RESEARCH ARTICLE

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Selecting Relict Montane Cloud Forests for Conservation Priorities: The Case of Western Mexico

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Natural Areas Journal 30:156–173

ABSTRACT: Montane cloud forests that occur along protected ravines have a fragmented distribution in western Mexico. These forests contain high species richness, and a number of endemic species and relict species. We identify montane cloud forests in western Mexico that deserve priority for conservation and in situ preservation. We rank the montane cloud forests based on tree species richness, the number of endemic vascular plants, the number of species with protection status, and the presence of relict tree species. We place tree species richness and floristic composition of montane cloud forests from western Mexico in a world context, comparing them with 110 forests throughout the world. Then, using Ward's dendrogram, we identify similarities in the floristic composition. Also, we determine which species in the montane cloud forests of western Mexico are protected by the Mexican Species Act, CITES, or IUCN Red List. Our results indicate that the montane cloud forest at Ojo de Agua del Cuervo in the state of Jalisco is unique in that it contains larger numbers of tree species, endemic vascular plants, and endangered plants than similar Asian forests containing ancient species. Ojo de Agua del Cuervo is floristically related at the generic level to forests in Asia, as well as those in Mexico containing Tertiary relict tree species. We propose a 56,395 ha biosphere reserve that includes Ojo de Agua del Cuervo and its surroundings. This proposed reserve would increase the number of preserved montane cloud forests, which are currently underrepresented among Mexican protected natural areas.

Index terms: biosphere reserve, classification, disjunct species, Mexico, montane cloud forest, sugar maple

INTRODUCTION

Montane cloud forests contain 10% of the total plant species richness of Mexico. These forests occur between 1200 and 2500 m above sea level (asl) in locations where humid temperate climates involve frequent or continuous presence of fog (Challenger 1998; Alcántara et al. 2002). The substantial biodiversity results, in part, from a unique biota transitional between tropical and temperate forests: there are floristic elements from deciduous forest of North America and Asia, as well as evergreen elements from South America (Miranda and Sharp 1950). In addition, 30% of the vascular plants in these forests are endemic to Mexico (Rzedowski 1991, 1996).

The current distribution of montane cloud forests is discontinuous and covers less than 0.8% of the land area of Mexico (Miranda and Sharp 1950; Vázquez-García 1995a; Challenger 1998; Palacio-Prieto et al. 2000). Along eastern and southern Mexico, montane cloud forests cover large areas, whereas in western Mexico, forests are much more restricted and mainly confined to ravines (Rzedowski 1996). It is not known, however, if the composition and species richness of montane cloud forests are similar in different parts of the country. The Mexican state of Jalisco probably contains the largest number of montane cloud forests remnants in western Mexico, but there has not yet been accurate determination of areal coverage.

Montane cloud forests are the only favorable habitat in Mexico for a number of temperate tree taxa whose ranges became diminished during Holocene warming. Fossil records from southern Mexico indicate trees with temperate affinity since the Lower Miocene (Palacios-Chávez and Rzedowski 1993). Climate changes during the Quaternary Period produced species extinctions and migrations, resulting in the current disjunct pattern of species and fragmented distribution of montane cloud forests, now considered "montane islands" (Toledo 1982; Vázquez-García 1995a; Kappelle and Brown 2001). Montane cloud forests now contain temperate tree genera such as *Abies* Mill., *Acer* L., *Carpinus* L., *Cornus* L., *Fagus* L., *Illicium* L., *Magnolia* L., *Prunus* L., *Ostrya* Scop., and *Tilia* L. that were present during cooler periods of the Pleistocene Epoch and even earlier (Palacios-Chávez and Rzedowski 1993). Some species of these genera occur in Jalisco's montane cloud forests, suggesting that the area could be a Tertiary refuge (Graham 1999; Vázquez-García et al. 2000; Vargas-Rodriguez 2005). Nonetheless, the presence and abundance of these genera in modern montane cloud forests are not the same among different Mexican forests (e.g., Vargas-Rodriguez 2005). Thus, forests containing more relict species might be accorded priority in conservation efforts.

