Species Wealth, Geographical Distribution and Conservation Status of the Genus Dahlia (Asteraceae) in Mexico

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Summary

Background and Objectives: The genus Dahlia (Asteraceae) is native to America and Mexico is its center of diversification. *Dahlia* is important in ornamental horticulture, its genetic improvement has generated more than 15,000 varieties. Mexico represents the main source of germplasm, so a study of its wealth and geographical distribution is essential. The objectives of this work were to analyze the richness of dahlia species in Mexico, their geographical distribution and evaluate their conservation status.

Methods: A database was developed with 1,980 georeferenced records, obtained from herbarium specimens, publications and from field collections. The information was analyzed using Geographic Information Systems, the species abundance was estimated by political division, vegetation types, regions, biogeographic provinces, elevational, latitudinal and longitudinal ranges, a 33 × 33 km grid and Protected Natural Areas (ANP).

Key results: Dahlia has 38 species, all grown in Mexico, 35 are endemic. The genre is present in 26 states. Hidalgo and Oaxaca have the largest number of species, followed by Guerrero. The state of Jalisco shows the greatest collection effort. Commonly, Dahlia species inhabit coniferous and oak forests. Its range of distribution covers from 24 to 3,810 m elevation, but the greatest number of species grows between 2,000 and 2,500 m. Two areas of greatest richness of dahlia species were found in Mexico. The first is in the northeast of Querétaro, east of Guanajuato and southeast of San Luis Potosí, in the Sierra Madre Oriental, the other in the northwest of Oaxaca, in the Sierra Madre del Sur. Finally, 23 species live within a Natural Protected Area. The Sierra Gorda in the state of Querétaro concentrates the greatest number of species.

Conclusions: The analysis of the species richness and its distribution showed that the greatest diversity of Dahlia is found in the Mexican Transition Zone in the provinces of Sierra Madre del Sur and Sierra Madre Oriental.

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INTRODUCTION

Mexico is a very diverse country with a territory of 1,960,189 km^2. Its complex geological history has resulted in the recognition of 11 morphotectonic provinces (Ferrusquía-Villafranca, 1998) and 60 variations of climate (García, 1998). In Mexico, 15 provinces are recognized as physiographic, 17 floristic, ten for vegetation types (Rzedowski, 1986), six ecological zones (Toledo and Ordóñez, 1998), 45 terrestrial eco-regions (Olson et al., 2001) and 14 biogeographical provinces (Morrone et al., 2017). These factors have allowed the presence of a great floristic wealth. According to Villaseñor (2016), the country grows 22,126 native species of angiosperms, of which 49.8% are endemic.

Asteraceae is the family with the greatest diversity of native plants in Mexico. 3,057 species have been registered, and of these 65.9% are endemic (Villaseñor, 2003, 2016). The Dahlia genus Cav. has its greatest diversity and endemism in Mexico. This is considered its center of diversification. Dahlia is a monophyletic group native to America; it is distributed from south of the USA to Colombia (Saar et al., 2003a). All species grow in Mexico, but D. australis (Sherff) P.D. Sørensen, D. coccinea Cav. and D. imperialis Roezl ex Ortgies extend to Central America and Colombia (Sørensen, 1969). In Mexico, they are commonly called "charahuescas", "camilas", "mirasoles", "jícamas", or simply "dalias".

The genus Dahlia includes perennial herbaceous or shrub plants, either terrestrial or epiphytic, with fasciculated tuberous roots that develop from a short rhizome. The stems are hollow or solid, herbaceous or lignified and erect. Leaves are opposite or whorled, simple or compound, often with stipels present in the base of the leaflets The inflorescence is a heterogamous head, formed by bracts, topped by ligulate and discoid flowers. The external bracts l (4-) 5 (-7) are green, fleshy, linear, ovate or obovate; extended, reflex or erect in the anthesis. The internal bracts (7-) 8 (-9) are membranous, ovate, and colored red, yellow or violet. The head has eight ligulate flowers, fertile or sterile, in white, violet, yellow, orange, red or purple. In addition, it produces 15-170 flowers of the disc, hermaphroditic, tubular, cone-shaped and hypocrateriform; with yellow, violet, purple or red corollas The seed is a type of cypsela acerosa, nailed, gray or black, with longitudinal grooves, glabrous or downy, with tuberculated extrusions, and with rudimentary or absent burrs (Fig. 1, Castro-Castro et al., 2012).

Dahlias are well known in ornamental horticulture. They have been the subject of intense modification genetics that has produced more than 50,000 cultivated varieties .These have changed their characteristics by increasing the inflorescence, forms of ray flowers, diversity of colors, size of individuals and flowering time. The cultivars belong to Dahlia pinnata Cav., and they have reportedly originated from crosses between D. coccinea and D. sorensenii H.V. Hansen & Hjert., D. merckii Lehm. and D. imperialis (Hansen & Hjerting, 1996; Mera et al., 2008).

Sørensen (1969) conducted a taxonomic review of Dahlia. He recognized 27 species (Table 1) and four sections: Section Dahlia, Section Entemophyllon, Section Epiphytum and Section Pseudodendron. After this work, 14 species have been renamed or described: Dahlia campanulata Saar, P.D. Sørensen & Hjert., D. congestifolia P.S. Sørensen, D. cordifolia (Sessé & Moc.) McVaugh, D. cuspidata Saar, P.D. Sørensen & Hjert., D. hjertingii H.V. Hansen & P.D. Sørensen, D. neglecta Saar, D. parvibracteata Saar & P.D. Sørensen, D. pugana Aarón Rodr. & Art. Castro, D. spectabilis Saar & P.D. Sørensen, D. sorensenii, D. sublignosa (P.D. Sørensen) Saar & P.D. Sørensen, D. tamaulipana J. Reyes, Islas & Art.Castro, D. tubulata P.D. Sørensen, and D. wixarika Art. Castro, Carr.-Ortiz & Aarón Rodr. (Sørensen 1980, 1987; Hansen and

Hjerting, 1996; McVaugh, 2000; Saar & Sørensen, 2000, 2005, 2006; Saar, 2002; Saar et al., 2002, 2003b; Hansen & Sørensen, 2003; Castro-Castro et al., 2012, 2015; Reyes-Santiago et al., 2018).

Taxonomic (Sherff, 1947, 1951a, b; Sørensen, 1969), phylogenetic (Giannasi, 1975, Gatt et al., 2000; Saar et al., 2003a), chromosomal (Hansen and Hjerting, 1996; Gatt et al., 1998) and palynological studies (Wodehouse, 1930) have been developed in Dahlia. Some of the taxonomic works include information on their distribution by country and state. However, there is no work that analyzes their geographic distribution using Information Systems Geographic (SIG).

Figure 1: Diversity of Dahlia Cav. in Mexico

A) D. australis, tuberous roots; **B)** D. campanulata, lignified stalk; **C)** D. Pugana, pinnate leaves; **D)** D. dissecta, a habit of rupicultural growth; **E)** D. hintonii, herbaceous bearing; **F)** D. tenuicaulis, habit of bush growth; **G)** D. australis, ligulated and tubular flowers; **H)** D. australis, bracts of the involucre; **I)** D. barkerae; **J)** D. brevis; **K)** D. campanulata; **L-Ñ)** D. coccinea Cav .; **O)** D. congestifolia; **P)** D. cordifolia; **Q)** D. cuspidata; **R)** D. dissecta; **S)** D. hintonii; **T)** D. imperialis; **U)** D. linearis; **V)** D. merckii.; **W)** D. mollis; **X)** D. neglecta; **Y)** D. parvibracteata; **Z)** D. pugana; **A ')** D. rudis; **B ')** D. scapigera; **C ')** D. scapigeroides; **D ')** D. sherffii; **E ')** D. sorensenii; **F ')** D. spectabilis; **G ')** D. tenuicaulis; **H ')** D. tenuis.

Photographs: Aarón Rodríguez (A6509, B6495, D6412, F5981, G-H6506, I5838, J5869, K6495, L-M6435, N5293, Ñ5144, O6474, P5224, Q6400, R7186, T6929, U6817, V6017, W6402, X6466, Z6850, A'6378, C'6352, of 6029, E'5273, G'4680, H'5254), Arturo Castro (E3078, S3078, Y3266, B'3274, in 3972), Marco Carrasco (C13)

Table 1 Geographical distribution of Dahlia Cav. by political division, regions, biogeographical provinces and types of vegetation in Mexico. The asterisk (*) indicates the endemic species of Mexico and by s the species considered by Sørensen (1969).

