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Conservation

Threatened status of neglected and underutilised *Jatropha* (Euphorbiaceae) species endemic to Mexico

Estado de amenaza para las especies menos conocidas o poco utilizadas de Jatropha *(Euphorbiaceae) endémicas de México*

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Abstract

Jatropha curcas is the best known species from the genus, an oilseed crop used for biodiesel production. It deserves attention as more species show similar oil content, phytochemical properties, or as a genetic resource in *J. curcas* breeding programs. The closest species to *J. curcas* show restricted distributions and are included in the IUCN Red List. In this study, the geographical distribution and conservation status was determined for 24 species in of the subgenus *Curcas* endemic to the Neotropic, except *J. curcas*, 20 are endemic to Mexico. Nine hundred and ninety-four herbarium specimens were used to assess their status by applying the IUCN Red List Categories and Criteria. The analysis shows that 11 species are threatened: 2 are critically endangered, 6 endangered and 3 vulnerable. Additionally, 5 species were assessed as nearly threatened, 4 as least concern and 2 as data deficient. Except for *J. contrerasii* and J. *websteri*, the threatened species have a narrow altitude range (< 500 m). With a growing emphasis on the exploitation of neglected and under-utilised species such as *Jatropha*, it is important to establish systematic collections for the assessment of threat status and to develop management strategies for their conservation.

Keywords: Conservation; Distribution patterns; Herbarium specimens; IUCN Red List

Resumen

Jatropha curcas es la especie mejor conocida del género por ser un cultivo oleaginoso utilizado para la producción de biodiesel, merece atención porque varias especies muestran un contenido similar de aceite, propiedades fotoquímicas

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o como un recurso genético en los programas de reproducción de *J. curcas*. Especies cercanas a *J. curcas* tienen una distribución restringida y están incluidas en la Lista Roja de la UICN. En este estudio, se determinaron la distribución geográfica y el estado de conservación de 24 especies del subgénero *Curcas*, todas endémicas del neotrópico; excepto *J. curcas*, 20 son endémicas de México. Se revisaron 994 especímenes de herbario para evaluar su estado de conservación aplicando las categorías y criterios de la Lista Roja de la UICN. El análisis muestra que 11 especies están amenazadas: 2 en peligro crítico, 6 en peligro y 3 vulnerables. Otras 5 resultaron como casi amenazadas, 4 con preocupación mínima y 2 como deficientes en datos. Las especies amenazadas tienen un rango de altitud estrecho (< 500 m), excepto *J. contrerasii* y *J. websteri*. Con el énfasis creciente en la explotación de especies poco conocidas y subutilizadas, como *Jatropha*, es importante establecer colecciones sistemáticas para evaluar el estado de amenaza y desarrollar estrategias de manejo para su conservación.

Palabras clave: Conservación; Patrones de distribución; Especímenes de herbario; Lista roja de la UICN

Introduction

The value of plant biofuels as alternatives to diesel fuel continues to be researched and hotly debated (Koh et al., 2009). Whilst biofuels can partially replace diminishing fossil fuel reserves, with fewer net greenhouse gas emissions environmental concerns persist, including risks to biodiversity. Due to its ability to grow on poor quality soils and little requirement for crop management, *Jatropha curcas* has been promoted as a sustainable source of oilseeds for biodiesel (Bahadur et al., 2013; Carels et al., 2012; Dagar et al., 2006; Divakara et al., 2010). The seed oil content is 28 - 42% of dry weight (Heller 1996; Kaushik et al., 2007) and seed yield ranges from 0.4 - 12 t- ha^{-1} y^{-1} after 5 years of growth, depending on planting density, genetic and agronomical practise (Openshaw, 2000). Furthermore, the environmental impact of growing *J. curcas* is lower than that of palm oil as long as no natural ecosystems are removed for the establishment of plantations (Stone, 2007). As the main form of *J. curcas* in cultivation across the world produces non-edible seeds, contaminated by a phorbol ester, agricultural production of the species ought not to compete with edible oils in the food market. However, there are traditional non-toxic varieties grown in Mexico which are now at significant risk of displacement by the available commercial seed lots (Vera-Castillo et al., 2014).

Jatropha curcas is one of approximately 187 species which comprise the genus *Jatropha* (Euphorbiaceae) in the tribe Jatropheae of subfamily Crotonoideae (WCSP, 2013). *J. curcas* (section *Curcas*) is thought to be the ancestor to the genus and shares several anatomical features with members of both the *Jatropha* and *Curcas* subgenera (Dehgan & Schutzman, 1994). The closest related species to *J. curcas* are in the subgenus *Curcas*, section *Curcas* and section *Platyphyllae*, which was recently divided into 3 subsections *Platyphyllae*, *Fremontioides*, and *Gaumeri* (Dehgan, 2012). Several species in the subsection *Fremontioides* are from a more recent origin and some species share characteristics with those in subgenus *Jatropha*.

The genus is distributed worldwide throughout the sub-tropical regions, primarily in the Neotropics. Mexico is believed to be the centre of origin, with 25% of species in the genus found in the country, of which 80% are endemic (Dehgan, 2012; WCSP, 2013). A few species extend their geographical range into Guatemala, Nicaragua and Costa Rica in Central America. *Jatropha* species in Mexico are mainly distributed in seasonally dry tropically forest (Fresnedo-Ramírez & Orozco-Ramírez, 2012), a biome that is highly threatened by deforestation (Trejo & Dirzo, 2000). Consequently, there is a very real threat that several species in the genus, mainly the endemics with narrow distributions, might be under threat of genetic erosion and, ultimately, extinction. This is further exacerbated by the unregulated exploitation of many species due to their medicinal properties and nutritional qualities (Devappa et al., 2010a, b; Dutra et al., 1996).

The socio-economic potential of several neglected and under-utilised species related to *Jatropha curcas* is well documented. Several species show high seed oil content: 20 - 27% for *J. glandulifera* Roxb., c. 28% for *J. gossypiifolia* L., and 32 - 48% for *J. multifida* L. (Banerji et al., 1985); 39% for *J. excise* Griseb., 36% for *J. macrocarpa* Griseb. and 36% for *J. hieronymi* Kuntze (Aranda-Rickert et al., 2011). Closely related species to *J. curcas* in Mexico show other socio-economic potential: *J. platyphylla* is cultivated for medicinal purposes in Michoacán, is grown as an ornamental and the seeds are consumed by descendants of the Lacapaxa tribe in Sinaloa (Makkar et al., 2011); *J. moranii* is cultivated as an ornamental (Dehgan, 2012); *J. gaumeri* was used by the Mayan's of Tixpeual and Tixcacaltuyub, Yucatán, in traditional medicine, handicraft, soap production and for its toxitity (Rico-Gray et al., 1991), and the root and latex also have medicinal value properties (Ankli et al., 2002; Dehgan, 2012). However, despite the large economic importance and management of *J. curcas*, little is known about the conservation status of closely related species in the genus *Jatropha* subgenus *Curcas*. This makes an assessment of their conservation status particularly important.