Conservation of these fragmented, relictual, and ancient forests via creation of a network of reserve should be a priority for the Mexican environmental agency (SEMARNAT). Only 20 of the 161 protected areas in the country contain montane cloud forests, comprising a total of 150,000 ha of these forests (Challenger 1998; Palacio-Prieto 2000; Luna-Vega et al. 2001; CONANP 2007). Of these 20 protected areas, six are biosphere reserves and 14 are national parks. Most of the protected areas in Mexico, however, have been established using non-biological criteria (Cantú et al. 2004). Since the concept of nature reserves was initiated in Mexico almost 130 years ago, none has been specifically designed to protect the montane cloud forest relicts in western Mexico. In addition, there is a lack of floristic and structural knowledge of many montane cloud forests in the region. Furthermore, montane cloud forests in Mexico are experiencing an accelerated rate of decimation. No more than 5250 ha remain in the central highlands of Chiapas, as of 2006, whereas 40,000 ha were reported for the same area in the Mexican National Forestry inventory in 2000 (Cayuela et al. 2006). In this sense, montane cloud forests are not as suitably protected in western Mexico as well as in the rest of the country.

Many biological criteria have been used to select areas that deserve protection around the world. Species richness and number of endemic species are the most often used criteria to select areas for conservation (Lamoreux et al. 2005). Rarity, environmental representativeness, declining habitats, threat level, biogeographic status, and climatic and physiographic representation are other traditional criteria used to establish reserves (Diamond 1986; Belbin 1993; Dobson et al. 1997; Prendergast et al. 1999). In this study, we use the available biological knowledge for montane cloud forests in western Mexico to assign them priority for conservation.

Our two major goals are to identify montane cloud forests in western Mexico that deserve greatest priority for conservation and to propose a natural area design to protect them. We assign a conservation priority to known identified relict montane cloud forests in western Mexico based on tree species richness, number of endemic vascular plants, number of species with protection status, and presence of relict tree species. We further examine how tree species richness and floristic composition of Mexican montane cloud forests relate to temperate and montane cloud forests around the world. Finally, we propose a specific in situ conservation strategy for that western Mexican cloud forest with the highest assigned priority (Ojo de Agua del Cuervo).

METHODS

Study Area

The western Mexico region is comprised of the states of Nayarit, Jalisco, Colima, and Michoacán (Figure 1). This region includes portions of the mountain chains Sierra Madre Occidental, Sierra Madre del Sur, and Eje Neovolcánico Transversal. Known northern limits of the geographic distribution of montane cloud forests are in Jalisco and Nayarit.

Tree Species Richness

The identification of species rich sites is a simple, but important, criterion used in selecting forests for conservation. We used data on species richness from 32 forest sites around the world to examine whether montane cloud forests of western Mexico differ significantly from other forests (Table 1). Although there are data for more forest sites, we used these forests because they were sampled using the same methods and same sample size. We also limited sampled forests to those where ≥ 20% of the species have temperate affinity, since this is the proportion usually present in Mexican montane cloud forests (Rzedowski 1996; Vargas-Rodriguez 2005). We used available data sets from Alwyn H. Gentry's forest transects (Phillips and Miller 2002), as well as data from measurements in disjunct montane cloud forests containing populations of Mexican beech [*Fagus grandifolia* var. mexicana (Martinez) Little] and cloud forest sugar maple [*Acer saccharum* subsp. *skutchii* (Rehder) Murray] in Mexico and Guatemala (Williams-Linera et al. 2003; Vázquez-García et al. 2000; Vargas-Rodriguez 2005) (Table 1). Quantitative data for western Mexico were only available for four montane cloud forest sites. The selected forests share genera such as Quercus L., *Fagus, Acer, Cornus, Fraxinus* L., *Magnolia*, and *Prunus*, among others. Tree species richness was based on individuals ≥ 2.5 cm diameter at breast height (dbh). All sites were similar in sampled area (0.1 ha) and sampling method (Gentry's transect) (Phillips and Miller 2002). We compared tree species richness among these 32 sites using ANOVA followed by Tukey-Kramer multiple comparison post-hoc procedure when there were significant differences ($P<0.05$). Statistical analysis was done using SAS v. 8.02 (SAS Institute 1999-2001).