BE thorny forest
ECB coniferous and oak forest
BMM mountain mesophilic forest
BTC tropical deciduous forest
BTP tropical evergreen forest
BTS tropical sub-deciduous forest
MX xerophilous scrub
P pasture
VAS aquatic and underwater vegetation

AC Altos de Chiapas
CB Cuenca del Balsas
DC Chihuahuan Desert
CP Pacific Coast
EVT Trans-Mexican Volcanic Axis
SMOR Sierra Madre Oriental
GCOS Sierra Madre Occidental
SMS Sierra Madre del Sur
T Tamaulipas
V Veracruz
ZTM Mexican Transition Zone

Species	**State**	**Region: Biogeographic Provinces**	**Type of Vegetation**
*s*Dahlia apiculata* (Sherff) P.D. Sørensen	Guerrero, Oaxaca, Puebla	**Neotropical**: CB; **ZTM**: SMS	BCE, BTC, MX
**s*Dahlia atropurpurea* P.D. Sørensen	Guerrero, Hidalgo, Estado de México	**ZTM**: EVT, SMS, SMOR	BCE
*s*Dahlia australis* (Sherff) P.D. Sørensen	Chiapas, Michoacán, Oaxaca, Puebla, Veracruz	**Neotropical**: CB, CP; **ZTM**: AC, EVT, SMS	BCE, BMM, BTC, MX
**s*Dahlia barkerae* Knowles & Westc.	Jalisco, Michoacán	**Nearctica**: DC; **ZTM**: EVT	BCE, BTC
**s*Dahlia brevis* P.D. Sørensen	Estado de México, Michoacán	**Nearctica**: DC; **ZTM**: EVT	BCE
**Dahlia campanulata* Saar, P.D. Sørensen & Hjert.	Oaxaca	**Neotropical**: CB; **ZTM**: SMS	BTC, MX
*s*Dahlia coccinea* Cav.	All of México except Baja California, Baja California Sur, Campeche, Quintana Roo, Tabasco, Yucatán	**Nearctica**: DC; **Neotropical**: CB, CP, V; **ZTM**: AC, EVT, SMS, SMOC, SMOR	BCE, BE, BMM, BTC, BTP, BTS, MX, P, VAS
**Dahlia congestifolia* P.D. Sørensen	Hidalgo	**ZTM**: EVT	MX
**Dahlia cordifoli*a (Sessé & Moc.) McVaugh	Guerrero	**Neotropical**: CB; **ZTM**: SMS	BCE, BTC
**Dahlia cuspidata* Saar, P.D. Sørensen & Hjert.	Guanajuato, Hidalgo, Querétaro	**Nearctica**: DC; **ZTM**: SMOR	BCE, MX
**s*Dahlia dissecta* S. Watson	Hidalgo, Querétaro, San Luis Potosí, Veracruz	**Nearctica**: DC; **ZTM**: SMS, SMOR	BCE, BMM, MX
**s*Dahlia foeniculifolia* Sherff	Nuevo León, Tamaulipas	**Nearctica**: T; **ZTM**: SMOR	BCE, MX
**s*Dahlia hintonii* Sherff	Guerrero	**ZTM**: SMS	BCE
**Dahlia hjertingii* H.V. Hansen & P.D. Sørensen	Hidalgo	**ZTM**: SMOR	BCE
*s*Dahlia imperialis* Roezl ex Ortgies	Chiapas, Guerrero, Oaxaca, Puebla, San Luis Potosí	**Nearctica**: DC; **Neotropical**: CB, CP, V; **ZTM**: AC, SMS	BCE, BMM, BTC, BTP, MX
**s*Dahlia linearis* Sherff	Guanajuato, Querétaro	**Nearctica**: DC; **ZTM**: SMOR	BCE, BE, MX
**s*Dahlia macdougallii* Sherff	Oaxaca	**Neotropical**: CB; **ZTM**: SMS	BCE, BTC
**s*Dahlia merckii* Lehm.	Ciudad de México, Guanajuato, Guerrero, Hidalgo, Estado de México, Michoacán, Morelos, Nuevo León, Oaxaca, Puebla, Querétaro, San Luis Potosí, Tlaxcala, Veracruz	**Nearctica**: DC; **Neotropical**: CB; **ZTM**: EVT, SMS, SMOR	BCE, BTC, MX, P, VAS

*s*Dahlia mollis* P.D. Sørensen	Guanajuato, Hidalgo, Querétaro	**ZTM**: SMOR	BCE
*s*Dahlia moorei* Sherff	Hidalgo, Querétaro	**ZTM**: SMOR	BCE
**Dahlia neglecta* Saar	Ciudad de México, Guanajuato, Hidalgo, Estado de México, Michoacán, Querétaro	**Nearctica**: DC; **ZTM**: EVT, SMOR	BCE, BTC, MX, P, VAS
**Dahlia parvibracteata* Saar & P.D. Sørensen	Guerrero	**Neotropical**: CB; **ZTM**: EVT	BCE, BTC
*s*Dahlia pteropoda* Sherff	Oaxaca, Puebla	**Neotropical**: CB; **ZTM**: SMS	BCE, BTC, MX
**Dahlia pugana* Aarón Rodr. & Art. Castro	Durango, Jalisco	**Neotropical**: CP; **ZTM**: EVT, SMS, SMOC	BCE, BTC
*s*Dahlia purpusii* Brandegee	Chiapas	**ZTM**:AC	BTP
*s*Dahlia rudis* P.D. Sørensen	Ciudad de México, Guerrero, México, Michoacán, Morelos, Oaxaca	**ZTM**: EVT, SMS	BCE, BTC, P, VAS
*s*Dahlia rupicola* P.D. Sørensen	Durango	**ZTM**: SMOC	BCE
*s*Dahlia scapigera* Knowles & Westc.	Ciudad de México, Guanajuato, México, Michoacán, Morelos, Veracruz	**Nearctica**: DC; **ZTM**: EVT	BCE, BTC, P
*s*Dahlia scapigeroides* Sherff	Guanajuato, Hidalgo, Querétaro, San Luis Potosí	**Nearctica**: DC; **ZTM**: SMOR	BCE, BMM, BTC, MX
*s*Dahlia sherffii* P.D. Sørensen	Chihuahua, Durango, Jalisco, Nayarit, Zacatecas	**Nearctica**: DC; **ZTM**: SMOC	BCE, BTC, P
**Dahlia sorensenii* H.V. Hansen & Hjert.	Chiapas, Ciudad de México, Guerrero, Hidalgo, Jalisco, México, Michoacán, Morelos, Nayarit, Oaxaca, Querétaro, Zacatecas	**Nearctica**: DC; **Neotropical**: CP; **ZTM**: EVT, AC, SMS	BCE, BTC, MX, P, VAS
**Dahlia spectabilis* Saar & P.D. Sørensen	San Luis Potosí	**ZTM**: SMOR	BCE
**Dahlia sublignos*a (P.D. Sørensen) Saar & P.D. Sørensen	Tamaulipas	**Nearctica**: DC; **ZTM**: SMOR	BCE, MX
**Dahlia tamaulipana* J. Reyes, Islas & Art. Castro	Tamaulipas	**ZTM**: SMOR	BCE
*s*Dahlia tenuicaulis* P.D. Sørensen	Guerrero, Jalisco, Michoacán, Oaxaca, Veracruz	**Nearctica**: DC; **Neotropical**: CB; **ZTM**: EVT, SMS	BCE, BMM, BTC
*s*Dahlia tenuis* B.L. Rob. & Greenm.	Oaxaca	**Neotropical**: CB; **ZTM**: SMS	BCE, BTC
**Dahlia tubulata* P.D. Sørensen	Coahuila, Nuevo León, Tamaulipas	**Nearctica**: T; **ZTM**: SMOR	BCE, MX
**Dahlia wixarika* Art. Castro, Carr.-Ortiz & Aarón Rodriguez	Durango, Jalisco	**ZTM:** SMOC	BCE

Geographic locations of the plants are important. With them it is possible to identify areas with high diversity of species, and its easy handling allows us to quickly recognize patterns of wealth and distribution. They can be manipulated, generated and analyzed for new information that (in combination with the already existing) is useful for decision-making in conservation (Hijmans and Spooner, 2001; Parthasarathy et al., 2006; Scheldeman et al., 2007). They are also useful for analyzing morphological characteristics in a geographic context (Sunilet al., 2009; Abraham et al., 2010). In Mexico we analyzed population patterns using GIS in plant vascular diseases (Cruz-Cárdenas et al., 2013), monocotyledon geophytes (Sosa and Loera, 2017), the Iridaceae tribe Tigridieae (Munguía-Lino et al., 2015), Cosmos Cav. (Vargas-Amado et al., 2013), Solanum L. Petota Dumort section, (Rodriguez,2015) and Lycianthes (Dunal) Hassl. Meizonodontae series (Anguiano-Constante et al., 2018). The results show that species richness is concentrated in the Mexican Transition Zone, mainly in the Trans-Mexican Volcanic Axis. In dahlias it is necessary to know the areas where their greatest diversity is found, with

the purpose of designing strategies for conservation, management and sustainable use. The objectives of this study were to identify the sites of abundance of the genus Dahlia in Mexico, find pattern distribution, show the preference for some kind of vegetation, elevation, latitudinal or longitudinal range, show the omissions in genus conservation within the Natural Protected Areas (ANP) and know the state of conservation of its species.

Database

A database was created with two types of information:

1) bibliographic references and 2) herbarium specimens deposited in biological collections. The bibliographic references included: Sherff (1947, 1951a, b), Sørensen (1969, 1980, 1987), McVaugh (1984), Hansen and Hjerting (1996), Saar and Sørensen (2000), Saar (2002), Saar et al. (2002, 2003b), Hansen and Sørensen (2003), Rzedowski and Calderón de Rzedowski (2008), Castro-Castro et al. (2012, 2015) and Reyes-Santiago et al. (2018). At the same time, the specimens were analyzed and determined to be deposited in collections of national herbaria (ANSM, BCMEX, CH, CHAP, CHAPA, CIIDIR, COCA, EBUM, ENCB, FCME, FEZA, HCIB, HEM, HUAA, HUAP, HUAZ, HUMO, IBUG, IEB, INEGI, IZTA, JES, MEXU, OAX, QMEX, SERO, SLPM, UAT, UCAM, USON, XAL and ZEA) and copies of foreign herbaria (ARIZ, ASU, BH, BM, C, CAS, CLEMS, CM, DBG, DEK, DES, F, GH, GMUF, HCHM, HNT, IA, ISC, K, LSU, MICH, MO, MSC, NCSC, NCU, NMC, NY, OBI, OS, RENO, RSA, TEX, UC, UCR, US, USCH, WIS and WTU) (acronyms according to Thiers, 2018). In addition, the electronic database of the Missouri Botanical Garden was consulted (TROPICOS, 2017). Finally, field collections were made in the summers of 2011 to 2017.

