Phytotaxa 670 (4): 191–202
https://www.mapress.com/pt/

Article

ISSN 1179-3155 (print edition)
PHYTOTAXA
ISSN 1179-3163 (online edition)

https://doi.org/10.11646/phytotaxa.670.4.1

Quercus purhepecha (Fagaceae), a new species of shrub oak endemic to the state of Michoacán, Mexico

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Abstract

Within the genus *Quercus* there are species with a shrubby habit that have been little studied worldwide. In Mexico, several shrub species within section *Quercus* are taxonomically highly problematic. These include eight named taxa that share traits such as abaxially tomentose leaves and growth of stems from one or multiple rhizomes, and there is evidence of additional undescribed species. Here, *Quercus purhepecha* is described and illustrated as a new tomentose shrubby white oak species, with a very restricted distribution within the Cuitzeo basin in the Trans-Mexican Volcanic Belt (TMVB), Michoacán state, Mexico. This new species is morphologically compared with *Q. frutex*, *Q. microphylla* and *Q. repanda*, which are similar taxa also distributed in the TMVB. In addition, a potential distribution model of *Q. purhepecha* for the Cuitzeo basin is presented.

Key words: endemic species, shrubby oaks, white oaks

Introduction

The genus *Quercus* Linnaeus (1753: 994) has recently been subdivided into two subgenera and eight sections (Denk *et al.* 2017) within which section *Quercus* (white oaks) has the widest distribution, being present in the Americas, Asia, and Europe. This section is particularly diverse in Mexico and Central America, with phylogenomic evidence suggesting recent and accelerated speciation processes in these regions (Hipp *et al.* 2020). Such diversification occurred along environmental gradients and involved variation in growth form (i.e. from large trees to shrub forms). Interestingly, the shrubby habit, which is apparently a derived character and has arisen independently several times in different oak lineages (Hipp *et al.* 2018) is particularly prevalent in the white oak section, with 39 species.

The number of shrubby oak species in Mexico remains uncertain, mainly due to the morphological gradation among some species and to the little attention that they have received (Sabás-Rosales *et al.* 2017, Valencia-A. 2021). De Luna-Bonilla *et al*. (2024) conducted extensive sampling, morphological characterization and modeling of the potential distribution of some species in section *Quercus* from northern and central Mexico characterized by a strictly

Accepted by Marie-Stéphanie Samain: 18 Oct. 2024; published: 5 Nov. 2024

shrubby habit and leaves with variably tomentose undersides, finding at least three taxa with these characteristics over the Trans-Mexican Volcanic Belt (TMVB); specifically *Quercus frutex* Trelease (1924: 82), *Quercus microphylla* Née (1801: 264) and *Quercus repanda* Bonpland (1809: 31) (Fig. 1).

During a meeting named "Taller Internacional sobre Conservación de Encinos en México y Centroamérica", held in Morelia, Michoacán, México in 2016, the last two authors of this paper recognized a population of a shrub oak as different to all other species described, but the specimens were without acorns and not sufficient to base a description on. Later, during the field sampling and herbarium revision for the characterization of shrub oak species (De Luna-Bonilla *et al.* 2024), the other authors of this article observed, in some localities of the Cuitzeo basin in the state of Michoacán, specimens that showed leaves with a shape and abaxial epidermis similar to those of *Q. laeta* Liebmann (1854: 179), but with a shrubby habit. These had been incorrectly determined previously as *Q. frutex* and were the same as those observed in 2016. Therefore, in this study we performed a leaf shape analysis using geometric morphometrics to analyze the differences of this oak with respect to the other tomentose shrubby species of section *Quercus* distributed in the TMVB (*Q. microphylla*, *Q. frutex* and *Q. repanda*), and an ecological niche model to predict the potential distribution area of this oak within the Cuitzeo basin, where it is exclusively distributed according to our observations and sampling.