Floristic Relationships and Relevance

We analyzed similarities in tree generic composition in 110 sites containing 354 genera from North and Central America, Europe, and Asia temperate and montane cloud forests. Multiple data sources were used for this analysis (Vázquez-García 1995b; Boyle 1996; Peters 1997; Phillips and Miller 2002; Williams-Linera et al. 2003; Reynoso 2004; Sahagún 2004; Vargas-Rodriguez 2005). Among the forests analyzed were those with relict populations of Mexican beech and cloud forest sugar maple in Mexico and Central America. Plot sizes and shapes varied from 300 to 2400 m2 and were 2-m x 50-m transects or circular plots (Curtis and McIntosh 1951; Gentry 1982). We used available data from 110 forests obtained with different sample schemes since comparability among these data is possible at the floristic composition level (Phillips and Miller 2002). Prior studies on Mexican floristic relationships have considered floristic checklists (no quantitative data), differing in collection intensity and life forms considered, making it difficult to conclude whether or not relationships are the result of differences in botanical exploration intensity and taxonomic understanding.

We constructed a matrix with presence-absence data of tree genera to analyze species composition similarities among

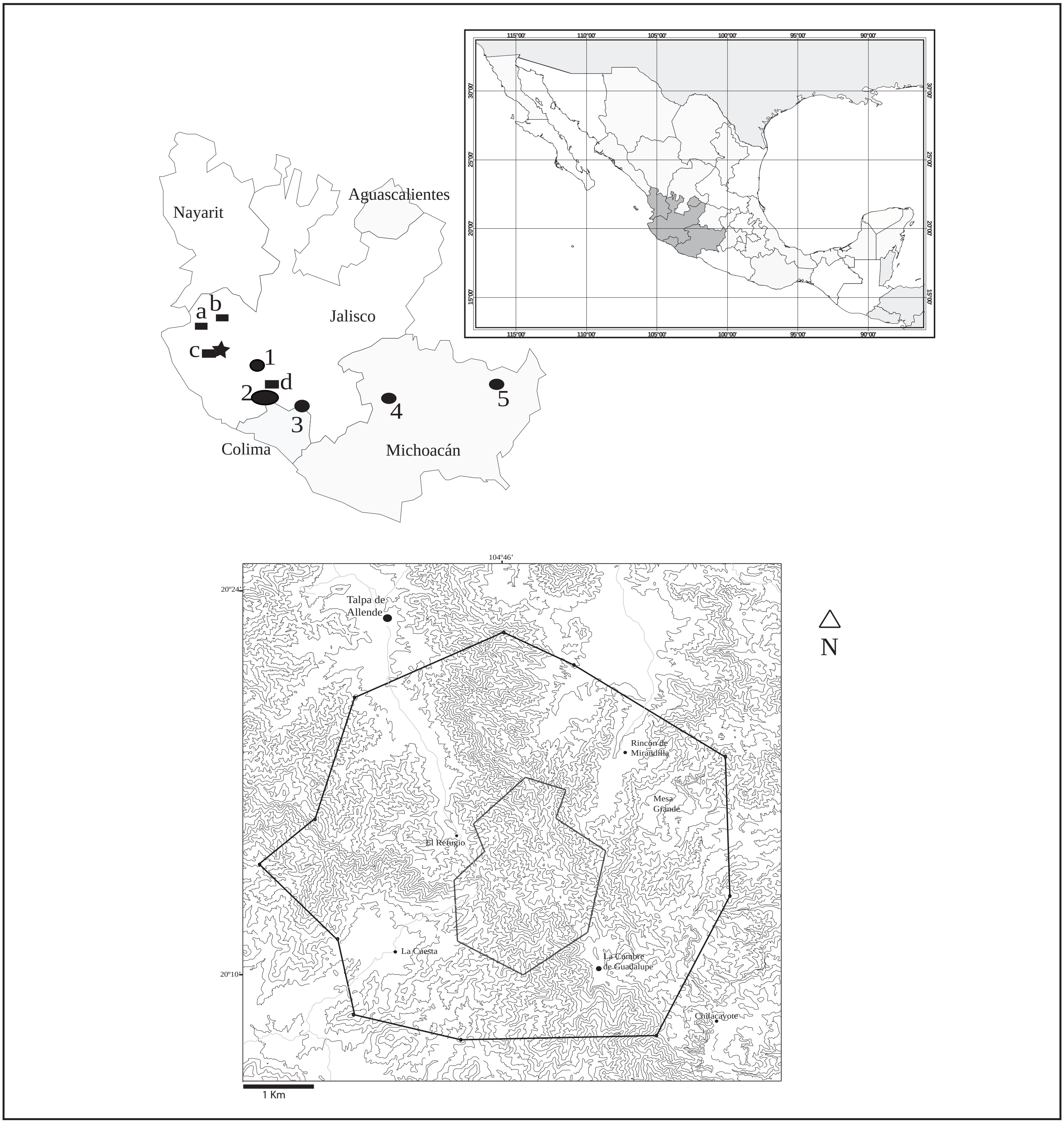


Figure 1. Location of western Mexico (upper map), montane cloud forests studied sites, and proposed polygon. Letters indicate 10 studied montane cloud forests with quantitative data: a) La Bulera, b) Milpillas, c) Ojo de Agua del Cuervo, d) Sierra de Manantlán (Las Joyas, La Moza, Quince Ocotes, and Cerro Grande at four different elevations). Numbers indicates the current protected areas with cloud forest for western Mexico: 1) Sierra de Quila Flora and Fauna Protection Area, 2) Sierra de Manantlán Biosphere Reserve, 3) Nevado de Colima National Park, 4) Pico de Tancítaro National Park, 5) Cerro de Garnica National Park. The star indicates the Ojo de Agua del Cuervo location. The proposed polygon (lower map) represents the Ojo de Agua del Cuervo Biosphere Reserve; inner polygon corresponds to core area.

Table 1. Temperate and montane cloud forests sites selected for tree species richness comparison.

Continent	State/Country	Locality	Source	Tree species richness
America	Ontario, Canada	Mt. St. Hilaire	Phillips and Miller (2002)	12