A recognised method to evaluate the extinction risk of a species is the IUCN Red List Categories and Criteria (IUCN, 2012), in combination with environmental information (Rodrigues et al., 2006). Where little information is available from field studies, herbarium specimens can be used as essential sources of information to clarify the distribution and conservation status of a plant species (Guerra-García et al., 2008; Willis et al., 2003). The IUCN Red List requires application of "best available evidence" to perform assessments and often herbarium specimens are the only source of information available. However, in some cases, species are only known from the type specimens in herbaria or from very few herbarium collections and conservation assessments are carried out when only limited herbarium specimens are available (Randrianasolo et al., 2002; Versieux & Wendt, 2007; Zizka et al., 2009).

The aims of this study were to apply the IUCN Red List Categories and Criteria to: *1)* assess the geographical extent of the 22 species of the genus *Jatropha* subgenus *Curcas* section *Curcas* and section *Platyphyllae*; both sections are all Mexican species and 2 more species that are distributed in adjoining regions of Central America; *2)* produce a Red List conservation assessment for each of the species, and *3)* recommend conservation strategies for the protection of the threatened species, in order to ensure that these neglected and underutilised species are available for the future.

Materials and methods

The geographical extent and conservation status were assessed for 22 species of *Jatropha* distributed in Mexico and 2 species found in adjacent countries (Table 1).

Herbarium specimens were the primary sources of information used in this study. Specimens deposited in the herbaria of the Natural History Museum Copenhagen (C), the Natural History British Museum (BM), the Royal Botanic Gardens, Kew (K) and Izta herbarium (IZTA) in Facultad de Estudios Superiores-Iztacala (FESI) at the Universidad Nacional Autónoma de México (UNAM) [acronyms based on Index Herbarium (Thiers, 2013)] were studied and databased. Additional on-line data sources were used, including the TROPICOS database (http://www.tropicos.org/) and the National Biodiversity Information System (SNIB) from the National Commission of Biodiversity in Mexico (Conabio) (http://www.conabio.gob.mx/remib/doctos/remib_esp.html). As well as existing published data by Dehgan (2012), were used to complete our datasets where applicable. Duplicate collections and records with incomplete information, e.g., historical collections with scant information, or with little geographical information not possible to georeferenced were excluded. This resulted in the identification of 994 specimens, across 24 species of the subgenus *Curcas*, for analysis. Exsiccatae data was put together into a master database with the following

Table 1

Studied species of *Jatropha* subgenus *Curcas* with respective taxonomic sections. The species are arranged following the taxonomy of Dehgan (2012).

1) Section *Curcas*	*J. pseudocurcas* Müll. Arg.
J. curcas L.**	*J. rufescens* Brandegee
J. malacophylla Standl.	*J. contrerasii* J. Jiménez Ram., & Mart. Gord.
J. mcvaughii Dehgan & G. L. Webster	*J. andrieuxii* Müll. Arg.
2) Section *Platyphyllae* subsection *Platyphyllae*	3) Section *Platyphyllae* subsection *Fremontioides*
J. bartlettii Wilbur	*J. fremontioides* Standl.
J. websteri J. Jiménez Ram.	*J. stevensii* G. L. Webster*
J. chamelensis Pérez-Jim.	*J. krusei* J. Jiménez Ram., & Mart. Gord.
J. pereziae J. Jiménez Ram.	*J. bullockii* E. J. Lott
J. stephani J. Jiménez Ram., & Mart. Gord.	*J. tlalcozotitlanensis* J. Jiménez Ram.
J. tehuantepecana J. Jiménez Ram., & A. Campos Vilb.	*J. jaimejimenezii* V. W. Steinm.
J. platyphylla Müll. Arg.	*J. moranii* Dehgan & G. L. Webster
J. alamanii Müll. Arg.	4) Section *Platyphyllae* subsection *Gaumeri*
J. costaricensis G. L. Webster & Poveda*	*J. gaumeri* Greenm.*

The recognised taxa are based on the monograph of Dehgan (2012). However, it is worth to note that there is a nomenclature issue with between *Jatropha platyphylla* and *J. peltata*, which is discussed by Dehgan (2012: 173). *Present or **planted in some of the neighboring countries to Mexico; Belize, Guatemala, Nicaragua, El Salvador, Honduras and/or Costa Rica.

fields: family, genus, species, collector, and collector number, year of collection, institution code, determinator, country, county, locality, latitude, longitude, altitude and remarks on occurrence. The locality position for records without latitude and longitude were geo-referenced based on collector descriptions using Google-Earth (http://earth.google.co.uk), Global Gazetteer Version 2.2 (http://www.fallingrain.com) or the digital map of Instituto Nacional de Estadística, Geografía e Informática (INEGI) http://www3.inegi.org.mx/sistemas/mapa/visualizador/Default.aspx. All data points were uploaded into Google Earth and altitude was estimated for records without this information and species distribution maps based on locality positions were completed using the online tool SimpleMappr (http://simplemappr.net).

The habitats were defined according to the Conabio eco-regions classification system (Challenger & Soberón, 2008). These data were obtained from the "Ecoregiones terrestres de México" vector data set at a scale of 1:250000 (INEGI et al., 2016). To show the habitat use, a layer of "land use and vegetation" at a scale of 1:250000 was obtained from Conabio (Conabio, 1999). Two comparator species growing outside of Mexico were analysed according to the terrestrial eco-region classified by WWF (WWF, 2013) and a layer was obtained from WorldMap (Lewis, 2011).

Species habitats were under numerous vegetation subtypes, herein, these were considered as: evergreen forest (including low, medium and high dry evergreen forest and evergreen thorny forest), semi-deciduous forest (including low, medium or high dry semi-deciduous forest) or dry deciduous forest (including low, medium and high dry deciduous forest and dry deciduous thorny forest); and species present in subtypes of vegetation within temperate mountain forest were assigned to temperate forest (including coniferous, *Quercus* or mixed forests) (Rzedowski, 1978).

Conservation assessments for 24 species in section *Curcas* and section *Platyphylla* in subgenus *Curcas* in the genus *Jatropha* are presented according to the IUCN Red List Categories and Criteria v 3.1 (IUCN, 2012). The species were assigned as critically endangered (CR), endangered (EN), vulnerable (VU), near threatened (NT), least concern (LC) and data deficient (DD) based on the type of data and the knowledge of the species (Table 3, Figs. 1, 2), including delimiting the risk status based on the area of geographical range (criteria B; Table 2) or the very small size of a restricted population (criteria D; Table 2).