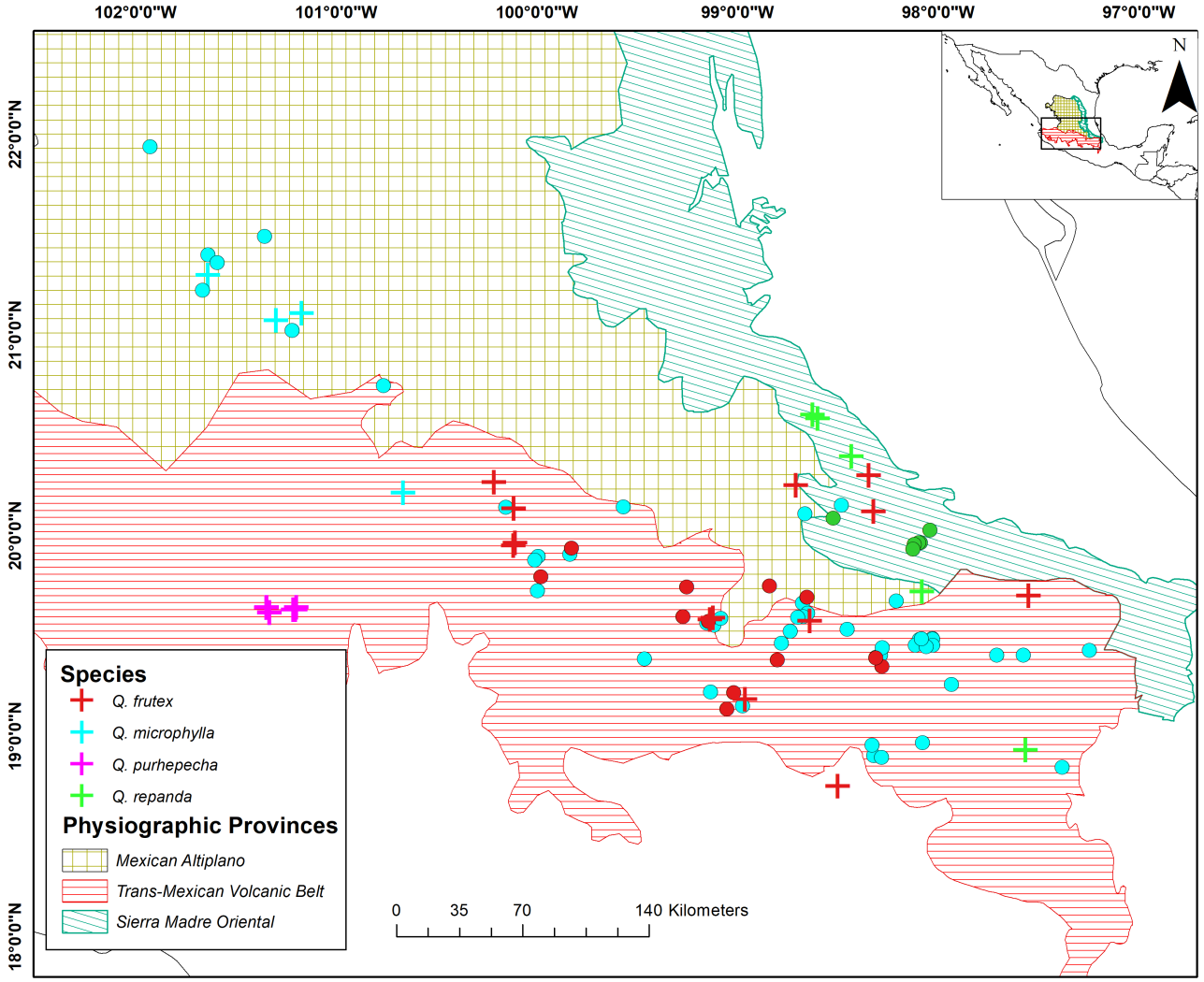

FIGURE 1. Points of occurrence of *Quercus frutex*, *Q. microphylla*, *Q. purhepecha* and *Q. repanda* in Mexico. In circles, georeferenced records from the iNaturalist website; in crosses, visited populations and corroborated specimens deposited in the MEXU and FCME herbaria.

Materials and methods

To obtain additional specimens of the new species, a revision of the MEXU and FCME herbaria was conducted, along with fieldwork in order to collect specimens with acorns. Five more locations were visited adding the same number of populations. The collected samples allowed us to assess morphological variation, enhance the species description, and characterize the habitat and distribution of the new species. The description format followed Valencia-A. *et al.* (2017) for Fagaceae. The species name was assigned following the rules of the International Code of Nomenclature for algae, fungi and plants (Turland 2018).

Given the low number of populations found, we used the electronic resource GeoCAT (https://geocat.iucnredlist.org/) to perform an analysis of the extent of occurrence (EOO) and area of occupancy (AOO) and provide a preliminary conservation status based on the IUCN Red List of Threatened Species criteria. Additionally, we included records from herbarium specimens and from the iNaturalistMX platform (when the photographs allowed us to confidently recognize the species with certainty) to determine the distribution of the species.

A leaf shape analysis was performed with a geometric morphometrics approach, using about ten individuals (8–14) and five leaves per individual for each sampled population for *Q. frutex* (5 populations), *Q. microphylla* (3), *Q. purhepecha sp. nov.* (2), and *Quercus repanda* (2) (Table 1). Using digitized images of mature leaves, 68 landmarks were placed to represent the shape of the leaf lamina. From the landmark dataset, leaf shapes were averaged for each individual using the Geomorph package (Adams *et al*. 2016). Subsequently, a canonical variate analysis (CVA) was performed with the Morpho package (Schlager 2017), both packages used in the R software (R Core Team, 2021).

TABLE 1. Collection sites of the populations for each species and number of individuals collected in Mexico.

Taxon	Locality, State	Number of individuals	Latitude	Longitude
Q. frutex	Huimilpan, Querétaro	9	20.264	-100.214
	Mezquititlán, Querétaro	8	20.135	-100.115
	Santiaguito, Hidalgo	9	20.25	-98.708
	Temascalcingo, Mexico State	9	19.948	-100.116
	Tulancingo, Hidalgo	10	20.119	-98.321
Q. microphylla	Lobos, Guanajuato	10	21.375	-101.622
	Villa Seca, Guanajuato	14	21.297	-101.64
	Guanajuato, Guanajuato	10	21.072	-101.3
Q. purhepecha sp. nov.	Atécuaro, Michoacán	9	19.630	-101.203
	Piedra, Michoacán	10	19.629	-101.213
Q. repanda	Huayacocotla, Hidalgo	10	20.6	-98.626
	Puerto, Veracruz	10	20.394	-98.433

In order to estimate the potential distribution of *Q. purhepecha* in the Cuitzeo basin, Michoacán, an ecological niche model was performed using the geographic coordinates of our observations in the field and herbarium specimens (see the location of the type and paratypes below) as well as bioclimatic variables from Cuervo-Robayo *et al*. (2020), along with elevation and slope information obtained from the EarthEnv database (Robinson *et al*. 2014, Amatulli *et al*. 2018, https://www.earthenv.org/). These layers were delimited using the Cuitzeo basin polygon (INEGI 2014), where the study species was recorded and served as a calibration area (*sensu* Rojas-Soto *et al*. 2024). The ecological niche model was performed with the Maxent algorithm (Phillips *et al*. 2006) as implemented in the *kuenm* package (Cobos *et al*. 2019) in R (R Core Team 2021). The relative importance of environmental variables for the model construction was evaluated using the jackknife technique. This method allows assessing the contribution of a particular variable with and without its presence in the overall model, facilitating the selection of the smallest subset of variables necessary to adequately describe the species' environmental niche (Baldwin 2009).