	Indiana, US	Cedar Bluffs	Phillips and Miller (2002)	24
	Ohio, US	Bankamp State Park	Phillips and Miller (2002)	21
		Hueston Woods, beech-maple	Phillips and Miller (2002)	20
		Hueston Woods, mixed forest	Phillips and Miller (2002)	21
	Pennsylvania, US	Kane, Allegheny National Forest	Phillips and Miller (2002)	13
		Laurel Ridge	Phillips and Miller (2002)	14
		Tidoute, Allegheny National Forest	Phillips and Miller (2002)	19
	New York, US	Montgomery Place	Phillips and Miller (2002)	18
		Cary Arboretum	Phillips and Miller (2002)	19
	Missouri, US	Tyson Reserve, Woods	Phillips and Miller (2002)	20
		Cuivre River State Park	Phillips and Miller (2002)	24
		Babler State Park	Phillips and Miller (2002)	18
		Valley View Glades	Phillips and Miller (2002)	22
	Virginia, US	Potomac	Phillips and Miller (2002)	22
	Florida, US	San Felasco Hammock	Phillips and Miller (2002)	17
		Univ. of Florida, Horticultural Woods	Phillips and Miller (2002)	24
	Tamaulipas, Mx	El Cielo Biosphere Reserve	Williams-Linera et al. (2003)	28
	Jalisco, Mx (western Mx)	Las Joyas, Sierra de Manantlán	Phillips and Miller (2002)	26
		Cañada La Moza, Sierra de Manantlán	Vargas-Rodriguez (2005)	20
		Quince Ocotes, Sierra de Manantlán	Phillips and Miller (2002)	36
		Ojo de Agua del Cuervo	Vargas-Rodriguez (2005)	31
	Veracruz, Mx	Bosque de Guadalupe	Phillips and Miller (2002)	34
	Chiapas, Mx	Benito Juárez	Phillips and Miller (2002)	23
	Chiapas, Mx	Tenejapa	Vargas-Rodriguez (2005)	36
	Guatemala	El Balsamal	Vargas-Rodriguez (2005)	41
	Colombia	Ucumari	Phillips and Miller (2002)	22
Europe	Finland	Liesjarvi National Park	Phillips and Miller (2002)	5
		Ruissalo	Phillips and Miller (2002)	10
	Germany	Suderhackstedt	Phillips and Miller (2002)	15
		Allacher Lohe	Phillips and Miller (2002)	20
Asia	Japan	Chiba	Phillips and Miller (2002)	37

temperate and montane cloud forests from different continents. This matrix is presented in Vargas-Rodriguez (2005). To analyze this matrix, we used Ward's linkage method cluster analysis together with Euclidean distance measure (McCune and Grace 2002). Hierarchical methods, such as Ward's method, find groups nested within groups, and these are represented in a dendrogram. This method is based on minimizing the error sum of squares. Ward's method is considered an effective tool, space-conserving, and has fewer propensities to chain than other methods (McCune and Grace 2002). The software used was PCORD v. 4 (McCune and Mefford 1999).