The extent of occurrence (EOO) and the area of occupancy (AOO) were automatically generated by uploading the dataset with latitudes and longitudes into the online tool GeoCAT (http://geocat.kew.org/). The EOO was calculated as the area within a minimum convex polygon (MCP) derived from the species occurrence points, and the AOO is sum of occupied cells (based on point occurrence data) multiplied by the cell size at the

Table 2
IUCN Red List Criteria B and D used for delimiting threat status (IUCN, 2012).

Criteria B. Geographic range in the form of either B1 extent of occurrence (EOO) and/or area of occupancy (AOO)			
(Threatened categories)	Critically Endangered	Endangered	Vulnerable
B1. EOO	< 100 km^2	< 5,000 km^2	< 20,000 km^2
B2. AOO	< 10 km^2	< 500 km^2	< 2,000 km^2
And at least 2 of the following 3 conditions:			
(a) Severely fragmented or number of locations	= 1	≤ 5	≤ 10
(b) Continuing decline observed, estimated, inferred or projected in any of: (i) EOO; (ii) AOO; (iii) area, extent and/or quality of habitat; (iv) number of locations or subpopulations; (v) number of mature individuals			
(c) Extreme fluctuations in any of: (i) EOO; (ii) AOO; (iii) number of locations or subpopulations; (iv) number of mature individuals			
Criteria D. Very small or restricted population			
(Threatened categories)	Critically Endangered	Endangered	Vulnerable
Number of mature individuals	< 50	< 250	D1. < 1,000
D2. *Only applies to the VU category* Restricted area of occupancy or number of locations with a plausible future threat that could drive the taxon to CR or EX in very short time			D2. typically: AOO < 20 km^2 or number of locations ≤ 5

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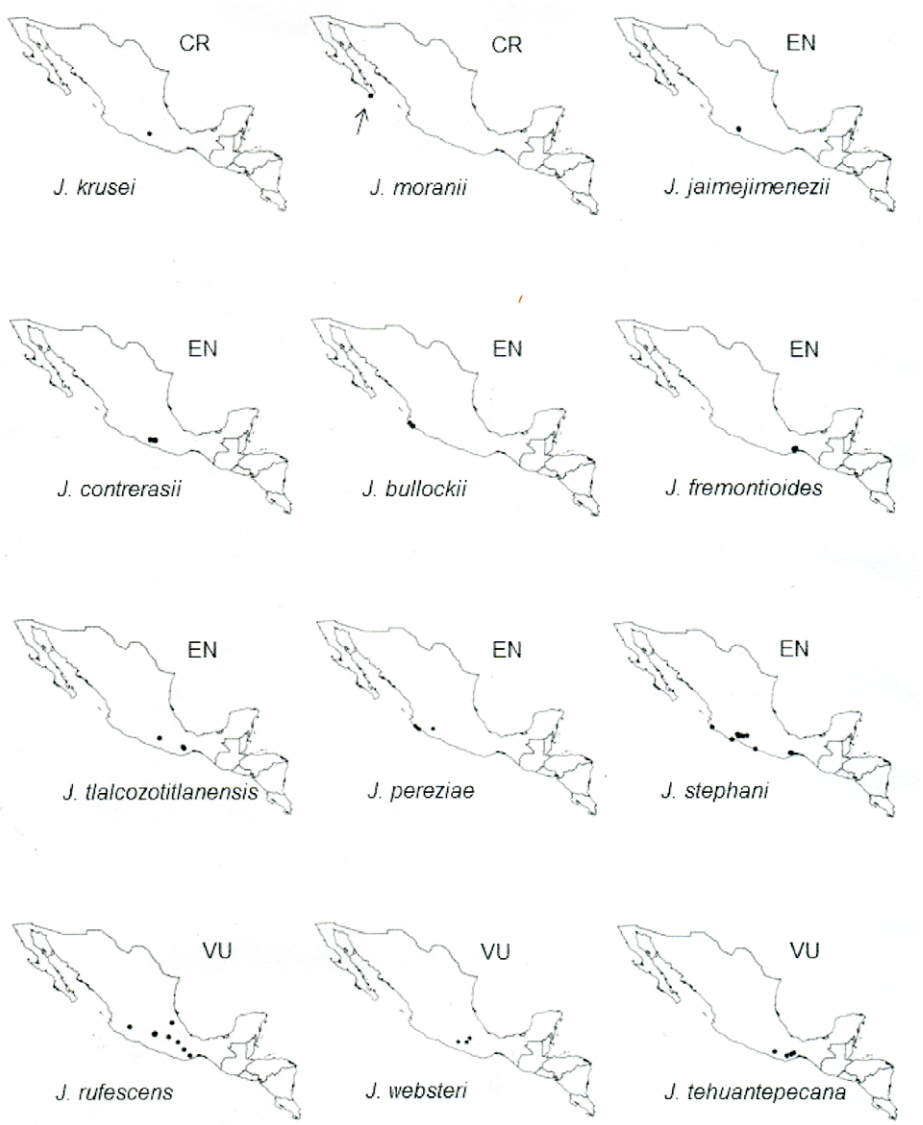

Figure 1. Distribution maps of *Jatropha* species presented from the most to least threatened; CR: *J. krusei*, and *J. moranii*; EN: *J. jaimejimenezii*, *J. contrerasii*, *J. bullockii, J. fremontioides*, *J. tlalcozotitlanensis*, *J. pereziae* and *J. stephani*; VU: *J. rufescens*, *J. websteri* and *J. tehuantepecana*.

reference scale of 2 × 2 km (4 km^2), as recommended by the IUCN (IUCN, 2012).