Initially, a model was developed that included 15 of the 19 bioclimatic variables, excluding variables bio08 (mean temperature of the wettest quarter), bio09 (mean temperature of the driest quarter), bio18 (precipitation of the warmest quarter), and bio19 (precipitation of the coldest quarter), because these layers displayed spatial artifacts influencing model results (Escobar *et al*. 2014, Booth 2022). Due to the scarcity of records for model training and following the recommendation of Phillips *et al*. (2006) and Phillips & Dudík (2008), only linear functions (*l*) were used. This

procedure allowed eliminating the least contributing variables in the initial model, resulting in the selection of six variables: bio02 (mean diurnal range), bio03 (isothermality), bio07 (temperature annual range), bio14 (precipitation of driest month), bio15 (precipitation seasonality) and slope.

Once the variables were selected, different values were explored for the regularization multiplier (0.1, 0.5, 1, and 2), allowing us to obtain several candidate models that were filtered to obtain a final model, considering three criteria: partial Receiver Operator Curve (pROC), partial Area Under the Curve (pAUC > 1; $p < 0.05$), a zero omission rate, given that we only had two test records, and the lowest corrected Akaike Information Criterion (AICc) value. These criteria allowed us to select a final model, which was subsequently binarized by calculating the 10-percentile value of the presence data.

Results

The canonical variate analysis recovered 78% of the variation in the first two axes, allowing us to visualize a clear separation of *Q. purhepecha* with respect to populations of *Q. frutex*, *Q. microphylla* and *Q. repanda* distributed in the TMVB. *Quercus purhepecha* showed on average a slightly obovate lamina shape with a rounded base, similar to the shape of *Q. repanda* that has a distinctly obovate lamina shape, but with an attenuated base and apex. On the other hand, the average leaf shape in *Q. frutex* is elliptic-oblong with an attenuated base and apex, very similar to *Q. microphylla,* which shows an elliptic-oblong shape but with a rounded base and an attenuated apex (Fig. 2).