Species Protection Status in Montane Cloud Forests of Western Mexico

We analyzed the number of species under legal protection in western Mexico. We selected 10 sites using the following criteria: similar surface area and methodology (0.1 ha, transects, individuals 2.5 cm dbh), presence of relict species, and geographic representativeness. The forests we compared were located in Jaliscan municipalities of: San Sebastián del Oeste (Milpillas and La Bulera sites), Talpa de Allende (Ojo de Agua del Cuervo), and Sierra de Manantlán (La Moza, Los Joyas, Quince Ocotes, and Cerro Grande at four different elevations) (Vázquez-García 1995b; Vázquez-García et al. 2000; Phillips and Miller 2002; Reynoso 2004).

We determined tree species protection status in these 10 sites from western Mexico using the species list from the Mexican Endangered Species Act (MESA) (Diario Oficial 2002), the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (CITES 2005), and the International Union for Conservation of Nature - Red List of Threatened Species (RLTS) (Walter and Gillett 1998).

Endemic Species in Montane Cloud Forests of Western Mexico

We analyzed the number of endemic species for western Mexico in the same 10 sites used in the protected species analysis. We identified endemic vascular plants for western Mexico occurring at the 10 montane cloud forests sites and their surroundings based on herbarium data and literature reports. Each of the species recorded at the 10 montane cloud forests were examined using floristic checklists and research papers for the region to classify them as endemic or non endemic to montane cloud forests in western Mexico. In addition, we listed endemic species occurring in the surrounding montane cloud forests. Floristic check lists are included in Flora Novo-Galiciana (McVaugh 1983, 1984, 1985, 1987, 1989, 1992, 1993, 2001), Flora de Manantlán (Vázquez-García et al. 1995), Flora de Jalisco collection (González-Villarreal 1986, 1990, 1996a, 1996b, 2000a, 2000b, 2000c, 2000d, 2001, 2002a, 2002b, 2004; Cervantes 1992; Vargas-Ponce et al. 2003; González-Villarreal et al. 2004; González-Villarreal and Jiménez-Reyes 2006), and research papers (Rodríguez and Ortiz 2001, 2003, 2006; Cuevas et al. 2002; González-Villarreal 2003a, 2003b; Dávila-Aranda et al. 2004).

Temperate and Montane Cloud Forest Protection in Western Mexico and Worldwide

We determined which of the 110 worldwide sites used in the floristic analysis were in some protection category. We consulted the Mexican Commission for Protected Areas (Comisión Nacional de Áreas Protagoras; http://www.conanp.gob.mx/anp/anp.php), the MAB-UNESCO list of biosphere reserves (Man and Biosphere Programme; http://www.unesco.org/mab/wnbrs.shtml), and pertinent literature for each region (Peters 1997; Challenger 1998; Phillips and Miller 2002; Vargas-Rodriguez 2005) to identify the protection status of studied sites.

Through personal exploration and experience in montane cloud forests from Jalisco, its surroundings areas, and interviews with the local inhabitants, we determined the current threats to these forests.

In situ Conservation: A Biosphere Reserve Proposal

We selected the montane cloud forests with the highest values of attributes previously mentioned as the most relevant area for in situ conservation and protection in western Mexico. We then developed a design for protected area.

We created a polygon for the forests and its surroundings to be proposed as protected areas under the biosphere reserve category. We used cartographic maps (1:50,000) together with a 2003 LANDSAT Thematic Mapper satellite imagery (14.25 m pixel) to determinate and create buffer and core area vertices. We used 1:50,000 m thematic maps for soil types, geology, vegetation, and land use to determinate abiotic characteristics of the area (INEGI 1974, 1976, 2001). GeoMedia v. 5.2 (Intergraph 2005) was used to georeference cartographic maps.

We considered biotic and abiotic criteria to determine the polygon boundaries. Biotic criteria included vascular plant species richness, number of endemic vascular plants for western Mexico, disjunct tree species, vegetation type, endangered species, and ecosystems. Abiotic criteria consisted of physical features such as soil type, elevational ranges and geomorphological heterogeneity, land use, and hydrological regions (Maddock and Benn 2000; Myers et al. 2000; Cantú et al. 2004; Boon and Gaston 2005; Breceda et al. 2005). We avoided the inclusion of main human population centers because of extensive disturbance and because human pressure tends to constitute strong opposition to legal decree of new reserves in Mexico (Cantú et al. 2004).