The information collected was compiled in Excel, grouping it into four categories: taxonomic, geographical, ecological and curatorial. The taxonomic section contains family, name of the genus, species name, sub-specific categories and authors. The geographical section groups country, state, municipality, locality, elevation latitude and longitude. The ecological section includes type of vegetation, associated species, observations and date of collection. Finally, the curatorial information notes the name of the herbarium, collector, associated collectors, number of collection and name of the evaluator.

Data processing

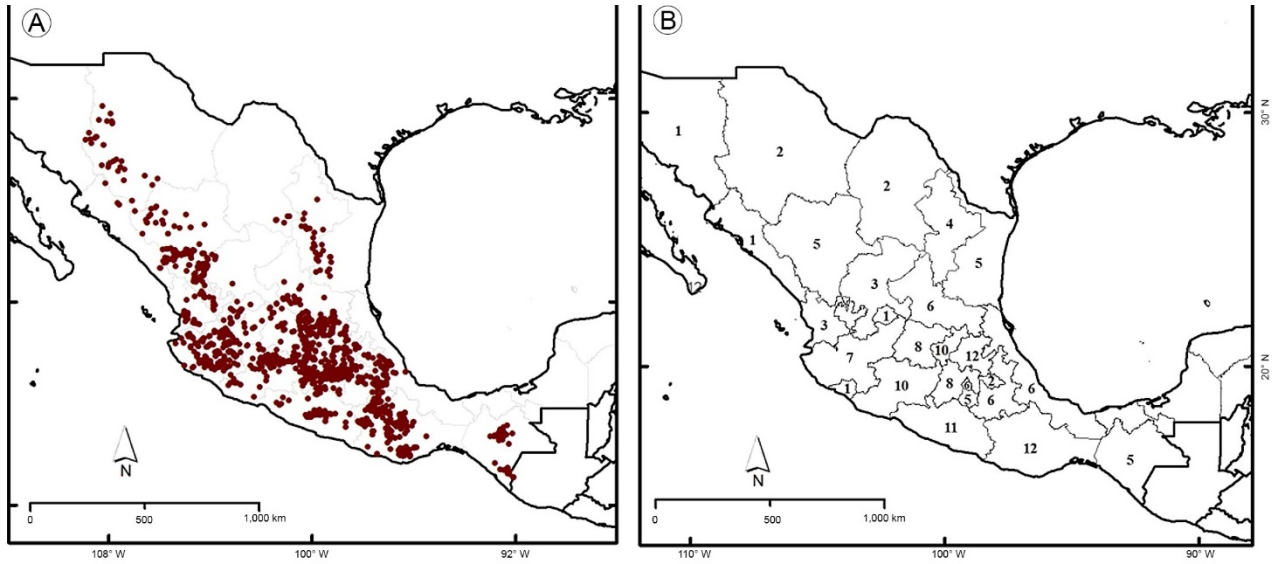
The geographic data was processed in ArcView 3.3 GIS (ESRI, 1992-1998) and DivaGis 4 (Hijmans et al., 2004). For use of the information, the database was transformed to a format compatible with a GIS (Hijmans et al., 1999) through the ArcView 3.3 computer program (ESRI, 1992-1998). The procedure consisted of using the coordinates of latitude and longitude of each record to generate a point within the GIS, associating it with the rest of the information contained in the base. The final result was a file with points from all the records, or thematic layer with the following information: gender, specific name, state, latitude, longitude and elevation corresponding to each point. Wealth analysis was done by political division, regions, biogeographical provinces, types of vegetation and geographic criteria.

We analyzed 1,980 records that represent 38 species of Dahlia (Fig. 2A). To calculate wealth by political division, the number of species were recorded in each state (Fig. 2B). The wealth per biogeographic province was estimated using a picture of presence-absence of the species and the regionalization scheme proposed by Morrone et al. (2017). This one proposes the Nearctic, Neotropical, the Mexican Transition Zone and 14 biogeographic provinces. The Mexican Transition Zone includes the

biogeographical provinces of Altos de Chiapas, Trans-Mexican Volcanic Axis, Sierra Madre Occidental, Sierra Madre Oriental and Sierra Madre del Sur. To the Nearctic region belong Baja California, California, Sonora, Chihuahuan Desert and Tamaulipas. The Neotropical region is composed of Cuenca del Balsas, the Pacific Coast, the Yucatan Peninsula and Veracruz. The richness by vegetation types was estimated using the potential vegetation mapping of Rzedowski (1990). This map is based on Rzedowski's proposal (1986) which includes 10 types of vegetation: tropical evergreen forest, tropical sub-deciduous forest, deciduous tropical forest, thorn forest, xerophilous thicket, pasture, Quercus (oak) forest, coniferous forest, mountain mesophyll forest, and aquatic vegetation and underwater.

Finally, the species' richness was quantified by geographical criteria: elevation, latitude and longitude. For this, we created a new presence-absence table by curves of level (CONABIO, 1998). The number of species per interval elevation, latitude, and longitude was recorded and plotted (Hijmans and Spooner, 2001, Vargas-Amado et al., 2013).

Figure 2 Distribution map of Dahlia cav. In Mexico A) Location B) By political state boundaries



Wealth analysis by Natural Protected Area (ANP)

A presence-absence chart was developed using the map of federal ANP of Mexico of the National Commission of Natural Protected Areas (CONANP, 2012). In agreement with the CONANP (2012), there are 176 of these areas grouped in six categories: Biosphere Reserves, National Parks, Natural Monuments, Resource Protection Areas, Natural, Areas of Protection of Flora and Fauna and Sanctuaries.

Analysis of the distribution area

The distribution area of each species was estimated using DivaGis 4 (Hijmans et al., 2004) and GeoCat (Bachman et al., 2011). First, the general distribution patterns were described; following were subsequently evaluated parameters: 1) MaxD, 2) the extension of the occurrence area (EOO), that is, the surface that includes all the records calculated with a minimum convex polygon and 3) the area of occupation (AOO), which is the area occupied by a taxon inside the EOO. In other words, it is the ideal area where a taxon can thrive. It is calculated with 2 × grids 2 km (4 km2) generated from the points of occurrence (Willis et al., 2003; IUCN, 2012).

State of conservation

The risk category of the dahlia species was estimated based on the criterion of geographical distribution, according to the Red List of the IUCN (IUCN, 2012). For this purpose, the MaxD, EOO and AOO values.

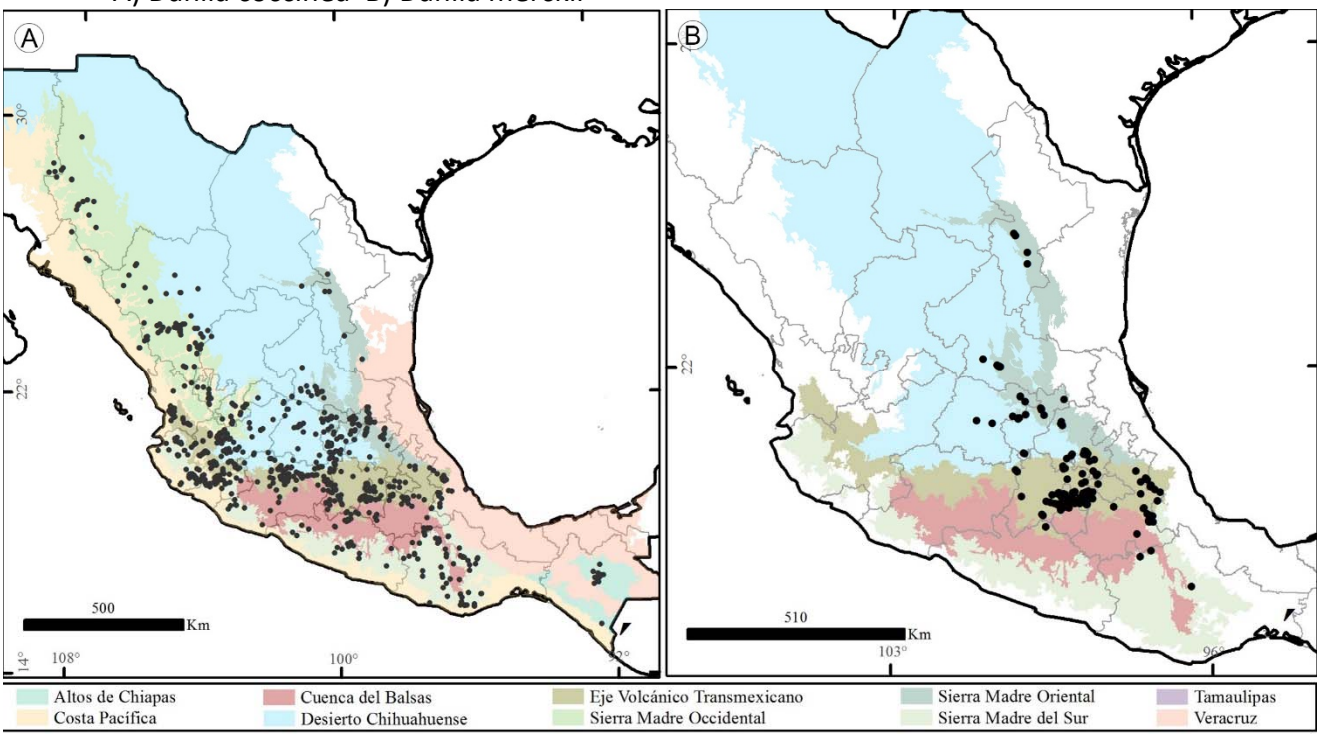
Results

Database and georeferencing: The database had 2249 records of dahlias, of which 269 were excluded because they were repeated localities, collections carried out outside of Mexico, cultivated species, or contain confusing and incomplete information. In the analysis we included 1980 records (38 spp.) of which 61% (1304) were georeferenced. The georeferenced data were collected mainly among the years 1900 and 2000. Dahlia pinnata and D. excelsa Benth. were not included in the analysis. The first is a cultivated species and the second is synonymous with D. imperialis (Sørensen, 1969; Hansen, 2007).