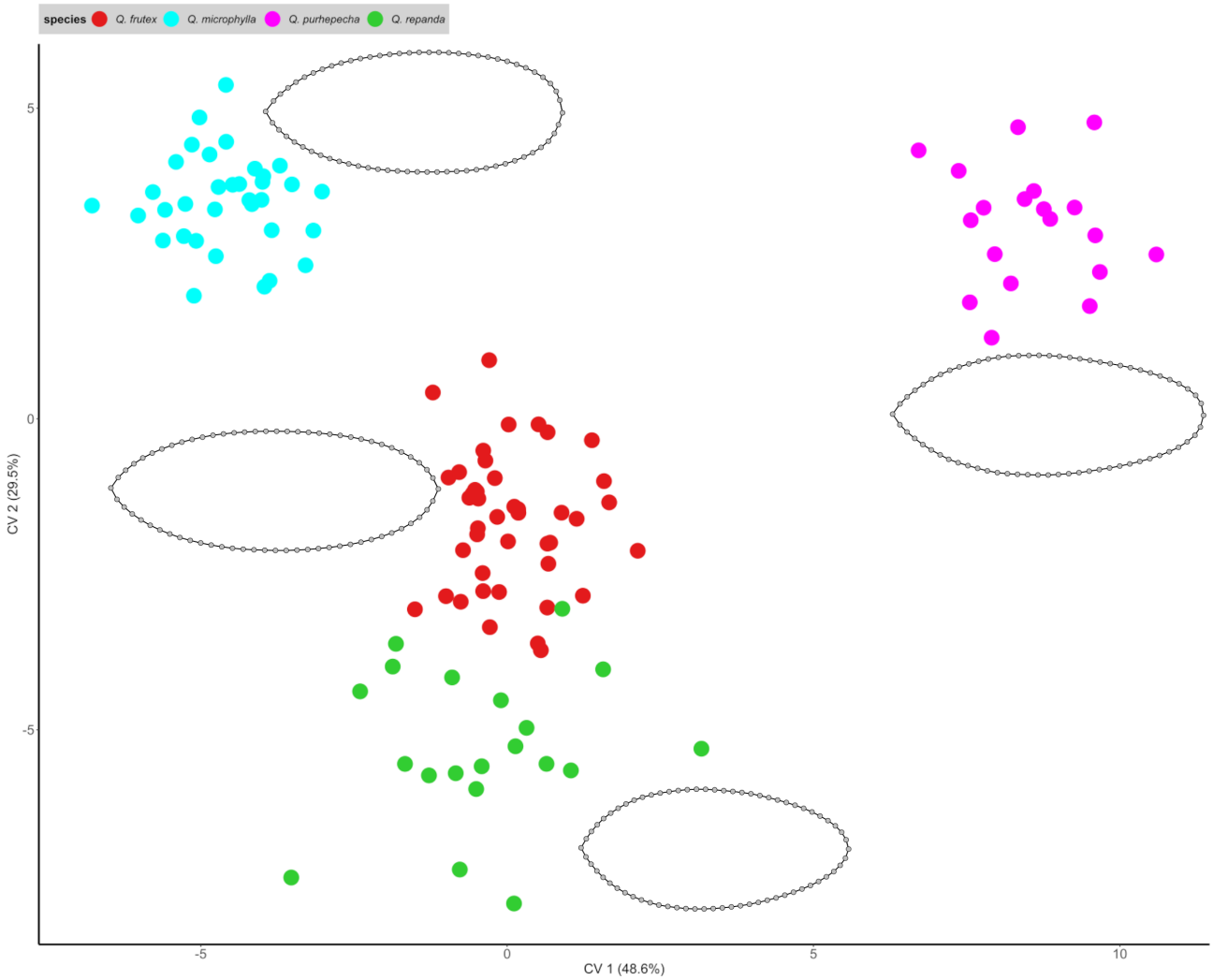

FIGURE 2. Scatter plot of the first two canonical variates. Each point represents the mean leaf shape of an individual. Representative morphology of each species is shown next to its respective cluster.

The ecological niche model was based on six key bioclimatic variables for *Q. purhepecha* which indicated that it occurs in areas with considerable fluctuations in daily and annual temperatures as well as marked dry seasons. In terms of vegetation type, the species is found in transition zones between the oak forest and subtropical deciduous scrub.

On the other hand, the potential distribution map resulting from the spatial projection of the ecological niche model indicated that the environmental suitability for *Q. purhepecha* increases to the south of the Cuitzeo basin and towards higher elevations, while in the north of the basin environmentally suitable areas are represented by smaller and more distant patches (Fig. 3). This map may be useful as a guide in the search for additional populations of *Q. purhepecha*.

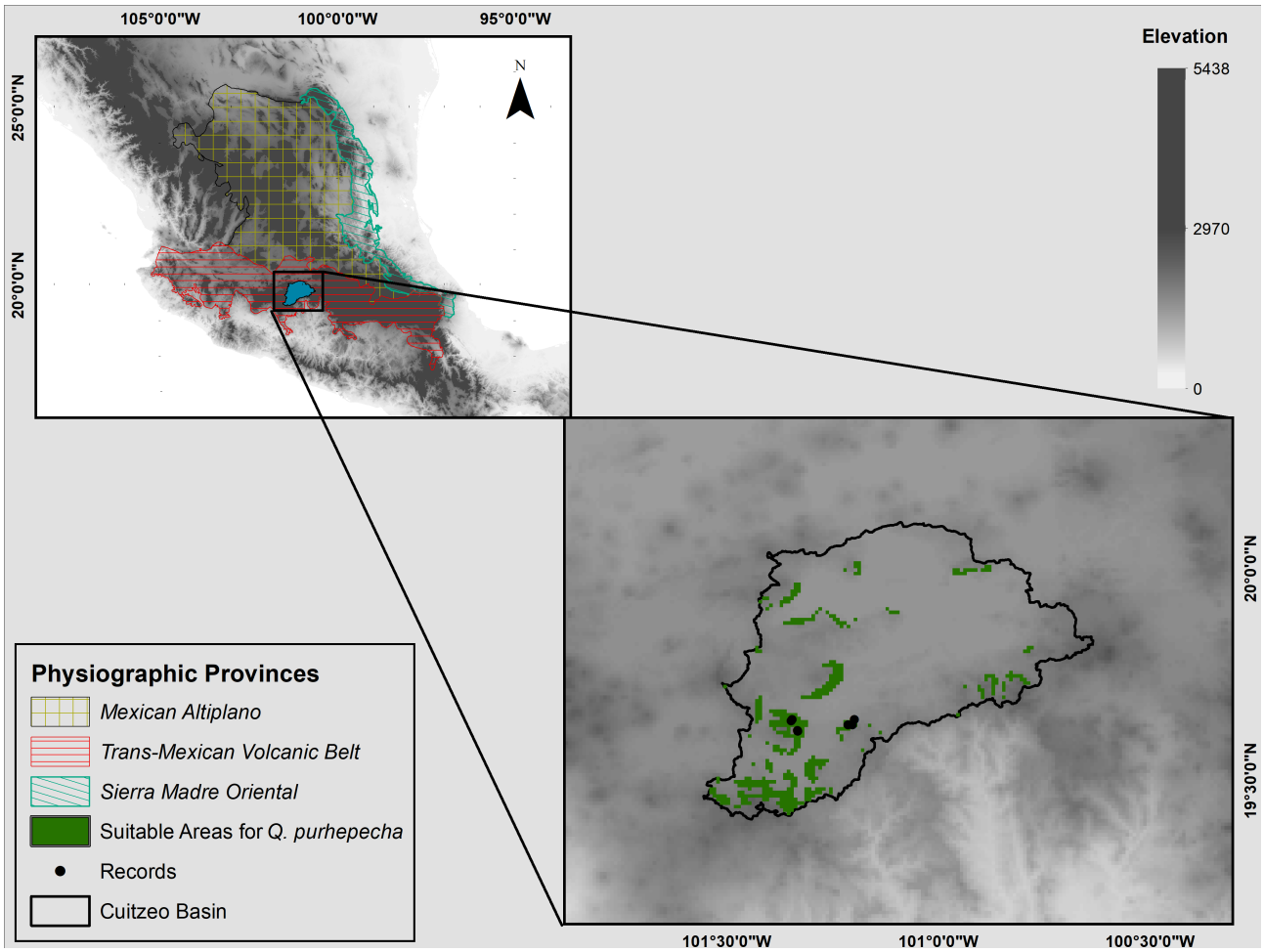

FIGURE 3. Potential distribution model for *Quercus purhepecha* in the Cuitzeo basin.