Additional criteria used to evaluate the threat category of the IUCN Red List Criteria included: *a)* protected areas: it was assumed that if 50% or more of the AOO is in a national protected area (NPA), the risk status was reduced to a less threatened category, though we are aware that some NPA are not properly managed. When 30% or less is in a NPA, status was left unmodified (Rodríguez et al., 2011). National protected areas include 176 biosphere reserves, national parks, natural monuments, areas for the protection of natural resources, flora and fauna, or sanctuaries, identified by Mexico´s Commission for Protected Natural Areas (Conanp, 2012) in Mexico and the World Data Base of Protected Areas (IUCN & UNEP, 2013); *b)* priority areas for conservation: if 50% or more of the AOO is within a priority area for conservation, the risk status was changed to a more threatened category. When 30% or less is within a priority area for conservation, status was left unmodified. Priority areas for conservation were taken into account because these are areas of high biodiversity potentially at risk from anthropogenic pressures as formally delimited by Mexico´s National Commission for the Knowledge and

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Use of Biodiversity, as (Conabio, 2004); *c)* elevation range: broad elevation range is considered an indicator for high plasticity in a species and it will therefore be found in more habitats than a species with a narrow elevation range (Holdridge, 1947). An elevation of 1,000 m or more is considered 'broad' and 500 m or less, is assumed to be 'narrow' (Rodríguez et al., 2011). Broad elevation distributions were considered to reassess the risk status to a less threatened category, this allows species to settle on a broader range, however, this does not exclude environmental threats such as over-collecting, change of land use, etc. As per narrow elevation distributions these were considered not to modify the threat status.

Results

The total dataset included 994 specimens representing 24 *Jatropha* species; however, 459 specimens alone represent *J. curcas*. Thirteen of the species were evaluated from more than 15 specimens, giving relative confidence level for the correct assessment based on only AOO and EOO (Rivers et al., 2011).

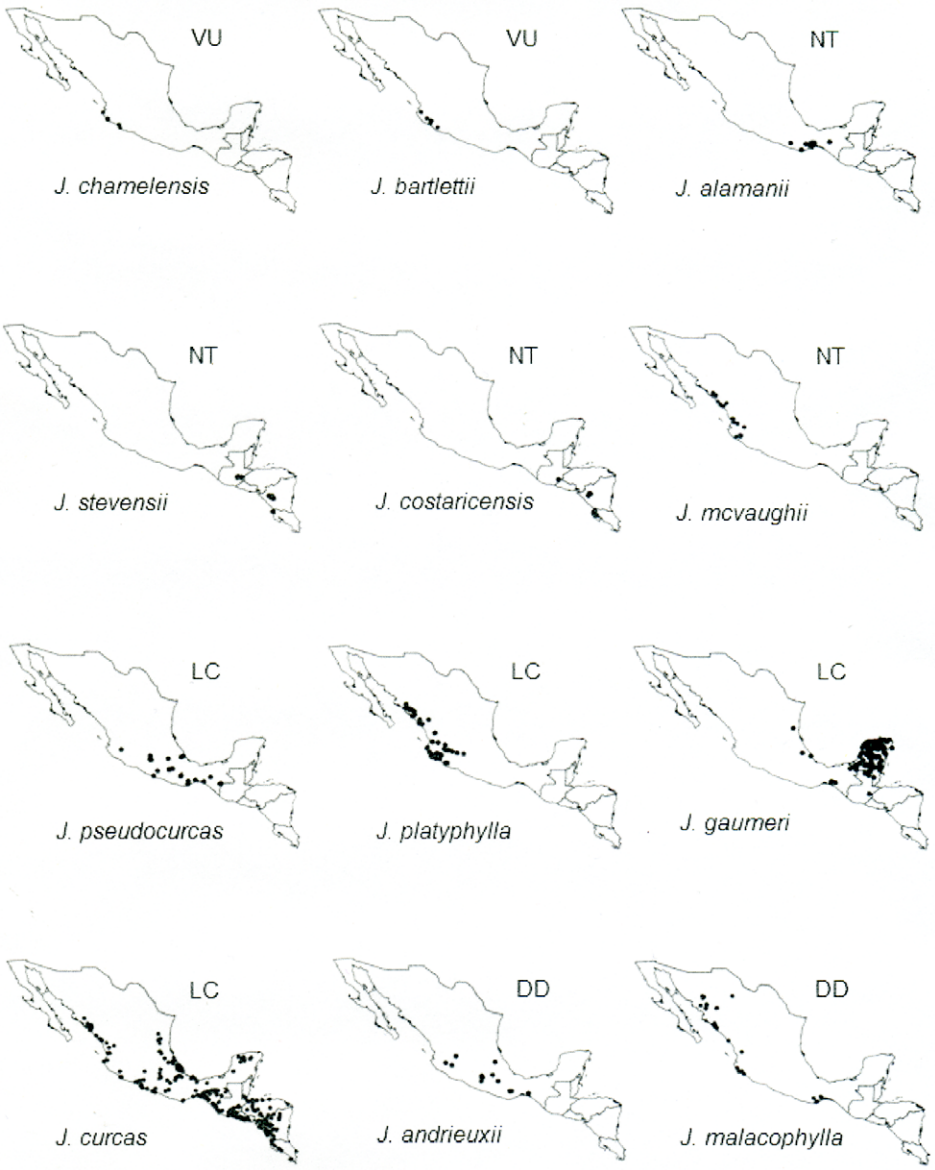

Figure 2. Distribution maps of *Jatropha* species presented from the most to least threatened. VU: *J. chamelensis* and *bartlettii*; NT: *J. alamanii, J. stevensii, J. costaricensis* and *J. mcvaughii;* LC: *J. pseudocurcas, J. platyphylla, J. gaumeri* and *J. curcas;* and DD: *J. andrieuxii* and *J. malacophylla.*

The geographic distribution of *Jatropha* species in section *Curcas* subsection *Curcas* and subsection *Platyphyllae* shows very diverse patterns, from wide to narrow ranges (Figs. 1, 2). Some species are restricted to an area of less than 20 km^2 while others are distributed over > 20,000 km^2. With the exception of *J. curcas*, all of the 24 species studied in sections *Curcas* and *Platyphyllae* are endemic to the Neotropics. However, 20 of those are endemic to Mexico and 6 species, each occurs in only 1 state (Baja California Sur, Guerrero, Jalisco, Michoacán and 2 in Oaxaca) (Table 3). For the Mexican endemics, their distributions extended south of 28°30' N in West Mexico and south of 23°45' N in East Mexico, and north of 15°40' N, 91°55' W. The majority of the species are distributed on coastal plains and hills along the Pacific Slope of Mexico, with a high concentration of species (8) in the southern part of the Isthmus of Tehuantepec. Some species are distributed in central parts of Mexico in the Balsas Basin and in the Trans- Volcanic Belt system, and few species occur in the coastal plains of the Gulf of Mexico. Only 2 species, *J. gaumeri* and *J. curcas* are distributed in the Yucatán Peninsula, and 1 species, *J. moranii* is present in the coastal plains of Los Cabos in Baja California Sur. Two of the studied species (*J. costaricensis* and *J. stevensii*) do not occur in Mexico; these have similar distribution patterns in the central highlands of Guatemala, Nicaragua and Costa Rica.