Wealth by political division

In Mexico, 38 dahlia species grow and are registered in 26 states. Its geographical distribution was irregular; Oaxaca, Hidalgo, Guerrero, Michoacán and Querétaro concentrated the greater diversity (Table 1, Fig. 2B). In Aguascalientes, Colima, Sinaloa and Sonora only D. coccinea grows. The intensity of collection was also variable; Jalisco, Oaxaca and Michoacán presented the highest number of records, with 58% of the observations.

Figure 3 Distribution map of widest distributed species
A) Dahlia coccinea B) Dahlia merckii



Dahlia coccinea and D. merckii had the widest distribution; they are present in 27 and 14 states, respectively. On the contrary, D. campanulata, D. congestifolia, D. cordifolia, D. hintonii, D. hjertingii, D. Macdougallii, D. parvibracteata, D. purpusii, D. rupicola, D. spectabilis, D. sublignosa, D. tamaulipana and D. tenuis. are known only from one state (Figs 3A, B).

Wealth by biogeographical regions and provinces

The Mexican Transition Zone housed all the species of Dahlia. On the other hand, in the Nearctic region are found 17 and in the Neotropical 14 species. The number of observations follows a similar pattern; the Mexican Transition Zone was the most collected with 1,636 records (83% observations); in the Nearctic 188 samples were obtained, and in the Neotropical 156 (Table 2). Dahlia was found in 10 biogeographical provinces (Table 2). The Sierra Madre del Sur and the Sierra Madre Oriental had the highest number of species (17 and 16 respectively), followed by the Chihuahuan Desert (15), the Trans-Mexican Volcanic Axis (14) and the Cuenca del Balsas (12). The less diverse provinces were the Altos of Chiapas, the Sierra Madre Occidental and the Pacific Coast with five species each, Veracruz and Tamaulipas with two. The analysis of the intensity of collection by province showed that 745 collections were made on the *Axis Volcánico Transmexicano*, which represents 38% of the records. On the other hand, in Veracruz there were six collections and in Tamaulipas two.

Table 2 Wealth of Dahlia cav. Species within geographic regions and provinces

Region	Species	Samples	Provinces	Species	Samples
Mexican Transition Zone	38	1636	Altos de Chiapas	5	72
			Sierra Madre Occidental	5	184
			Sierra Madre Oriental	16	254
			Sierra Madre del Sur	17	381
			Trans-Mexican Volcanic Axis	14	745
Nearctica	17	188	Chihuahuan Desert	15	186
			Tamaulipas	2	2
Neotropical	14	156	Cuenca del Balsas	12	93
			Pacific Coast	5	57
			Veracruz	2	6

Wealth by vegetation types

Dahlia inhabits nine types of vegetation. In the conifer and oak woods, 35 species were recorded. Deciduous tropical forest had 20 and the xerophilous thicket had 17. Conversely, in the tropical sub-deciduous forest only Dahlia coccinea grows; seven species of dahlia are in pasture, six in mountain mesophilic forest, five in aquatic vegetation and underwater, three in evergreen tropical forest and two in thorny forest (Table 1). Dahlia coccinea had the greatest ecological range. It was registered in nine types of vegetation (Table 1), followed by D. imperialis, D. sorensenii, D. neglecta and D. merckii in five. Dahlia australis, D. scapigeroides and D. rudis thrive in four. At the other extreme, D. atropurpurea, D. brevis P.D. Sørensen, D. hintonii, D. hjertingii, D. mollis, D. moorei, D. rupicola, D. spectabilis, D. tamaulipana and D. wixarika grow only in the coniferous and oak forest. D. congestifolia was found in the xerophytic scrub and D. purpusii in the evergreen tropical forest (Table 1).

Wealth by elevation, latitude and longitude

The dahlia grows from 24 to 4,000 m elevation (Fig. 4A), notable by the largest number of observations (837). It thrives on a gradient of 15 to 29° north latitude (Fig. 4B) and longitudinally, in a range that goes from 92 to 108°W (Fig. 4C). Of the total species, 33 were found from 2,001 to 2,500 m (Fig. 4A). Dahlia coccinea has the widest elevation range (24-3,033 m). On the other hand, D. congestifolia (2,660- 2,769 m), D. hjertingii (2,165-2,252 m) and D. spectabilis (2,213- 2,237 m) have the most restricted elevational amplitude, while D. scapigera. and D. merckii are found above 3,500 m (Fig. 5). The highest diversity was found at 20°N, where 17 species are native (Fig. 4B). In contrast, between 27 and 29°N there were only two. The largest number of observations is recorded at 19°N. Longitudinally, dahlias registered a range that goes from 92 to 108°W (Fig. 4C), but its maximum richness it was located at 99°W with 23 species, while at 106°, 107° and 108° W were located two (Fig. 4B). The highest number of records was at 99°W.

Figure 4: Abundance of dahlia species by geographic criteria A) Elevation B) Longitude C) Latitude

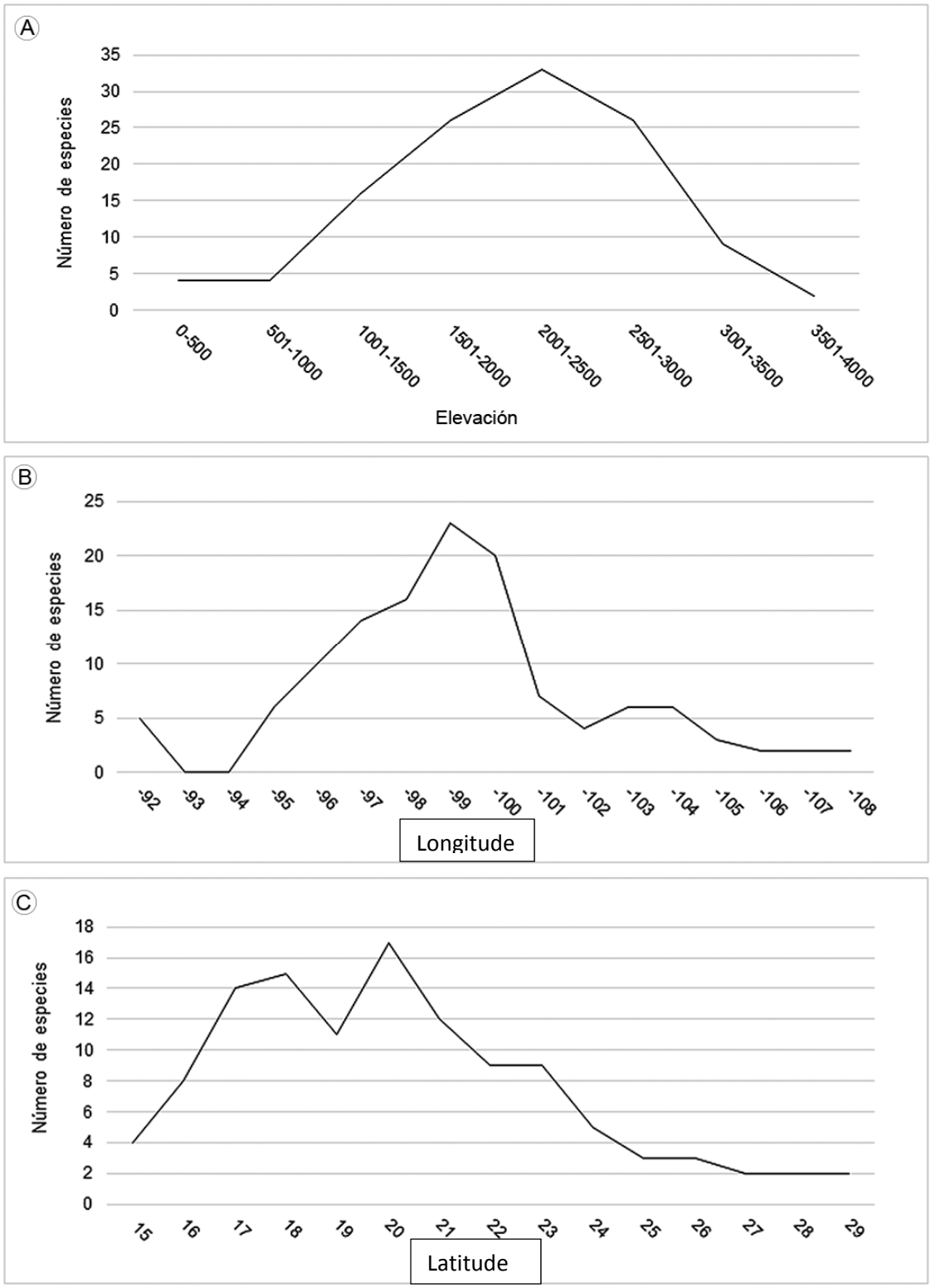
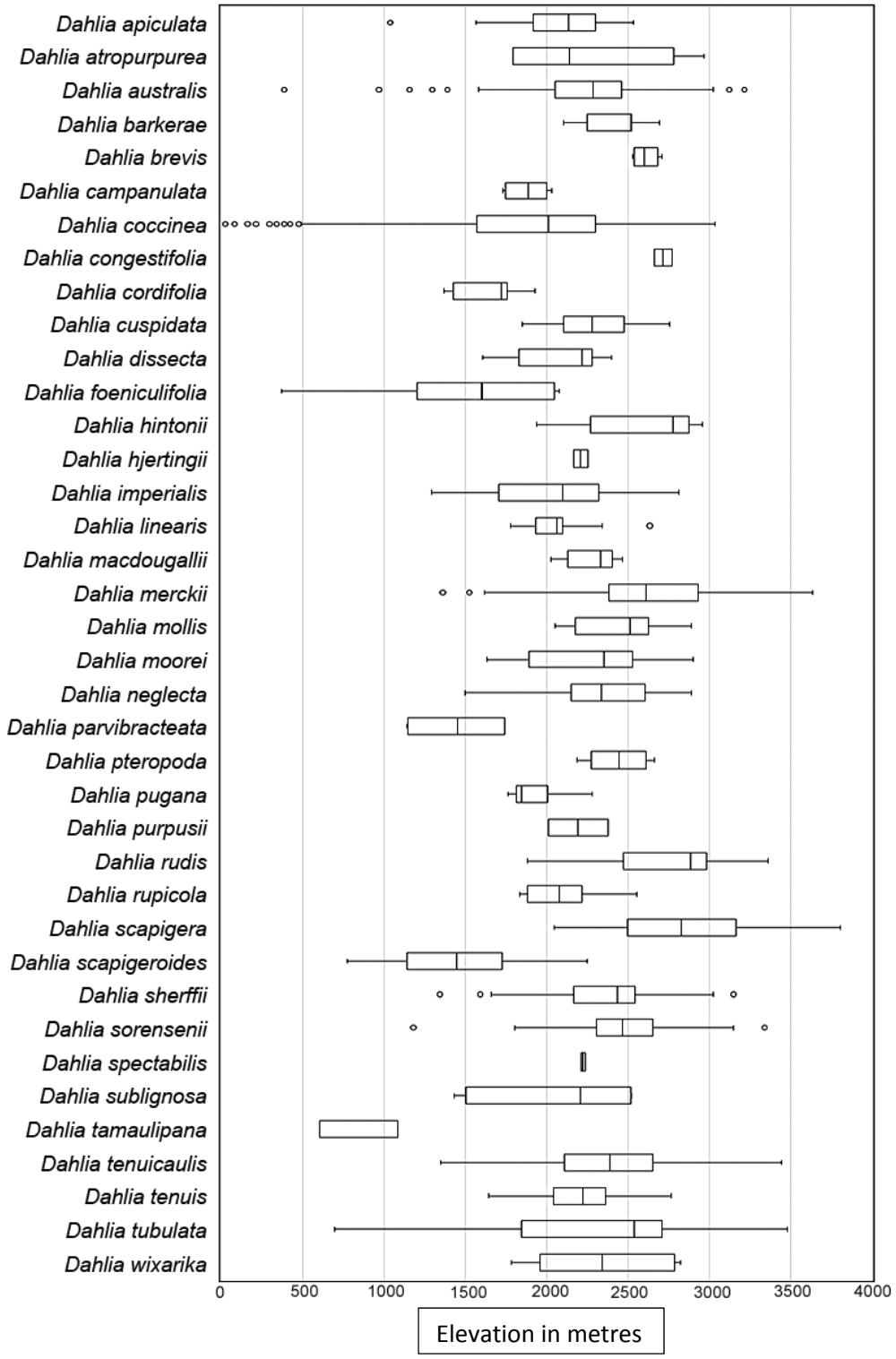