Taxonomy

Quercus purhepecha De Luna-Bonilla, S. Valencia & Coombes *sp. nov.* (Figs. 4, 5).

Type:—MEXICO. Michoacán. Municipio Morelia: Carretera Morelia-Atécuaro, al lado del camino, 2240 m. 19.63º N, 101.20º, 21 September 2022, O. *De Luna Bonilla & S. Morales ODL-543* (holotype FCME183410!, isotypes HUAP!, MEXU!) (Fig. 6).

Diagnosis:—*Quercus purhepecha* can be confused with *Q. laeta*, *Q. frutex*, *Q. microphylla* and *Q. repanda*. From *Q. laeta* (a tree with toothed leaves) it can be distinguished by its shrubby, rhizomatous habit and by having both toothed and untoothed leaves. From *Q. frutex* it can be distinguished by its rhizomatous habit and leaves that are not or only slightly revolute. From *Q. microphylla* it can be distinguished by its rhizomatous habit and the presence of shortly stipitate vs. sessile fasciculate trichomes on the abaxial blade surface. From *Q. repanda*, which also has a rhizomatous habit, it is distinguished by its not or only slightly revolute leaves (distinctly revolute in *Q. repanda*) and the lack of amber trichomes.

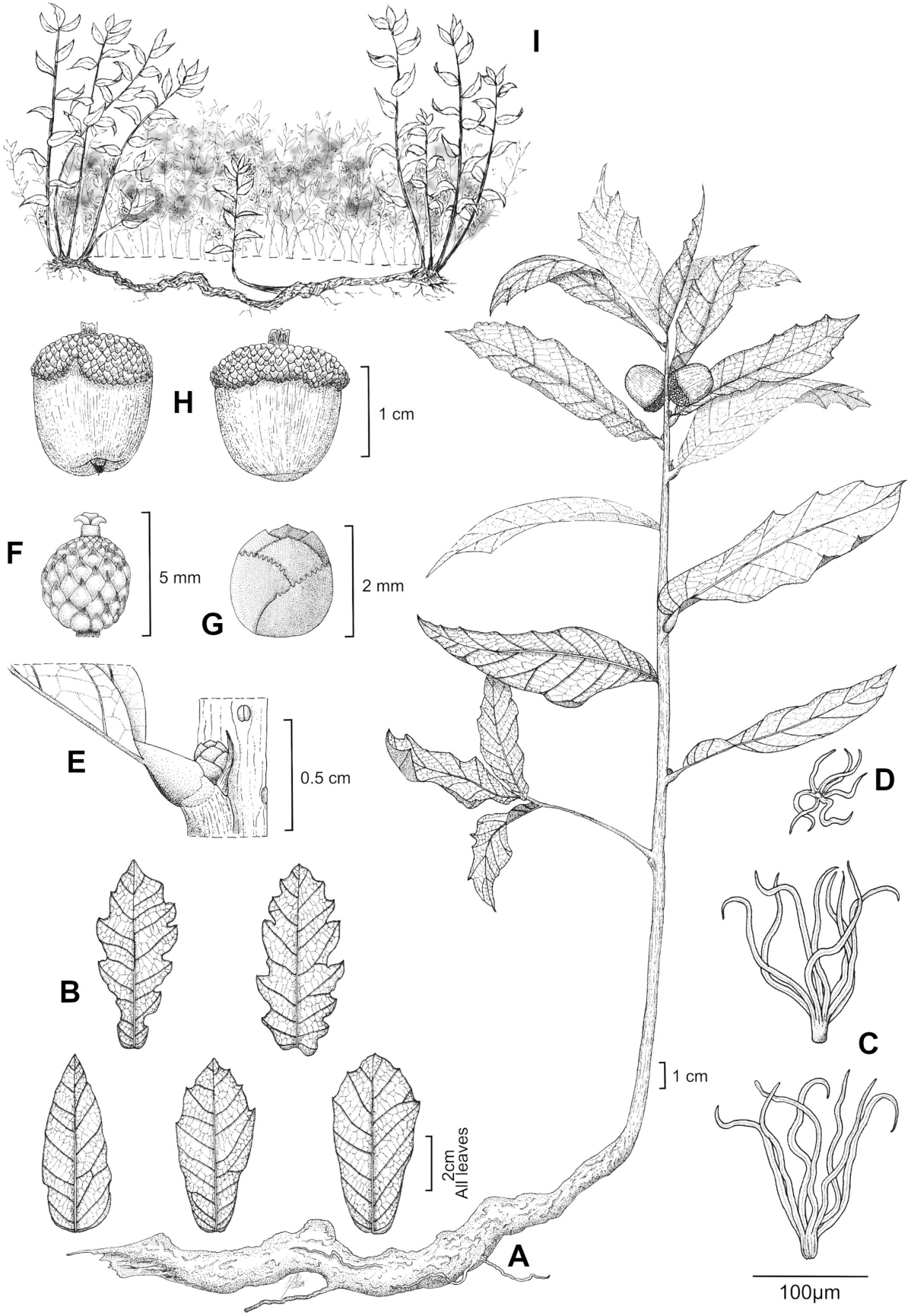

FIGURE 4. **A-I** *Quercus purhepecha*. **A**. Mature stem emerging from the rhizome; **B**. Different leaf morphologies; **C**. Stipitate fasciculate trichomes present on the underside of the leaf; **D** fasciculate trichomes present on upper side of the leaf; **E** Detail of the thickened petiole and bud; **F** Female flower; **G** detail of rounded buds with irregularly fimbriated scales; **H** Mature acorns; **I**. General habit of an individual with detail of the rhizome. Drawn by Moises Emanuel Bernal Hernández based on ODL-543 (FCME).

