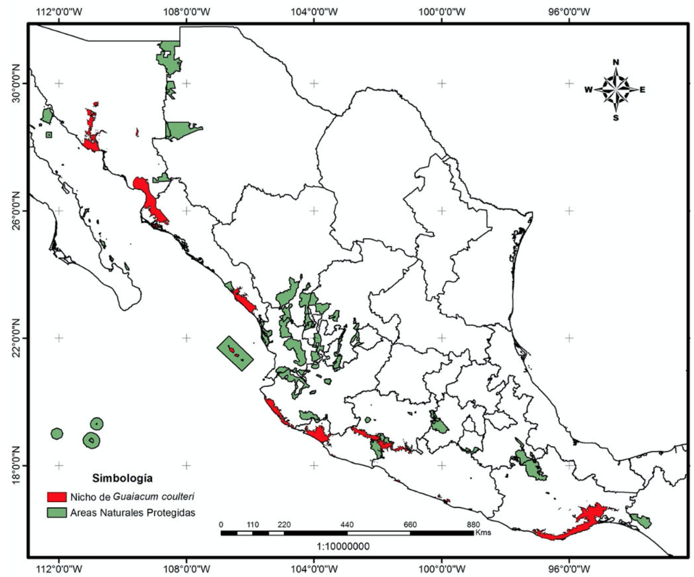

Figure 2. Distribution of the potential niche of *G. coulteri* in natural protected areas of Mexico.

locations, only 17 records occur within the protected natural areas, which confers 12.23% of the total data for the modeling of the ecological niche (Figure 2 and Table I).

Conclusions

The results obtained suggest that the *G. coulteri* potential niche modeling coincides with the current distribution described for the species, although there were also areas of the model that are not located within the Natural Protected Areas, such as Sierra de Álamos-Rio, Cuchujaqui in Sonora, Sierra of Manantlán in Colima, National Marshes in Nayarit and CADNR043 in Nayarit. The resulting model can be used as a foundation for proposing field work in specific sites, such as some priority areas for conservation, where the presence of the species has been suggested by the model. Yet, there is no evidence of the potential niche of the species in the model. For this propose, specific sites with suitable conditions should be proposed strategically for their development regarding conservation purposes. When overlaying the modeling of *G. coulteri* on the map of the Natural Protected Areas system, it was observed that 91% is not included within the limits of these areas close to the known distribution of the species. The model shows that the species is found only in 11 of the 57 ANPs close to its known distribution, so it is considered to be insufficiently represented in the current system of ANPs.

TABLE I
SURFACE (KM^2) OF *G. coulteri* IN PROTECTED NATURAL AREAS

Name	Area Km^2	Niche area in the ANP	Percentage
Zicuirán-Infiernillo	2637.04	518.33	19.66
Marías Islands	6353.12	217.69	3.43
Golfo de California Islands	3745.53	201.15	5.37
Chamela-Cuixmala	130.74	80.16	61.31
Huatulco	119.44	80.08	67.05
Meseta de Cacaxtla	503.18	6.38	1.27
Bahía de Chamela Islands	19.69	0.21	1.09
Teopa Beach	0.12	0.10	87.48
Escobilla Beach	0.3	0.3	100
Maruata y Colola Beach	0.33	0.01	3.67
El Veladero	36.27	0.01	0.03
Total	13545.76	1104.42	

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