The majority of the species (22 of 24) studied occur in dry deciduous forest and half of the species also grow in temperate forest (Table 3). The species assessed as threatened are restricted to dry deciduous forest, except *Jatropha tlalcozotitlanensis* which also grows in temperate forest; and *J. contrerasii* is restricted to temperate forest. The species have altitudinal ranges extending from sea level to 2,650 m, with approximately half of the species found at sea level and the others adapted to higher altitudes above 600 m. The majority of the threatened species have a narrow altitude range (< 500 m), except *J. contrerasii* and *J. websteri*.

Based on the IUCN Red List Categories and Criteria ver. 3.1 (IUCN, 2012), 13 out of the 24 species are assessed as threatened: *Jatropha krusei and J. moranii* as CR; *J. jaimejimenezii*, *J. contrerasii*, *J. bullockii*, *J. fremontioides*, *J. tlalcozotitlanensis*, *J. pereziae*, and *J. stephani* as EN and *J. bartlettii*, *J. websteri*, *J. tehuantepecana*, and *J. chamelensis* as VU. Four species *J. mcvaughii*, *J. alamanii*, *J. costaricensis*, and *J. stevensii* are assessed as NT, 4 species as LC and 2 species as DD (Table 3). Six of 7 species in section *Platyphyllae* subsection *Fremontioides* are assessed as threatened for which 2 species are CR and 4 are EN.

Table 3

List of conservation status assessed *Jatropha* species with location in protected areas (letters) and priority areas for conservation (numbers) in parentheses. The distribution in Mexico and Central America (level 4 codes of TDWG), number of records and subpopulations, the extent of occurrence and area of occupation with a grid of 2 x 2 km, estimated altitude range and types of habitat.

Species	Distribution	Records (subpopula–tions)	Extent of occurrence (EOO) km^2	Area of occupancy (AOO) km^2	Altitude (m)	Habitat	Conservation status
J. krusei	MXS-GR	1	NA	4	560	Depression with dry deciduous forest.	CR B1ab(i,ii,iii,iv) + B2ab(i,ii,iii,iv)
J. moranii	MXN-BS	3 (2)	NA	8	100 - 130	Coastal plains and low hills with dry deciduous forest.	CR B1ab(i,ii,iii,iv) + B2ab(i,ii,iii,iv)
J. jaimejimenezii [i]	MXS-MI	4 (2)	8	12	240 - 360	Depression with dry deciduous forest.	EN B1ab(iii) + B2ab(iii)
J. contrerasii	MXS-GR-MI	3 (3)	409	12	1,100 - 1,900	Mountains and hills with temperate forest.	EN B1ab(iii) + B2ab(iii)
J. bullockii [c, q & 7]	MXS-JA	27 (6)	417	48	0 - 275	Coastal plains and hills with dry deciduous forest.	EN B1ab(i, ii,iii,iv) + B2ab(i,ii,iii,iv)

Table 3
Continued

Species	Distribution	Records (subpopulations)	Extent of occurrence (EOO) km^2	Area of occupancy (AOO) km^2	Altitude (m)	Habitat	Conservation status
J. fremontioides (23, 24)	MXS-OA	6 (5)	482	20	0 - 300	Coastal plains, canyon and hills with dry deciduous forest.	EN B1ab(i,iii) + B2ab(i,iii)
J. tlalcozotitlanensis	MXS-GR-OA	5 (3)	2,959	12	700 - 975	Canyon, hills and depressions with dry deciduous forest and mountains with temperate forest.	EN B1ab(i,ii,iii,iv) + B2ab(i,ii,iii,iv)
J. pereziae (c)	MXS-CL-JA-MI	8 (5)	4,448	20	0 - 60 (320)	Coastal plains, hills and depression with dry deciduous forest.	EN B1ab(iii)+2ab(iii)
J. rufescens (f & 15)	MXC-ME-PU, MXS-JA-OA	10 (9)	185,810	36	1,100 - 2,000	Mountains and hills with temperate forests. Depressions and valleys with dry deciduous forest.	VU B1ab(i,ii,iii,iv) + B2ab(i,ii,iii,iv)
J. websteri (20)	MXC-PU, MXS-GR	5 (5)	5,845	20	600 - 1,400	Depression with dry deciduous forest.	VU B ab(i,ii,iii,iv) + B2 ab(i,ii,iii,iv); D2
J. tehuantepecana (23, 24)	MXS-OA	4 (4)	6,975	16	1,650 - 1,900	Mountains with dry deciduous forest.	VU B1ab(i,ii,iii,iv) + B2ab(i,ii,iii,iv); D2
J. chamelensis (c, r & 7, 17)	MXS-CL-JA-MI	24 (8)	7,142	48	0 - 180 (440)	Coastal plains and hills with dry deciduous forest.	VU B1ab(i,iii) +B2ab(i,iii)
J. bartlettii (d & 17)	MXS-CL-JA-MI	10 (10)	4,792	36	500 - 2,200	Mountains with temperate forests. Few in hills and coastal plains in dry deciduous forest.	VU B2ab(iii)
J. alamanii (R & 23, 24)	MXT-CI-OA	26 (19)	23,271	88	0 - 870	Coastal plains, hills and canyons with dry deciduous forest or evergreen forest.	NT
J. stevensii (x)	COS, GUA, NIC	23 (10)	50,141	56	75 - 440	Central highland in dry deciduous forest and Xeric shrubland in Motagua valley.	NT
J. costaricensis (x, z)	COS, GUA, NIC	17 (11)	52,461	52	0 - 700	Mountains and central highland in dry deciduous forest and temperate forest.	NT
J. mcvaughii (d, R & 4, 7, 8)	MXN-SI, MXS-JA-NA	23 (20)	65,070	84	0 - 1,750	Hills and coastal plains in dry deciduous forest. Mountains or foothills with temperate forests.	NT
J. pseudocurcas (s & 23)	MXC-ME-PU, MXG-VC, MXS-GR-JA-MI-OA, MXT-CI	24 (>20)	279,565	92	0 - 2,100	Depressions,valleys, coastal plains and hills with dry deciduous forest. Mountains and hills with temperate forests. Coastal plains and low hills with humid evergreen forest.	LC