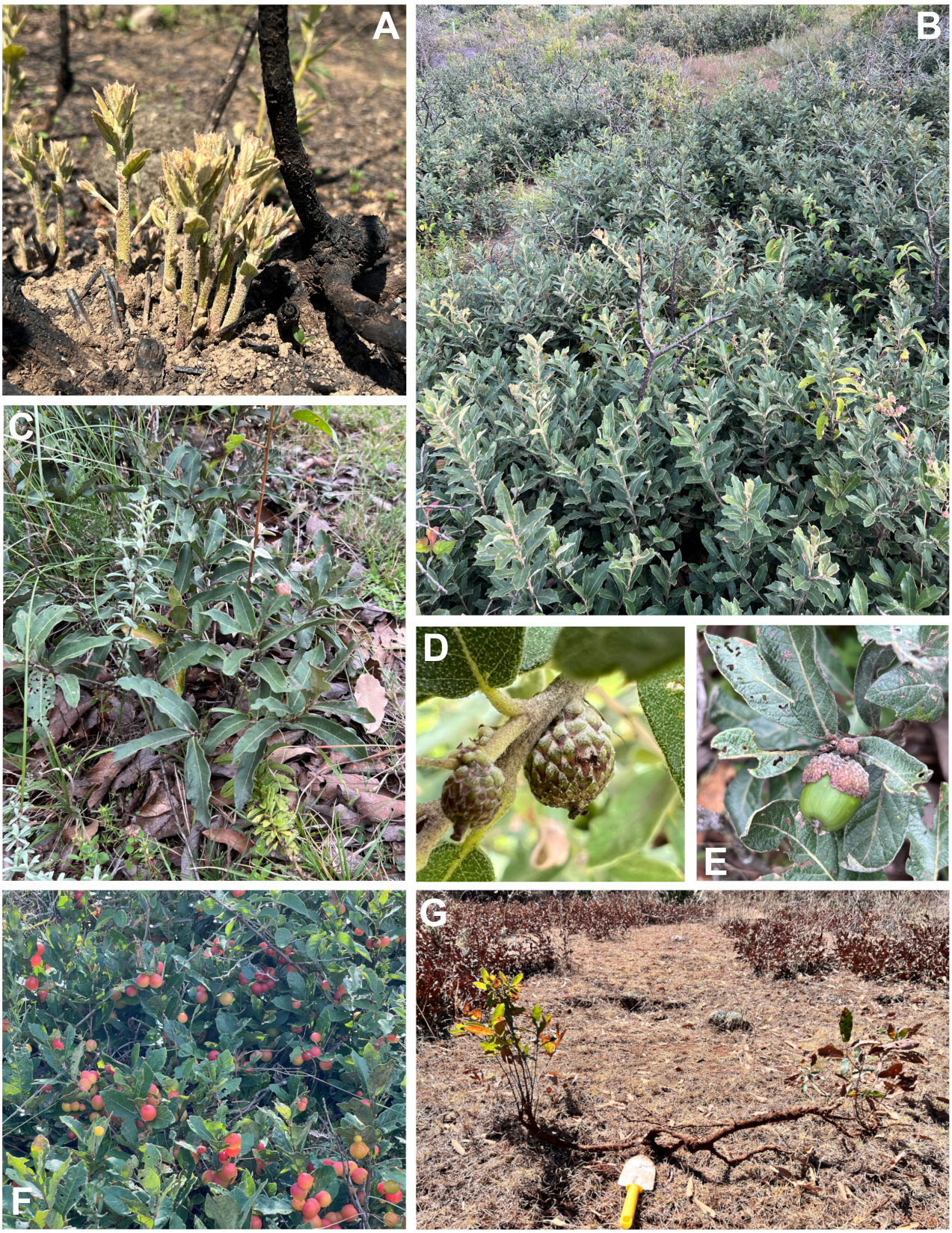

FIGURE 5. **A-G** *Quercus purhepecha*. **A**. Multiple stems emerging from the rhizome from a burned individual; **B**. General appearance of the shrub, composed of multiple stems; **C**. Solitary individual not yet forming a dense shrub; **D**. Female flowers; **E**. Mature acorn; **F**. Multiple wasp galls growing on the leaves of different stems; **G**. Detail of the rhizome and the insertion of the stems. Photos by O. De Luna-Bonilla.