Figure 5: Range of species dahlias by elevation



Wealth by cells

Mexico was divided into 4,026 cells, of which 534 had at least one record, that is, 13.26% of the analyzed surface (Figs 6A-C). The number of species per cell varied from one to nine. We found three cells with nine species, one with eight, 12 with seven, 15 with six, 38 with five, 49 with four, 69 with three, 115 with two and 232 with one. To analyze the observations, 80 records were assigned to one cell, two others had 50 and 58 each (Fig. 6A). The best collection area was located in the center of the country, between the State of Mexico and Mexico City (Fig. 6B).

The wealth analysis showed two zones of high diversity. The first is formed by a cell that contains nine species in an approximate area of 1,089 km^2. It is located in the northeast of Querétaro, at the border with Guanajuato, between the Sierra Madre Oriental and the Chihuahuan Desert (Table 3, Fig. 6C). There are present Dahlia coccinea, D. cuspidata, D. dissecta, D. linearis, D. merckii, D. mollis, D. moorei, D. neglecta and D. scapigeroides (Table 3).

The second diversity zone includes two tables with nine species each, in an area of 2,178 km^2. It is located in the northwest of Oaxaca, near Puebla, between the Cuenca del Balsas, and the Sierra Madre del Sur. The nine localized species in the first table are D. apiculata, D. australis, D. campanulata, D. coccinea, D. imperialis, D. Macdougalli, D. merckii, D. pteropoda, and D. sorensenii. The second table included D. apiculata, D. australis, D. campanulata, D. coccinea, D. imperialis, D. merckii, D. pteropoda, D. sorensenii, and D. tenuicaulis (Table 3, Fig. 6C).

Dahlia coccinea occupied 256 cells, followed by D. merckii with 44 (Table 4). These data suggest its wide distribution in the country. Dahlia congestifolia, D. spectabilis and D. tamaulipana were located only in one cell (Table 4).

Figure 6 Map of observed locations for Dahlia cav. in squares of 33x33 km.

A) Abundance of species B) Abundance of observations C) Abundance of species and ANP locations

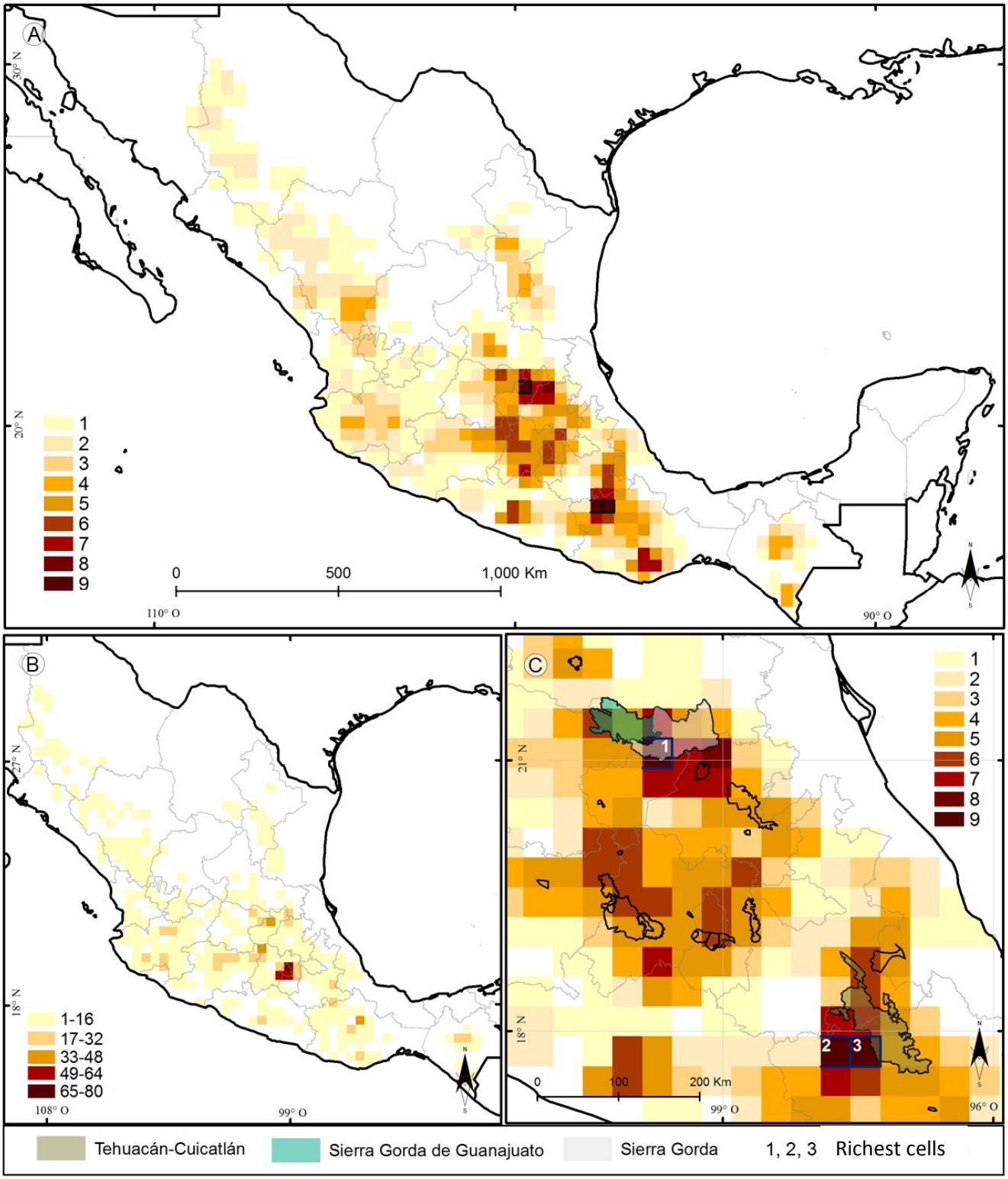


Table 3 Species wealth among the most diverse cells. Cell numbers correspond to those in Figure 6c.