Table 3
Continued

Species	Distribution	Records (subpopulations)	Extent of occurrence (EOO) km^2	Area of occupancy (AOO) km^2	Altitude (m)	Habitat	Conservation status
J. platyphylla (c & 4-8, 16, 17)	MXE-DU, MXN-SI, MXS-CL-JA-MI-NA	65 (>20)	187,272	232	0 - 2,650	Coastal plains and hills with dry deciduous forest and desert shrubs, mountains or hills with temperate forests and arid to semiarid hills and plains with desert scrubs and grassland.	LC
J. gaumeri (a, b, g, I, p, t, u, v, D, E, F & 13, 31-35)	MXC-PU, MXE-TA, MXG-VU, MXT-CA-CI-QU-YU, BLZ, GUA	149 (>20)	645,072	480	0 - 300 (750, 1600)	Plains and hills with humid semi-deciduous forest, humid evergreen forest and dry deciduous forest. Mountains and hills with temperate forests	LC
J. curcas (b, e, f, h, k, l, o, x, y, A-C, G-Q, S & 5,6 9-14, 17, 19, 21, 22, 25-30)	*MXC-MO-PU, MXE-TA, MXG-VC, MXN-SI, MXS-CL-GR-JA-MI-NA-OA, MXT-CA-CI-YU, BLZ, COS, ELS, GUA, HON, NIC	459 (>20)	2,112,735	1,244	0 - 2,300	Hills and plains with dry to humid deciduous forest and in mountains with temperate forest.	LC
J. stephani (j & 7, 18, 24)	MXS-GR-JA-MI-OX	19 (14)	89,727	52	30 - 400	Depression, coastal plains, hills, canyons and mountains with dry deciduous forest.	EN B2ab(iii)
J. andrieuxii (b, n & 20, 21)	MXC-PU, MXS-JA-GR-OA	20 (14)	204,592	60	500 - 2,000	Depression, canyons, mountains, coastal plains and hills with dry deciduous forest. Mountains and hills with temperate forests. Arid to semiarid hills and plains with desert scrubs and grassland. Coastal plains and hills with humid evergreen forest.	DD
J. malacophylla(c, m & 1-3, 7, 23, 24)	MXE-CU, MXN-SI-SO, MXS-CL-JA-NA-OA	57 (>20)	773,875	156	0 - 2000	Coastal plains, canyons and hills with dry deciduous forest. Few in mountains or foothills and plains with temperate forests.	DD

*Regional distribution: Mexico Federal protected - biosphere reserves: Calakmul (a), La Sepultura (b), Chamela-Cuixmala (c), Sierra de Manantlán (d), Sierra de Huautla (e), Tehuacán-Cuicatlán (f), Sian Ka'an (g), Los Tuxtlas (h), Río Lagartos (i), Zicuiran-Infiernillo (j); - national parks: El Veladero (k); - national monument: Yaxchilán (l); - areas of natural resources: Cuenca Alimentadora del Distrito de Riego 043 (m), Cuenca Hidrográfica del Río Necaxa (n); - areas of flora and fauna:

Cobio Chichinautzin (o), Yum Balam (p); - sanctuary: Islas de la Bahía de Chamela (q) (CONANP, 2012). Mexican states protected areas: Zona de Uso Comun en Cerro Bandera de la Sierra Tolistoque (r), Sierra de Nanchititla (s), Kabah (t), Balam-Ku (u). Belize national protected forest reserve: Mountain Pine Ridges (v). Costa Rica national protected - national park: Santa Rosa (x); - forest reserve: Golfo Dulce (y); - wetland: Río Cañas (z). El Salvador national protected - national park: El Imposible y Balsamero (A); - natural area: Parque Walter Tilo Deininger (B); - protected area: Santa Rita (C). Guatemala national protected - national park: Mirador - Río Azul (D), Tikal (E); - biotope: Naachtún - Dos Lagunas (F). Honduras national protected wildlife reserve: Laguna de Caratasca (G). Nicaragua national protected - biosphere reserve: Zona de Amortiguamiento, Bosawas (H); - national park: Volcán Masaya (I), Archipiélago de Zapatera (J); - nature reserve: Cerro Kilambe (K), Zona de Amortiguamiento, Tisey Estanzuela (L), Zona de Amortiguamiento, C. Apante (M), Complejo Volcánico San Cristobal Casitas (N); - natural resource: Miraflor/ Moropotente (O). International protected areas: El Cielo (P), Xiriualtique-Jiquilisco (Q), Marismas Nacionales (R), Zone de conservation de Guanacaste (S) (IUCN & UNEP, 2013).

Priority areas for conservation: Sierra Alta Tarahumara-Barrancas (1), Sierra Alamos-El Cuchujaqui (2), San Javier-Tepoca (3), Río Presidio (4), Pueblo Nuevo (5), Cuenca del río Jesús María (6), Chamela-Cabo Corrientes (7), Manantlán-Volcán de Colima (8), El Cielo (9), Sierra Gorda-río Moctezuma (10), Bosques Mesófilos de la Sierra Madre Oriental (11), Encinares tropicales de la planicie costera Veracruzana (12), Cuetzalan (13), Ajusco-Chichinautzin (14), Nevado de Toluca (15), Cerro Viejo-Sierras de Chapala (16), Sierra de Coalcomán (17), Infiernillo (18), Sierra Madre del Sur de Guerrero (19), Cañón del Zopilote (20), Sierras de Taxco-Huautla (21), Valle de Tehuacán-Cuicatlán (22), Sierra sur y costa de Oaxaca (23), Sierras del norte de Oaxaca-Mixe (24), Sierra de los Tuxtlas-Laguna del Ostión (25), Selva Zoque-La Sepultura (26), El Triunfo-La Encrucijada-Palo Blanco (27), El Momón-Montebello (28), Lacandona (29), Bosques mesófilos de los Altos de Chiapas (30), Dzilam-Río Lagartos-Yum Balam (31), Río Hondo (32), Zonas forestales de Quintana Roo (33), Sur del Punto Put (34), Silvituc-Calakmul (35) (Arriaga et al., 2000).

Abbreviations for geographical distribution according to Brummitt (2001): MXC, Mexico Central -DF, México Distrito Federal; -ME, México State; -PU, Puebla; MXE, Mexico Northeast -CU, Chihuahua; -DU, Durango; -GU, Guanajuato; -TA, Tamaulipas; MXB, Mexico Gulf -VC, Veracruz; MXN, Mexico Northwest -BC, Baja California; -BC Baja CaliforniaSur; -SI, Sinaloa; -SO, Sonora; MXS, Mexico Southwest -CL, Colima; -GR, Guerrero; -JA, Jalisco; -MI, Michoacán; -NA, Nayarit; -OA, Oaxaca; MXT, Mexico Southeast -CA, Campeche; -CI, Chiapas; -QR, Quintana Roo; -TB, Tabasco; -YU, Yucatán; BLZ, Belize; COS, Costa Rica; ELS, El Salvador; GUA, Guatemala; HON, Honduras; NIC, Nicaragua.