Description:—*Shrubs* rhizomatous, 0.3–0.7 m tall, *twigs* (1)1.3–2.3(2.7) mm in diameter, gray to pale-reddish, slightly furrowed, glabrous to tomentose, retaining sparse stipitate fasciculate trichomes, with conspicuous lenticels; *buds* ovoid, 2.6–3 mm long, scales broadly ovate, glabrous, reddish-brown, margin irregularly fimbriated. *Mature leaves* with *petioles* 2.3–3.4 mm long × 1.0–1.3 mm in diameter, yellowish to slightly reddish toward the base, glabrescent with sparse whitish fasciculate stipitate trichomes, *stipules* linear to narrowly lanceolate 2.8–5.6 mm long, glabrescent or somewhat floccose, retaining sparse grayish sessile fasciculate trichomes, usually persistent even when leaves are mature; *lamina* coriaceous, slightly obovate, oblong, ovate-lanceolate, rarely ovate, 3.5–5.2(7) cm long × (1.2)1.4–2(2.5) cm wide, 2.5–3 times longer than wide, *apex* acute, attenuate to rounded, *margin* thickened, flat or slightly revolute, entire or with 1–2 short mucronate teeth, some leaves of juvenile shoots from the base of the plant or the rhizome may have up to 7 teeth almost from the base, *base* rounded or slightly subcordate, *secondary veins* (6)7–10(12) on each side of the midvein, ascending, moderately curved towards the margin, branched and anastomosed before reaching the margin, *adaxial blade surface* dull, glaucous, secondary veins slightly impressed, glabrous to glabrescent, preserving scarce fasciculate trichomes laxly distributed towards the base of the lamina and midvein, *abaxial blade surface* whitish to grayish, tomentose to glabrescent, with fasciculate shortly stipitate trichomes with whitish crispate rays becoming dark with age, laxly distributed, not obscuring the white-papillose and somewhat bullate epidermis. *Fruits* annual, 1–2 on a grayish, pubescent to glabrous peduncle 0.7–2 cm long × 1.2–2.5 mm in diameter; *cupules* hemispheric to slightly conical, 8.3–12 mm long × 13–19 mm in diameter, scales triangular to narrow-triangular towards the margin of the cupule, base of scales keeled and white-pubescent, *nuts* brownish, glabrous, ovoid to oblong-ovoid, 15.5–18.3 mm long × 11–15 mm in diameter, ca. ½ their total length included in the cupule.

Distribution and ecology:—Mexico (Michoacán). Elevation 2100–2450 m. It grows at the margin of the oak forest, in patches that spread mainly rhizomatously, in poor and shallow soils; associated with *Q. castanea* Née (1801: 276), *Q. deserticola* Trelease (1923: 79) and *Erythrina leptorhiza* Mociño & Sessé ex de Candolle (1825: 413). Flowering in January and February; fruits mature in September. Some plants had numerous galls. These are caused by wasps of the genus *Atrusca* Kinsey (1936: 105) (Juli Pujade, *pers. comm*. 2024).

Preliminary conservation status:—As a result of the analysis of extent of occurrence (EOO = 42.2 km^2) and area of occupancy (AOO = 2.25 km^2) implemented by GeoCAT, the preliminary conservation status of the species would be Critically Endangered (CR). It is of noteworthy importance to point out that since the species presents vegetative propagation, it is very complicated to establish the exact number of individuals, but it can be inferred from field work that it is low. In addition, considering the low number of locations where the species was observed, and its distribution near the city of Morelia, which is experiencing rapid growth (Cigna and Tapete, 2021), a conservation plan for the species should be considered a priority.

Etymology:—The specific epithet is dedicated to the indigenous people of the P'urhepechas who inhabit the state of Michoacán, where this species of oak is endemic.

Additional specimens examined:—MÉXICO, MICHOACÁN. Municipio Morelia: Av. Atécuaro aprox. 300 m después del km 2 ladera SE, 2144 m. 19.64258°N, 101.19885°O, 27 October 2022, *O. De Luna Bonilla & S. Morales ODL-550* (FCME); 2 km al SE de la Piedra del Indio sobre la montaña, 2144 m. 19.62979°N, 101.21345°O, 7 August 2021, *O. De Luna Bonilla & A. González Rodríguez ODL-501* (FCME); Camino a cerro del Águila aprox. a 3 km de Joya de la Huerta sobre la brecha, 2450 m. 19.61688°N 101.33292°O, 23 October 2023, *O. De Luna Bonilla ODL-598* (FCME); 2 km al SO del poblado Cuanajillo Grande al lado de la brecha principal, 2270 m. 19.64234°N 101.34571°O, 31 October 2023, *O. De Luna Bonilla ODL-627* (FCME); Cerro del Águila subiendo por Tacícuaro, 2350 m, 19°39'04"N, 101°22'00"O, 30 August 2007, *G. Cornejo Tenorio et al. 2267* (MEXU); Cerro del Águila subiendo por Tacícuaro, 2350 m, 19°39'04"N 101°22'00"O, 30 August 2007, *G. Cornejo Tenorio et al. 2257* (MEXU); Cerro del Águila, subiendo por San Nicolás Obispo, 2170 m, 19°37'52"N 101°19'53"O, 12 July 2007, *E. Sánchez García et al. 95* (MEXU); Lado Noreste del Cerro del Águila, subiendo por el poblado de San Nicolás Obispo, 2315 m, 19°38'06"N 101°20'24"O, 11 April 2008, *E. Sánchez García et al. 573* (MEXU).

Notes:—Leaves on adult shoots of *Quercus purhepecha* can be confused with those of *Q. frutex* while those on vigorous, juvenile shoots can be confused with those of *Q. laeta,* species that are also present in the Trans-Mexican Volcanic Belt, although not in the Cuitzeo basin. In addition to the differences noted in Table 2, from *Q. frutex* it is distinguished by its rhizomatous growth, as well as its smaller leaf blades (3.5–5.2(7) × (1.2)1.42(2.5) cm. *Quercus frutex* can also be distinguished from *Q. purhepecha* by its densely tomentose twigs, and lamina 1.2–4.8 × 0.7–1.5 cm. *Quercus laeta* is always a tree with leaf blades 6.5–9(15) × 2.4–3.7(4.5) cm. One of the most important aspects that has not been considered in the studies of shrub oaks is the general morphology and growth form (shrub type). In the case of *Q. purhepecha*, dense patches are composed of multiple single, thin, sparsely branched stems that grow from the

rhizome, while in the case of *Q. frutex*, branching is generally from a single thickened stem emerging from the rhizome that branches further towards the apical zone.