Wealth Area	Cells	Number of Species	Species	State or City	Geographic Region
1	1	9	*D. coccinea*, *D. cuspidata*, *D. dissecta*, *D. linearis*, *D. merckii*, *D. mollis*, *D. moorei*, *D. neglecta*, *D. scapigeroides*	Querétaro (Cadereyta, Peñamiller, Pinal de Amoles, San Joaquín y Tolimán) y Guanajuato (Atarjea)	Sierra Madre Oriental & Chihuahuan Desert
	2	9	*D. apiculata*, *D. australis*, *D. campanulata*, *D. coccinea*, *D. imperialis*, *D. macdougallii*, *D. merckii*, *D. pteropoda*, *D. sorensenii*	Oaxaca (Asunción Cuyotepeji, Concepción Buenavista, Huajuapan de León, La Trinidad Vista Hermosa, San Andrés Dinicuiti, San Andrés Lagunas, San Antonio Acutla, San Bartolo Soyaltepec, San Cristóbal Suchixtlahuaca, San Francisco Teopan, San Jerónimo Silacayoapilla, San Juan Bautista Coixtlahuaca, San Juan Teposcolula, San Marcos Arteaga, San Mateo Tlapiltepec, San Pedro Nopala	Cuenca del Balsas & Sierra Madre del Sur
2	3	9	*D. apiculata*, *D. australis*, *D. campanulata*, *D. coccinea*, *D. merckii* *D. sorensenii*,	San Pedro Yucunama, Santa Magdalena Jicotlán, Santa María Camotlán Santa María Chachoápam. Santa María Nativitas. Santiago Cacaloxtepec, Santiago Huajolotitlán, Santiago Ihuitlán Santiago Tepetlapa, Santo Domingo Tonalá, Santo Domingo Tonaltepec; Santo Domingo Yodohino Teotongo, Tepelmeme, Tlacotepec Plumas, Villa de Chilapa de Díaz Villa de Tamazulápam Villa Tejúpam, Villa Tezoatlán y Zapotitlán Palmas) y Puebla (Chila)	

Table 4: Summary of the geographical distribution of Dahlia Cav. in Mexico. The grid size is 33 × 33 km. MaxD (km), maximum distance between two more distant points; EOO (km^2), extension of the area of occurrence of a taxon; AOO (km^2), occupation area of a taxon; CaR, Risky Category; CR, Critically Endangered; EN, Endangered; NT, Near Threatened; VU, Vulnerable; * Species present in an ANP

Species	Quantity	Number of cells	MaxD	EOO	AOO	CaR
*Dahlia apiculata**	27	10	180.3	13,446.9	108	EN
D. atropurpurea	5	4	407	24,039.8	20	EN
*Dahlia australis**	101	32	1026	184,200.8	356	EN
*Dahlia barkerae**	8	2	274	1871.3	28	EN
Dahlia brevis	10	5	89.6	1306	32	EN
D. campanulata	5	4	86.4	2046.8	20	EN
*Dahlia coccinea**	929	256	2235.9	1,142,724.5	3188	NT
D. congestifolia	2	1	0.3	0	8	CR
Dahlia cordifolia	8	2	31.3	233.7	24	EN
*Dahlia cuspidata**	12	5	136.3	2318.1	44	EN
*Dahlia dissecta**	15	9	543.4	31,560	56	EN
*D. foeniculifolia**	6	6	171.7	5449.8	24	EN
Dahlia hintonii	7	3	123.6	727.2	24	EN
Dahlia hjertingii	2	2	53.6	0	8	CR
*Dahlia imperialis**	46	17	1227.6	316,577	156	EN
*Dahlia linearis**	23	7	140.9	5687.9	76	EN
D. macdougallii	5	3	265.3	4832.3	20	EN

*Dahlia merckii**	190	44	937.3	182,532.1	624	VU
Dahlia mollis *	9	5	70	633.7	28	EN
Dahlia moorei *	16	5	105.9	1386.6	52	EN
Dahlia neglecta *	37	13	371.7	64,482.8	139	EN
D. parvibracteata	4	2	7.5	0.3	12	EN
Dahlia pteropoda *	5	4	312.2	6424.6	20	EN
Dahlia pugana *	16	6	366.3	25,666.9	48	EN
Dahlia purpusii	2	2	1.4	0	4	CR
Dahlia rudis *	43	13	376.7	29,374.5	140	EN
Dahlia rupicola	7	2	12.2	12.1	24	EN
*Dahlia scapigera**	54	21	546.1	69,820.9	184	EN
D. scapigeroides *	26	15	261.6	13,657.6	92	EN
Dahlia sherffii *	84	39	930.9	130,548.8	336	EN
*Dahlia sorensenii**	91	31	1361.6	335,708.7	308	EN
Dahlia spectabilis	2	1	1	0	4	CR
Dahlia sublignosa	5	3	64.2	602.2	20	EN
D. tamaulipana	3	1	3.2	0	8	CR
*Dahlia tenuicaulis**	141	32	993	229,358.3	452	EN
Dahlia tenuis	12	5	89.5	2567.8	44	EN
Dahlia tubulata *	17	12	319	29,095.4	60	EN
*Dahlia wixarika**	5	5	125.2	2464.5	20	EN

Wealth by ANP

Dahlia was found in 36 ANP (Table 5). Of 1,980 records analyzed, 435 are within a Biosphere Reserve, National Park, Natural Resources Protection Area or Flora and Fauna Protection Area. They were not found in Natural Monuments or Sanctuaries. The Sierra Gorda Biosphere Reserve in Querétaro was the richest with nine species (D. coccinea, D. cuspidata, D.dissecta, D. linearis, D. merckii, D. mollis, D. moorei, D. neglecta and D. scapigeroides), followed by Los Mármoles (Hidalgo), Sierra Gorda of Guanajuato and Tehuacán-Cuicatlán (Puebla-Oaxaca), with six species each. Most diverse cells coincided with Sierra Gorda, Sierra Gorda of Guanajuato and Tehuacán-Cuicatlán (Fig. 6C). D. coccinea grows in 25 ANP and D. merckii in 13. Thus, 23 species of dahlia are sheltered in ANP (Table 5).

Distribution area

In Mexico, the dahlia has a wide distribution. It is found in almost all states except Baja California, Baja California Sur, Campeche, Quintana Roo, Tabasco and Yucatán (Fig. 2). All species live in Mexico; 35 of them are endemic. Dahlia grows throughout the Mexican Transition Zone, extends towards the Cuenca del Balsas, the Pacific Coast, the Chihuahuan Desert, Tamaulipas and Veracruz. Dahlia coccinea and D. sherffii have the most northerly distribution along the Sierra Madre Occidental; D. tubulata is present in the Sierra Madre Oriental. The southern species are D. australis, D. imperialis and D. purpusii (see Fig. 7). Dahlia australis, D. imperialis and D. coccinea extend to Central America and Colombia.

Table 5 Distribution of dahlias in Federal Natural Protection Areas of Mexico

APFF: Áreas de Protección de Flora y Fauna; APRN: Áreas de Protección de Recursos Naturales; PN: Parque Nacional; RB: Reserva de la Biosfera.

Category	ANP/Number of species/Number of items	Species
RB	Barranca de Meztitlán/1/3	*D. scapigeroides*
PN	Benito Juárez/2/4	*D. australis*, *D. tenuicaulis*
PN	Cañón de Río Blanco/3/19	*D. australis*, *D. coccinea*, *D. merckii*
APRN	CADNR026/4/4	*D. coccinea*, *D. foeniculifolia*, *D. merckii*, *D. tubulata*
APRN	CADNR043/4/43	*D. coccinea*, *D. pugana*, *D. sherffii*, *D. wixarika*
PN	Cascada de Basaseachi/1/2	*D. coccinea*
APFyF	Corredor Biológico Chichinautzin/3/14	*D. coccinea*, *D. merckii*, *D. rudis*
PN	Cumbres de Monterrey/1/1	*D. coccinea*
PN	El Chico/1/3	*D. merckii*
PN	El Cimatario/1/1	*D. coccinea*
APFF	El Jabalí/1/8	*D. coccinea*
PN	El Tepozteco/5/18	*D. coccinea*, *D. merckii*, *D. rudis*, *D. scapigera*, *D. sorensenii*
RB	El Triunfo/1/1	*D. imperialis*
PN	Insurg. Miguel Hidalgo & Costilla/1/1	*D. sorensenii*
PN	Insurg. José María Morelos/2/9	*D. barkerae*, *D. coccinea*
PN	Iztaccihuatl-Popocatepetl/2/6	*D. merckii*, *D. sorensenii*
RB	La Michilía/2/3	*D. coccinea*, *D. sherffii*
APFF	La Primavera/2/8	*D. coccinea*, *D. pugana*
PN	Lagunas de Zempoala/3/22	*D. coccinea*, *D. merckii*, *D. rudis*
PN	Los Mármoles/6/20	*D. coccinea*, *D. cuspidata*, *D. dissecta*, *D. merckii*, *D. mollis*, *D. moorei*
RB	Mariposa Monarca/4/25	*D. coccinea*, *D. rudis*, *D. scapigera*, *D. sorensenii*
APFF	Nevado de Toluca/2/6	*D. rudis*, *D. scapigera*
APFF	Pico de Tancítaro/1/1	*D. scapigera*
APFF	Sierra de Álvarez/2/10	*D. coccinea*, *D. merckii*
RB	Sierra de Huautla/1/2	*D. coccinea*
RB	Sierra de Manantlán/2/48	*D. coccinea*, *D. tenuicaulis*
PN	Sierra de Órganos/1/1	*D. sherffii*
APFF	Sierra de Quila/1/4	*D. coccinea*
RB	Sierra Gorda/9/73	*D. coccinea, D. cuspidata, D. dissecta, D. linearis, D. merckii, D. mollis, D. moorei, D. neglecta, D. scapigeroides*
RB	Sierra Gorda de Guanajuato/6/16	*D. coccinea, D. cuspidata, D. linearis, D. merckii, D. mollis, D. scapigeroides*
RB	Tehuacán-Cuicatlán/6/32	*D. apiculata, D. australis, D. coccinea, D. imperialis, D. merckii, D. pteropoda*
APFF	Tutuaca/2/3	*D. coccinea, D. sherffii*
PN	Volcán Nevado de Colima/1/2	*D. tenuicaulis*
RB	Volcán Tacaná/1/2	*D. imperialis*
RB	Zicuirán-Infiernillo/1/2	*D. coccinea*
APRN	ZPFTC Cuencas de los Ríos Valle de Bravo, Malacatepec, Tilostoc & Temascaltepec/4/18	*D. coccinea, D. merckii, D. rudis, D. scapigera*