Size and shape criteria were also taken into account. Patch size and shape are two of the most important variables that influence species richness (Nebbia and Zalba 2007). More circular patches tend to capture more species, reducing edge effects (Nebbia and Zalba 2007). Since protected areas are suggested to be more circular in shape (Kunin1997), we considered a minimum surface of 10,000 ha and a minimum distance of 8 km from core area boundaries to buffer area boundaries (Diario Oficial 1988; Alverson et al. 1994; Primack 2002). In addition, we followed the minimum area suggestion of 30,000 ha for some biosphere reserves to fulfill the requirements of the United Nations Educational, Scientific and Cultural Organization (UNESCO) (Deutsches Nationalkommitee 1996). We organized the polygon as interrelated core and buffer zones. The core area is proposed to exclude human activity, except for research and monitoring, thus offering long-term protection to landscapes, ecosystems, and species within that core. The buffer area, which surrounds the core area, will be designated for the sustainable use of forest resources, rehabilitation of degraded areas, education, training, tourism, and recreational activities (Diario Oficial 1988; UNESCO-MAB, www.unesco.org/mab).

RESULTS

Tree Species Richness

Fifteen of the 32 (46.9%) temperate and montane cloud forests around the world had significant differences in terms of richness (one-way ANOVA, $F = 27.53$, $P = <0.0001$, $df = 30$) (Table 2). The montane cloud forests in western Mexico, Quince Ocotes, Las Joyas, and Ojo de Agua del Cuervo were among these 15 forests. The Ojo de Agua del Cuervo forest had higher tree species richness than all 25 temperate forests from both North America and Europe. These forests were distributed in Ohio, Indiana, Pennsylvania, New York, and Missouri in the United States, Ontario in Canada, Finland, and Germany (Table 2). In Mexico, Ojo de Agua del Cuervo had higher species richness than montane cloud forests in Tamaulipas (northeastern Mexico) and La Moza (western Mexico). A total of 43 tree species ≥ 1 cm dbh have been documented in only 0.3 ha (31 species per 0.1 ha) of Ojo de Agua del Cuervo. In contrast, a forest containing cloud forest sugar maple in La Moza, western Mexico, exhibited lower species richness (20 per 0.1 ha) (Vargas-Rodriguez 2005). Nonetheless, no differences occurred in species richness among Mexican forests that included tropical elements such as those in Chiapas and Veracruz (southern and eastern Mexico, respectively). In addition, the Japanese forest, Chiba, was not different in species richness from Ojo de Agua del Cuervo.

Floristic Relationships and Relevance

The dendrogram produced from cluster analysis identified seven site groups with 65% of retained information. The first group was composed of sites distributed exclusively in the United States. A second cluster consisted of a heterogeneous group of sites from eastern Canada-U.S., Europe, and Asia. The third group consisted of sites from the Pacific, with the exception of one located along the Gulf of Mexico; four montane cloud forests of western Mexico were also in this cluster. A fourth group was composed of sites containing relict populations of cloud forest sugar maple and beech from Mexico and sites from Asia. This Mexican group of 11 forest sites (two of them from western Mexico) was the only one that showed floristic similarities with the Japanese forest Chiba and two forests in China, Fanjing Shan and Miao'er Shan forest (Figure 2). None of 63 Mexican temperate and montane cloud forests sites analyzed clustered with other Asian temperate forests (Figure 2). The fifth group contained only sites from Cerro Grande, Sierra de Manantlán in western Mexico. This group was probably separated due to its karstic soils and recent geological origin, despite the geographically short distance to other montane cloud forests. The sixth group was made up of sites in Oaxaca, Mexico, and the last group consisted of sites in Central America (Figure 2). More humid sites in Oaxaca and Costa Rica containing more genera with tropical affinities were grouped in these last clusters.