FIGURE 6. Holotype of *Quercus purhepecha*. Photo by Gabriela Flores-Valencia.

Discussion

The Mexican shrub oak species of section *Quercus* with tomentose twigs and leaves are difficult to delimit and have been referred to by some authors as a species complex (Valencia-A. 2021, De Luna-Bonilla *et al.* 2024). The detailed study of these species, including leaf shape analysis with geometric morphometrics techniques, and the characterization of micromorphology (particularly trichomes), geographic distribution and climate niche, have allowed clarification of some taxonomic problems, such as the recognition of six species distributed in the north of Mexico (Sabás-Rosales *et al*. 2017), and the delimitation of *Q. microphylla* and *Q. frutex*, which are distributed mainly in the TMVB (De Luna-Bonilla *et al*. 2024). In this context, the species named here as *Q. purhepecha* was characterized and described.

Quercus purhepecha also shows tomentose leaves and twigs, but otherwise is distinct from all previously described shrub oak species that present these characters. The known distribution of *Q. purhepecha* is restricted to the Cuitzeo basin. It was originally confused with shoots of *Q. laeta* (this was disproved when the stems were explored and a rhizomatous growth form was clearly defined), and with *Q. frutex*. The analyses developed in this study, which

included the comparison with other species with a shrubby habit, tomentose leaves and distributed in the TMVB (with which *Q. purhepecha* could also be confused, such as *Q. microphylla* and *Q. repanda*), allowed us to recognize *Q. purhepecha* as a distinct and hitherto undescribed species, which can be distinguished by its shrubby habit with the development of single stems from the rhizome, persistent, linear to narrowly lanceolate stipules, leaf blades obovate, oblong, ovate-lanceolate or rarely ovate, with a revolute, slightly thickened to flat margin and fasciculate and shortly stipitate trichomes on the abaxial surface of the leaves (Table 2).

An interesting aspect that needs to be highlighted is the scarcity of acorns that *Q. purhepecha* produces, which together with its shrubby habit, rhizomatous growth, and restricted distribution, could suggest a mainly vegetative propagation mode. Additional population genetics studies are suggested to test this hypothesis.

TABLE 2. Comparison of morphological characteristics between *Q. purhepecha* and similar shrub oak species

Character	***Q. purhepecha***	***Q. microphylla***	***Q. repanda***	***Q. frutex***	***Q. laeta***
Habit	Shrubs with multiple single sparsely branched stems	Shrubs branching from a single thickened stem	Shrubs with multiple single sparsely branched stems	Shrubs branching from a single thickened stem	Trees with single stems
Pubescence young shoots	Tomentose	Tomentose	Tomentose	Densely tomentose	Floccose
Stipules	Persistent	Deciduous, or persistent in the apical buds	Persistent	Deciduous	Deciduous
Petiole length (mm)	2.3–3.4	2.2–3.4	3.5–7	1–7	6–8.7(10)
Blade shape	Slightly obovate, oblong, ovate-lanceolate	Elliptic-oblong	Obovate to oblanceolate	Elliptic-oblong	Oblong, oblanceolate to obovate
Base	Rounded or slightly subcordate	Truncate to rounded	Cuneate to rounded	Attenuate-rounded to subcordate	Cordate to subcordate
Apex	Acute, attenuated to rounded	Obtuse to rounded	Attenuate	Obtuse to rounded	Obtuse to rounded
Margin with number of teeth on each side	Entire or with 1–2, rarely up to 7 short teeth	Entire or with 2–3 lobes	Entire, repand or crenate & revolute,	Entire & revolute	With 2–5 mucronate short teeth
Secondary veins on each side of the midvein	(6)7–10(12)	5–7	5–9	5–8(10)	7–10
Abaxial blade surface	White-papillose and somewhat bullate	Papillose and slightly bullate	Bullate and papillose	Bullate and papillose	White-papillose
Fasciculate trichomes on abaxial blade surface	Shortly stipitate	sessile	sessile	stipitate	sessile
Rays of trichomes	Crispate	Crispate	Crispate	Curved or crispate	Crispate and somewhat contorted
Glandular trichomes	Absent	Absent	Present, amber-colored	Absent	Absent, rarely present, hyaline
Fruits	1–2	1–2	2–3	1–2	1–6
Peduncle length (mm)	7–20	8–9	10–25	Absent or ca. 20 mm long	14–18

Acknowledgements

We thank Saddan Morales and Gonzalo Contreras for their collaboration in the field work. We also thank Moises Emanuel Bernal Hernández for the illustration of the species, and Professor Benjamín Lucas Juárez for his guidance about the P'urhepecha people. This work constitutes a partial fulfillment of the Posgrado en Ciencias Biológicas of the

National Autonomous University of Mexico (UNAM). Oscar De Luna thanks the Posgrado en Ciencias Biológicas-UNAM and the Consejo Nacional de Humanidades Ciencias y Tecnologías (CONAHCYT) for the doctoral scholarship and financial support to develop graduate studies at UNAM (scholarship/CVU:717866/742699). The authors are grateful to the National Geographic Society (grant NGS-73961R-20) for funding.

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