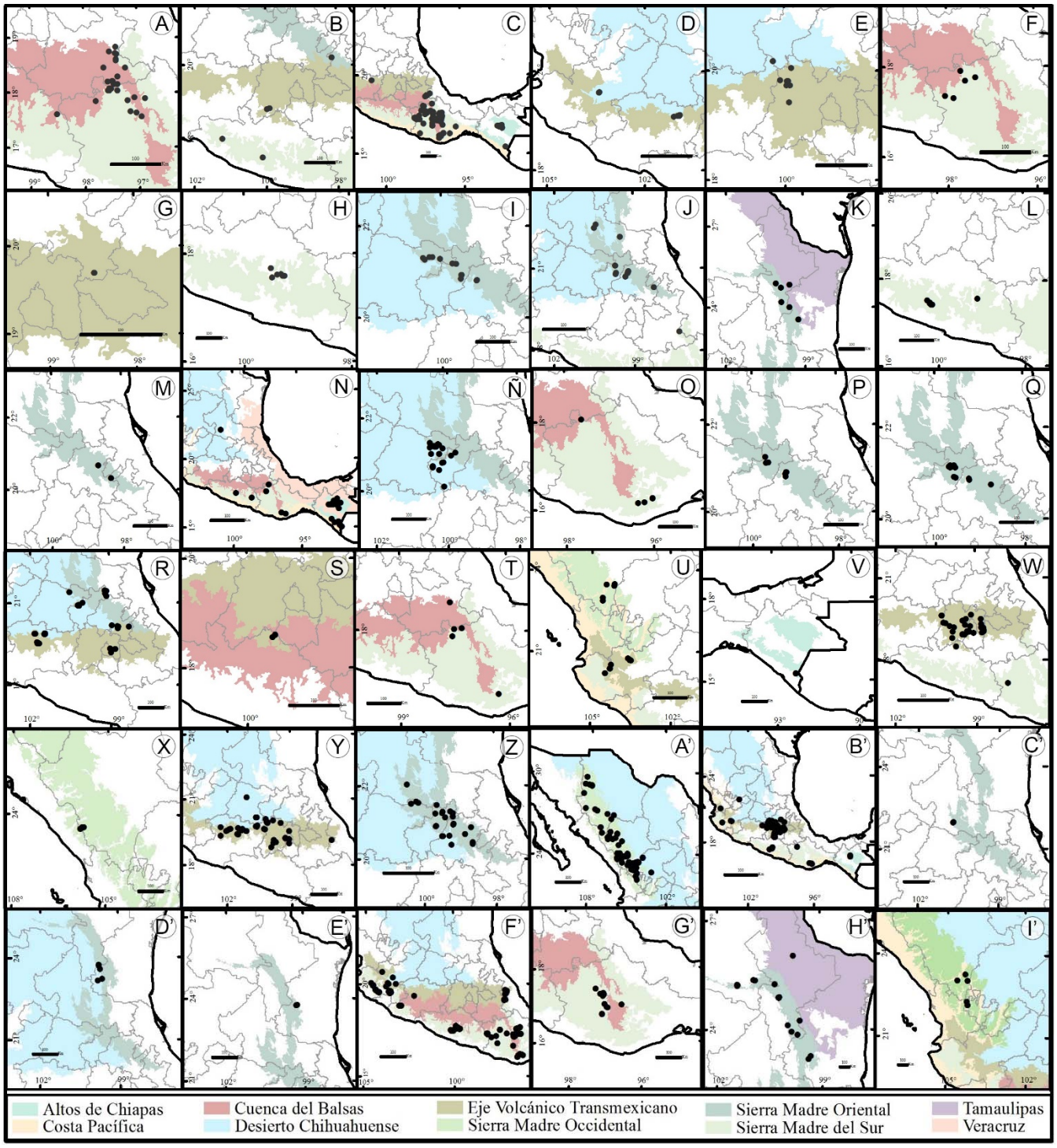
The numbers of collection by species was variable (Table 4, Figs 3,7). Dahlia coccinea was represented by 929 records, followed by D. merckii with 190 and D. tenuicaulis with 141. At the opposite end, D. congestifolia, D. hjertingii, D. purpusii and D. spectabilis are located with two records each. Dahlia coccinea and D. sorensenii had the greatest distance between two points, while D. congestifolia and D. spectabilis showed the lowest (Table 4). The EOO and AOO estimates revealed that the distribution of the Dahlia species is not uniform. The highest value of EOO was 1,142,724.5 km^2 for D. coccinea, while the lowest was presented by D. parvibracteata (0.3 km^2). The highest AOO value was 3,188 km^2 for D. coccinea and the lowest of 4 km^2 for D. purpusii and D. spectabilis. In general, the values of EOO were maintained above 20,000 km^2 in D. atropurpurea, D. australis, D. coccinea, D. dissecta, D. imperialis, D. merckii, D. neglecta, D. pugana, D. rudis, D. scapigera, D. sherffii, D. sorensenii, D. tenuicaulis, and D. tubulata. Values of 5,000 to 20,000 km^2 were observed in D. apiculata, D. foeniculifolia, D. linearis, D. pteropoda and D. scapigeroides. Dahlia barkerae, D. brevis, D. campanulata, D. cordifolia, D. cuspidata, D. hintonii, D. macdougallii, D. mollis, D. moorei, D. sublignosa, D. tenuis, and D. wixarika had EOO from 100 to 5,000 km^2. EOO under 100 km^2 were observed in D. parvibracteata and D. rupicola. D. EOO was not estimated for D. congestifolia, D. hjertingii, D. purpusii, D. spectabilis and D. tamaulipana, having only two records of each species. With the exception of D. coccinea, almost all species obtained values of AOO below 2,000 km^2. Dahlia merckii had AOO of 624 km^2, 31 species showed areas from 10 to 500 km^2. Dahlia congestifolia, D. hjertingii, D. purpusii, D. spectabilis, and D. tamaulipana resulted in values smaller than 10 km^2 (Table 4).

Dahlia coccinea showed the widest geographical distribution (Table 1, Fig. 3A) and is found in 26 states, in two regions, the Mexican Transition Zone, and in nine biogeographical provinces. 929 records were found, representing 47% of the data. Its elevation interval was the largest between 24 and 3,033 m. It thrives in the conifer and oak forest (527 records), tropical deciduous forest (190), xerophilous scrub (76), pasture (75), mesophilic mountain forest (27), tropical sub-deciduous forest (13), spiny forest (8), aquatic and underwater vegetation (8) and tropical evergreen forest (5).

State of conservation

According to the geographical distribution (criterion B) represented for the occupation area (AOO, B2 (a)), all dahlia species are at risk. Dahlia congestifolia, D. hjertingii, D. purpusii, D. spectabilis and D. Tamaulipana are categorized as Critically Endangered (CR, Table 4). Thirty-one species are considered endangered (EN), D. merckii is Vulnerable (VU) and D. coccinea Almost Endangered (NT). Oaxaca and Guerrero, the Sierra Madre Oriental, plus the coniferous and oak forests have the highest number of species in CR and EN. Finally, none of the species in CR is within an ANP, while 21 species in EN are.

Figure 7: Distribution maps for 36 dahlia species



***Dahlia* Cav.: A)** *D. apiculata*; **B)** *D. atropurpurea*; **C)** *D. australis*; **D)** *D. barkerae*; **E)** *D. brevis*; **F)** *D. campanulata:* **G)** *D. congestifolia*; **H)** *D. cordifolia*; **I)** *D. cuspidata*; **J)** *D. dissecta*; **K)** *D. foeniculifolia*; **L)** *D. hintonii*; **M)** *D. hjertingii*; **N)** *D. imperialis*; **Ñ)** *D. linearis*; **O)** *D. macdougallii*; **P)** *D. mollis*; **Q)** *D. moorei*; **R)** *D. neglecta*; **S)** *D. parvibracteata*; **T)** *D. pteropoda*; **U)** *D. pugana*; **V)** *D. purpusii*; **W)** *D. rudis*; **X)** *D. rupicola*; **Y)** *D. scapigera*; **Z)** *D. scapigeroides*; **A')** *D. sherffii*; **B')** *D. sorensenii*; **C')** *D. spectabilis;* **D')** *D. sublignosa*; **E')** *D. tamaulipana*; **F')** *D. tenuicaulis*; **G')** *D. tenuis.*; **H')** *D. tubulata*; **I')** *D. wixarika*.

Discussion

Database and georeferencing

Sørensen (1969) and Turner (2010) developed distribution maps of the dahlia species. However, no work had analyzed its geographical distribution and wealth using SIG. This work concentrates the information of the dahlia specimens deposited in 32 biological collections of Mexico and 38 foreign sources. The information contained in these collections is important, because it represents the basis for studies on the distribution of biodiversity (Powney & Isaac, 2015). Of the 1,980 records used in the analyses, 1,304 (61%) contain estimated latitude and longitude values. This reflects the recent use of GPS (Global Positioning System). In addition, the process of geo-referencing demands time and effort. To increase the accuracy it is necessary to evaluate all possible evidence - locality, elevation, type of soil and vegetation where the species grows. In some cases, knowing the collector routes is necessary and very useful (Willis et al., 2003).