Section *Platyphyllae* subsection *Platyphyllae* comprises the most species in section *Platyphyllae* and they are assessed as EN (3 species), VU (5), NT (2), LC (2) and DD (1). The species in section *Curcas* are assessed as NT, LC and DD, and the 1 species in section *Platyphyllae* subsection *Gaumeri* is assessed as LC (Tables 1, 3). A review of the degree of protection for the 11 threatened species reveals that 7 have no subpopulations within protected areas. In addition, 5 species occur in priority areas for conservation which currently have no management or implemented legislation (see Materials and methods additional criteria for the protected and priority areas for conservation).

Discussion

Herbarium specimens are an essential source of information to demonstrate the distribution and conservation status of a plant species when field data is limited (Brummitt et al., 2008; Guerra-García et al., 2008). However, diversity studies based on herbarium specimens can be biased due to uneven collection intensity, particularly oversampling in areas of high species richness and in easily accessible areas (MacDougall et al., 1998). In this study, this was the case of the high density of collections from within and in close proximity to the well managed biosphere reserve of Chamela-Cuixmala [managed by the National Autonomous University of Mexico (UNAM)] in the Chamela Bay region of Jalisco. Bias was also present in the distribution of *Jatropha curcas*, with collection gaps in inaccessible areas along the coast. Gaps in the distribution contribute to the assessment of 2 species as DD (Fig. 2). About half of the threatened species assessed in this study are represented by less than 10 records could undermine confidence. However, a study by Rivers et al. (2011) showed that species with as few as 3 specimens can be used to classify the threat status correctly, and the IUCN Red List guidelines state assessments can be made for species only known from 1 locality (IUCN Standards and Petition Subcommittee, 2013). There are other studies assessing species threat status according to the IUCN Red List that also used few herbarium specimens, such as Randrianasolo (2002) comparing older and recent collections for 16 species of Anacardiaceae genera in Madagascar where 19 evaluations of the threat status were based on less than 10 specimens; Versieux & Wendt (2007) studying the diversity and distribution of 283 Bromeliaceae species in Brazil and the threat status of more than 200 species were based on less than 10 specimens and 50 of those species were only represented by 1 specimen; and Zizka (2009) evaluating 27 Bromeliaceae species from Chile and 10 of the species were represented by less than 10 specimens. There is a risk of extrapolating conclusion to small datasets, nonetheless, these evaluations are better than nothing, and waiting until more herbarium collection are available, to avoid species disappearing without not knowing where are present. Currently for new species descriptions a conservation assessment is suggested or requested, sometimes using 4-5 collections, evaluations are suggested such as for *Opuntia delafuentiana* Martínez-González, Luna-Vega, Gallegos-Vázquez & García-Sandoval (2015), *Dahlia rupicola* P.D. Sørensen (2018), *Cestrum chiangi* Mont.-Castro (2018). It is not only the geography data, it is also the nature and characteristics of the species, all features are potential data to be used, for example as is discussed below.

Bias can be reduced when considered additional criteria such as habitat and level of protected areas (see Materials and methods), considering species existence outside common habitats and combining field surveys with herbarium materials in regional herbaria. By collating information from herbarium specimens with such additional criteria (Table 3), the conservation assessment of 24 species of *Jatropha* subgenus *Curcas* section *Curcas* and section *Platyphyllae* from Mexico and Central America are presented.

The Pacific coast of in Mexico is dominated by dry deciduous forest. These forests are considered as an important biogeographical area harbouring many endemic species and a high species richness (Gentry, 1995; Lott & Atkinson, 2006). This corresponds well in the case of *Jatropha* species, except *J. contrerasii* which grows in temperate pine forest. However, the distribution of the species varies from coastal plains, depressions, hills and mountains.

The present analysis of the geographic distribution of *Jatropha* species showed extended distribution into areas not previously reported by Dehgan (2012); for example, *J. websteri* present in Guerrero; *J. contrerasii*, *J. pereziae*, and *J. chamelensis* in Michoacán; and *J. bartlettii* recorded in Colima and Michoacán. *Jatropha alamanii* was recorded (Cabrera *9263*, MO, MEXU) in Quintana Roo and included in the distribution reported by Dehgan (2012). However, the collection point was potted far away, as outlier in the EOO polygon and therefore we studied this collection in detail. The investigation revealed it was not *J. alamanii* as earlier reported (verified by Jimenez, per.com., 2013) and it is now determined as *J. gaumeri* (verified by Casas, per.com., 2014). New records were also identified for *J. stevensii* in Costa Rica and Guatemala; *J. costaricensis* in Guatemala and Nicaragua; and *J. gaumeri* in Puebla, Veracruz and Chiapas.

All of 11 *Jatropha* species, assessed as threatened, according to the IUCN Red List Categories and Criteria v 3.1 (IUCN, 2012) (Table 3), are endemic to Mexico. The major threats are declining habitat quality due to changes of land use for livestock, plantations, expansion of infrastructure to accommodate human population growth,

logging and tourism (Arriaga et al., 2000; Trejo & Dirzo, 2000; Wilson, 2008). Eight of the 11 threatened species also have a narrow altitude range, indicating specialised growth habitats (Holdridge, 1947). All species evaluated as threatened, except *J. contrerasii* and *J. tlalcozotitlanensis*, are restricted to dry deciduous forest to which a major threat is decline in area and quality (Trejo & Dirzo, 2000).

Two species were evaluated as CR: *Jatropha krusei* and *J. moranii*. The first is known from only 1 herbarium specimen collected in 1969 and has never been recorded since, even though the area it occurs in, the hills of Tepehuaje in Guerrero is a well surveyed area with many endemic species. The species grows in dry deciduous forest which is under threat from deforestation (Trejo & Dirzo, 2000) and this area is a newly defined priority area for conservation of Mexican dry forest (Ceballos et al., 2010). Furthermore, the hills of Tepehuaje are in the Papagayo River hydrologic region priority area for conservation, which is threatened by urban expansion, increase in crop and livestock production, and the over-exploitation and pollution of water resources (Arriaga et al., 2002). *J. moranii* is known from 3 herbarium specimens and is endemic to Los Cabos in Baja California Sur. This area is one of Mexico's most popular touristic areas with large and growing transnational touristic companies (López-López et al., 2006), suggesting a major threat and the possible extinction of the wild populations of the species. Furthermore, this species is being cultivated as a natural bonsai tree (Dehgan, 2012) and the wild population is considered to be critically endangered.