Wealth of species and area of distribution

Although they are not the same environment, in Oaxaca and Hidalgo grow 12 dahlia species (Table 1). Oaxaca is the state with the greater floristic diversity of the country (Cevallos-Ferriz and Ramírez, 2004; García-Mendoza et al., 2004; Villaseñor, 2016). It has been cited for 266 families, 1946 genera and 10,229 species of vascular plants (Villaseñor, 2016). The family Asteraceae is an example of this diversity; Villaseñor et al. (2004) recorded the presence of 897 species grouped in 188 genres, a figure that offers the greatest degree of wealth in the state. Endemism is also important: Suárez- Mota and Villaseñor (2011) found that 133 species of Asteraceae are endemic to Oaxaca. Villaseñor et al. (2004) cite for the state D. apiculata, D. australis, D. coccinea, D. imperialis, D. macdougallii, D. merckii, D. pinnata, D. pteropoda, D. tenuicaulis and D. tenuis. In the present work are recorded D. campanulata, D. rudis and D. sorensenii. Dahlia campanulata was described by Saar et al. (2003b) as endemic to Oaxaca and previously has been cited by Castro-Castro et al. (2012). Dahlia pinnata was not included in the analysis to be cultivated. It is believed to be a hybrid between D. coccinea and D. sorensenii (Mera et al., 2008).

Based on floristic backgrounds, the abundance of dahlias in Hidalgo could be foreseen. In its territory grow 4,734 species of vascular plants, representing 20% of the species from Mexico (Villavicencio et al., 2002; Villaseñor, 2016). Luna-Vega et al. (2000) conducted an analysis of traces in the mountain mesophilic forest, with a base in 967 species of vascular plants integrated in 496 genera and 145 families. The Asteraceae family had the greatest number of species. The work of Ponce-Vargas et al. (2006) found that Asteraceae contains the largest number of genera and species in the mesophilic mountain forest of the municipality Lolotla. The results of the present study show the same tendency. Castro-Castro et al. (2012) mentioned 12 species of dahlia, but Mera al. (2008) cited 13. Castro-Castro et al. (2012) noted the presence of D. scapigera and omitted D. australis and D. rudis. In contrast, Mera et al. (2008) recognized the existence of D. australis and D. rudis but excluded D. scapigera. Our results do not support the presence of D. rudis or D. scapigera, although they confirm the existence of D. atro-purpurea. Errors in taxonomic determination explain the difference in the results.

The states of Aguascalientes, Colima, Sinaloa and Sonora only registered Dahlia coccinea (Table 1). Villaseñor (2016) reports the presence of D. rupicola in Sinaloa, D. sherffii in Sinaloa and Sonora,

D. sorensenii in Sonora and D. tenuicaulis in Colima. This work did not find records of these species in the mentioned states. In In these cases, it is necessary to check local herbaria and use potential distribution models to evaluate if that is a natural pattern, or if there is a bias due to the intensity of botanical exploration.

The greatest number of Dahlia section species grows in the Mexican Transition Zone. The region includes the biogeographical conditions associated with mountain ranges in Mexico. The Pseudo-dendron and Epiphytum sections have a similar distribution pattern. In contrast, the Dahlia section does not show a defined pattern. It is mainly in the Mexican Transition Zone, but also in the Nearctic and Neotropical regions. On the other hand, the Entemophyllon section groups species of habitats more arid that grow in the Nearctic region, in the extreme South of the Chihuahuan Desert, between the Sierra Madre Oriental and the Trans-Mexican Volcanic Axis. The zone includes the arid parts of the states of Guanajuato, Querétaro, and Hidalgo covered by xerophilous scrub, with patches of thorny forest, coniferous and oak forest.

Saar et al. (2003a) generated a phylogenetic hypothesis of dahlia, in which dahlia section Entemophyllon is the first divergent group. Thus, it could be inferred that dahlias began diversification by colonizing xerophilous ecosystems. However, its diversity is greater in temperate and cold environments of Mexico. The Sierra Madre del Sur concentrates the largest number of dahlia species. Its complex geological, physiographic history and climatic variation have favored biological diversity, since it is estimated that 30% of the biodiversity of Mexico (Santiago-Alvarado et al., 2016). Espinosa et al. (2016) recorded 6,467 species of angiosperms, Dahlia represents 0.3% of that diversity. About, Turner and Nesom (1998) reported the presence of 356 endemic species of Asteraceae within the Sierra Madre del Sur, 179 of them are part of the Heliantheae tribe where Dahlia was grouped.

In Mexico, wealth patterns have been analyzed in different groups of plants (Cruz-Cárdenas et al. 2013; Vargas-Amado et al., 2013; Munguía-Lino et al., 2015; Sosa and Loera, 2017; Anguiano-Constante et al., 2018). The results show that species abundance is concentrated in the Trans-Mexican Volcanic Axis. Dahlia has a different abundance pattern. The Sierra Madre del Sur hosts the greatest wealth, followed by the Sierra Madre Oriental (Table 2). The three regions belong to the Mexican Transition Zone.

Dahlia thrives in nine types of vegetation, although the greatest number of species is found in the coniferous and oak forest. This observation supports the Rzedowski's claim (1986), who found that Asteraceae is the best represented in those forests. In the oak forest, 15 to 20% of the genera are of Asteraceae, and at a species level there is a large amount of endemisms. The ecosystems associated with temperate climates contribute to Mexico's biological diversity. Its biogeographic history is associated with very old events that originated a great variety of species and environments (Sánchez et al., 2003). In contrast, eight records of Dahlia coincided with aquatic and underwater vegetation when finding points of occurrence of D. coccinea, D. merckii, D. neglecta, D. rudis and D. sorensenii in these areas. Dahlia is not a genus with species of aquatic habits. It may be associated with cliffs near waterfalls, at streams, or temporary flooding, but not having structures that allow them to grow in saturated places. The layer of potential vegetation used in the analysis (Rzedowski, 1990) represents an approximation of the distribution of vegetation types in Mexico.

Thirty-six dahlia species grow between 2,000 and 2,500 m elevation. Sørensen (1969) stated that the dahlia thrives between 1,500 and 4,300 m. Castro-Castro et al. (2012) mentioned the presence of Dahlia in a range of 1,500 to 3,700 m. Both papers registered that D. coccinea also grows close to sea level. The

data of Castro-Castro et al. (2012) are congruent with the results of this study, since D. coccinea has the widest elevation range (24 to 3,033 m) and D. scapigera grows at an elevation maximum - 3,808 m. No record was found above 4,000 m, as was stated by Sørensen (1969). In summary, most dahlia species thrive between 2,000 and 2,500 m, which represents an elevation range of 500 m. The latitude with the highest diversity of Dahlia is 19 °N. This strip coincides with the Trans-Mexican Volcanic Axis, while the distance with the highest number of species (99 ° W) agrees with the Sierra Madre Oriental, the eastern portion of the Trans-Mexican Volcanic Axis and the Sierra Madre del Sur.

In the analysis of wealth by grid, the cell with greatest diversity shelters nine species (Fig. 6A). Its zone is located in the northeast portion of the state of Querétaro, belongs to the Sierra Madre Oriental and is located within the Sierra Gorda. The area includes the Sierra Gorda and Sierra Gorda Biosphere of Guanajuato (CONANP, 2012). Hernández-Cerda and Carrasco-Anaya (2004) affirmed that the climatic diversity present in the Sierra Madre Oriental includes 99% of the climates of Mexico. The environments vary from very arid to warm-humid, and as a result there is a great biological richness. Dahlia is an example of it.

The types of vegetation in the Sierra Gorda are varied; there are coniferous and oak forest, tropical deciduous forest, tropical sub-deciduous forest, xerophilous scrub, mountain mesophyll forest and pasture (Arreguín-Sánchez and Fernández-Nava, 2004). In all recorded were dahlia species. In general Asteraceae houses 74 genera and 166 species. In a study on abundance of Asteraceae in El Bajío, Villaseñor and Ortiz (2012) proposed in Querétaro ten cells that represent priority areas for the protection of their resources, based on the presence of endemic species. The zone of high diversity of dahlias here matches three of the cells proposals and can be added to other jobs that support the protection of the Sierra Gorda.

The second diversity zone is subject to certain degree of protection. It comprises two cells located in the northwest of the state of Oaxaca. One is close to the reserve of the Tehuacán-Cuicatlán Biosphere; there grow nine dahlia species. Other works have obtained similar results. Villaseñor et al. (2005) estimated the wealth of species of the sub-families or tribes of Mutisieae, Senecioneae and Tageteae (Asteraceae). Its results show three sites of high diversity in Oaxaca; two of them coincide with the cells richest found in this work. These results and those of Suárez-Mota et al. (2018) provide information for justify the incorporation of new areas to the reserve of the Tehuacán-Cuicatlán Biosphere. Finally, 23 species of Dahlia are present in 36 ANP, and zones of abundance are within or very close to three biosphere reserves.

State of conservation

The AOO and EOO are useful for assessing the risk category of the species according to criterion B of the Red List (IUCN, 2012; Maes et al., 2015). In the category EN they are the taxa that have AOO less than 500 km^2 (Bachman et al. al., 2011; IUCN, 2012). Once again, Dahlia is a genus native to Mexico. It is the national flower and represents a symbol of floriculture. Consequently, this demands a follow-up for its protection. Dahlia scapigera and D. tenuicaulis are on the list of the Official Mexican Standard NOM-059-SEMARNAT-2010 (SEMARNAT, 2010), with the category: "subject to special protection ". Following the criteria of the IUCN (2012), D. congestifolia, D. hjertingii, D. purpusii, D. spectabilis and D. tamaulipana are in CR. In these cases, it is suggested that you evaluate your protection category in accordance with the Standard Official Mexican NOM-059-SEMARNAT-2010 (SEMARNAT, 2010) to include it in the IUCN Red List (IUCN, 2012).

Contribution of authors

MCO, GVA and AR conceived and designed the study. GML and MCO performed the analyses. MCO, ACC, AR, GML and MH contributed to the acquisition of data. MCO, GML and AR performed the data interpretation and wrote the manuscript. All the authors contributed to the discussion, review and approval of the final manuscript.

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