Five species were evaluated as EN: *Jatropha jaimejimenezii*, *J. contrerasii*, *J. bullockii*, *J. fremontioides*, and *J. tlalcozotitlanensis*. *J. jaimejimenezii* is known from 4 herbarium collections and is endemic to the biosphere region Zicuiran-Infiernillo in Michoacán. Although *J. jaimejimenezii* is distributed in a protected area, it grows next to water resources and close to agricultural farmland which represents a potential threat to habitat quality loss (Conanp, 2012). Furthermore, the species is specialized to grow in a narrow altitude range which is considered to limit its survival to environmental changes. *J. contrerasii*, is known from less than 5 herbarium specimens, the habitat is severely fragmented and the species is dioecious. For insect pollinated species such as *Jatropha* (Neves & Viana, 2011; Reddi & Reddi, 1983; Vaknin, 2012), a combination of dioecy and severe habitat fragmentation might affect plant-pollinator interactions (Aguilar et al., 2006; Bawa, 1980; Kremen et al., 2007). *J. bullockii* is endemic to the coast of Jalisco and 70% of its AOO are in the protected biosphere reserve of Chamela - Cuixmala and the Islas de la Bahía de Chamela sanctuary. However, subpopulations outside of the protected areas are threatened by habitat loss (30% of the coastal forest at Jalisco has been lost in the last 2 decades) and several species in this area are considered endangered (Arriaga et al., 2000). Previous IUCN Red List assessments reported this species as EN in 1997 and VU D2 in 1998 (World Conservation Monitoring Centre, 1998a). This evaluation reports *J. bullockii* with a higher threat status than reported here and therefore the assessment needs to be published at the IUCN Red List (IUCN) website. *J. fremontioides* is endemic to the south of the Isthmus of Tehuantepec in Oaxaca. The species is only known from 6 herbarium specimens, half of which were collected close to villages and roads. Two out of 5 subpopulations grow in priority areas for conservation which have currently no management legislation and these areas are threatened by increasing population and tourism. Furthermore, a change in land use to livestock, coffee plantations and logging is also occurring, resulting in a fragmented landscape (Arriaga et al., 2000). The population of *J. tlalcozotitlanensis* had an AOO of only 12 km^2, it is severely fragmented and the habitat is at risk of decline (Trejo & Dirzo, 2000).

Three species were assessed as VU: *Jatropha websteri*, *J. tehuantepecana*, and *J. chamelensis*. *J. chamelensis* is distributed in Jalisco, Colima and Michoacán close to the Pacific coast and are threatened by increasing tourism (Wilson, 2008). These species are dioecious and grow in fragmented habitats, as the forests of Jalisco have declined in extent due to agricultural activities and human population expansion (Arriaga et al., 2000). *J. chamelensis* has almost half of the subpopulations in the protected areas of the Chamela-Cuixmala biosphere reserve and the sanctuary Islas de la Bahía de Chamela. However, the remaining subpopulations are in priority areas for conservation and these areas are threatened by deforestation (Arriaga et al., 2000). Previous IUCN Red List assessments of *J. chamelensis* reported the species as EN in 1997 and VU D2 in 1998 (World Conservation Monitoring Centre, 1998b). These assessments were carried out more than 15 years ago and must be re-evaluated and published at the Red List (IUCN) website. Most herbarium specimens of *J. websteri* are collected in agricultural landscapes close to settlements and water resources, and 1 subpopulation is in the priority area for conservation Cañón del Zopilote, an area threatened by grazing, extraction of firewood and seasonal agriculture (Arriaga et al., 2000). *J. tehuantepecana* is known from less than 5 herbarium specimens, has severely fragmented habitats and is dioecious. It has 2 subpopulations in priority areas for conservation, Sierra Sur and Costa de Oaxaca and Sierras del Norte de Oaxaca-Mixe, which are threatened by a change in land use to livestock, coffee plantations and logging, producing a severely fragmented landscape (Arriaga et al., 2000).

Moreover, climate change plays a fundamental effect not just on presence or absence of pollinators, other

physical environment interactions, such as producing CO2 carbon emissions caused by burning fossils; if biofuels, like that derived from Jatropha, are specifically conceived of as a way to reduce emissions of the anthropogenic greenhouse gases that cause climate change, this will help reduction on the carbon footprint.

The conservation assessments for *Jatropha* species in Mexico indicate an urgent need to implement conservation actions, at both the "ex situ" and "in situ levels". Our current work, linking botanical institutions in Mexico, Denmark and the UK, has enabled the collection of seeds of 10 species from the Mexican states of Oaxaca and Puebla and their storage at the gene bank of Chapingo Autonomous University (CAU). In addition, this work contributed to 23 seed accessions of wild *Jatropha ssp.*, corresponding to 14 of 48 wild Mexican species, now in storage at CAU. All species belong to the subgenus *Curcas* and are endemic to Mexico, except *J. curcas*. Seeds of 4 of the species have been added and conserved in the FESI UNAM seed bank; duplicates were sent to Kew's Millennium Seed Bank. In total, 5 of the Kew collections are from subgenus *Curcas (J. curcas*, *J. cinerea*, *J. dioica*, *J. rzedowskii*, and *J. neopauciflora*). Furthermore, neglected and underutilised species, including *Jatropha* species, are being propagated in local villages with local communities, as part of Kew's Project MGU-the Useful Plants Project, which is independent of this study. For at least 2 reasons, further field studies are essential. Firstly, it is important to conduct ground-truthing to confirm the existence of older specimens and for species with low specimen numbers, such as *J. moranii* and *J. krusei* which were last collected in 1969. The establishment of field surveys in areas with similar vegetation and soil to the current occupancy is a fundamental component of this. Secondly, it is difficult to make large seed collections as *Jatropha* species often only appear as single trees or as a few individuals at each locality. Consequently, a large scale conservation programme is required to adequately collect and conserve the seeds of this genus.

In conclusion, *Jatropha* species most closely related to *J. curcas* have both narrow and wide geographical ranges with the majority of species distributed in the dry deciduous forest of the Pacific Coast of Mexico, which is declining in extension and habitat quality. Several of the species are restricted to small areas and as a consequence, 10 of the 24 species assessed are herein evaluated as threatened according to the IUCN Red List Categories and Criteria (IUCN, 2012). With a growing emphasis on the exploitation of neglected and under-utilized species such as *Jatropha*, it is important to establish systematic collections for assessment of threat status and to develop management strategies for their conservation. Summing up, it is well known that plants are able to reduce the amount of carbon dioxide in the atmosphere and realized O_2, hence decreasing global warming. Moreover, biofuels, when grown from plants, can thus offset their CO_2 emissions because they take up the gas during growth that is produced when the fuel is burned, therefore *Jatropha* species are worthwhile to conserve because they are a source for biofuels. As stated "To encourage research, development and national integration of advanced technologies for generating renewable, clean energy such as tidal, solar, hydrogen, and biofuel energy sources, among others" by Semarnat-INECC (2016).

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