Species Protection Status in Montane Cloud Forests of Western Mexico

The number of montane cloud forest tree species under a protection category was higher in Ojo de Agua del Cuervo (Talpa de Allende, Jalisco) than in the other nine montane cloud forests sites from western Mexico. Thirteen tree species from Ojo de Agua del Cuervo were included in MESA, CITES, or RLTS. Eleven species (26% from total tree richness) were included in MESA, 14% under the endangered category, 7% threatened, and 5% under special protection (Table 3). Montane cloud forests from Sierra de Manantlán followed the Ojo de Agua del Cuervo in the number of protected species (Table 3). The rest of the sites (Milpillas, La Bulera, and Cerro Grande) had fewer numbers of protected species (Table 3).

Endemic Species in Montane Cloud Forests of Western Mexico

There were no endemic tree species ≥ 2.5 cm dbh present in the 0.1 ha sampled at each of the 10 montane cloud forest sites. However, considering all vascular plant species present surrounding the study sites, we identified a total of 40 endemic vascular plants for western Mexico. All endemic species found were present in the montane cloud forests. In all cases, the surrounding sites were no farther than eight kilometers from the center of the study sites. Asteraceae was the most species rich family (13) followed by Fabaceae (6). Only one endemic pine (Pinus jaliscana Pérez de la Rosa) was noted in the area. The largest number of endemic species was found along the Ojo de Agua del Cuervo ravine (28), followed by Milpillas-Bulera-San Sebastián del Oeste sites (18), La Moza-Quince Ocotes-Las Joyas complex (14), and Cerro Grande (1) (Table 4). Microspermum gonzalezii Rzed., Verbesina culminicola McVaugh, Marina dispansa (Rydb.) Barneby, and Muhlenbergia iridifolia Soderstr. had very restricted distributions and were only found in and around Ojo de Agua del Cuervo.

Temperate and Montane Cloud Forest Protection in Western Mexico and Worldwide

Of the 110 temperate and montane cloud forests sites analyzed worldwide for similarities in generic composition, 89% had some type of protection status. The majority of protected sites were included in the state park category, as well as four biosphere reserves. Two of these biospheres reserves were located in Mexico, one in

Table 2. ANOVA summary for 14 sites in 6 countries that were significantly different (P < 0.05) in tree species richness from Ojo de Agua del Cuervo, Mexico.

Country	Site	P value
Canada	Mt. St. Hilaire, Ontario	P<0.0001
USA	Bankamp State Park, Ohio	P=0.0051
	Cedar Bluffs, Indiana	P=0.0277
	Hueston Woods, beech-maple, Ohio	P=0.0277
	Kane, Allegheny National Forest, Pennsylvania	P=0.0277
	Laurel Ridge, Pennsylvania	P=0.0005
	Tridoute, Allegheny National Forest, Pennsylvania	P<0.0001
	Tyson Reserve Woods, Missouri	P=0.0123
	Montgomery Place, New York	P=0.0033
Mexico	El Cielo Biosphere Reserve, Tamaulipas	P=0.002
	La Moza, Sierra de Manantlán	P<0.0001
Colombia	Ucumari	P<0.0001
Finland	Liesjarvi National Park	P<0.0001
	Ruissalo	P=0.0002
Germany	Suderhackstedt	P<0.0001

Guatemala, and the fourth in Canada. In Mexico, the El Cielo Biosphere Reserve protects an important relict population of cloud forest sugar maple and beech. The area was recently recognized at the Mexican Federal level (Cantú et al. 2001; Sánchez-Ramos et al. 2005). The Sierra de Manantlán Biosphere Reserve, located in western Mexico, protects four montane cloud forests sites included in this study. None of the other montane cloud forests from western Mexico analyzed were included in a protected area of any category. Other montane cloud forests along Mexico lacked protection status. These include the highly diverse montane cloud forests in Oaxaca and the relict populations of Fagus grandiflora var. mexicana from Veracruz and Hidalgo states.

In situ Conservation: A Biosphere Reserve Proposal

We selected the montane cloud forests at Ojo de Agua del Cuervo as the most relevant area for in situ conservation and protection in western Mexico based on tree species richness, number of endemic species, floristic relationships, presence of relict tree species, and number of species with protection status. We selected a biosphere reserve category because the local community participates in conservation practices and because regional scientific institutions in the area participate in management based on this protection model (Halffter 1984; Batisse 1986). In addition, biosphere reserves have proven to be the most effective method for preventing vegetation loss in Mexico (Figueroa and Sánchez-Cordero 2008).

We constructed the proposed preserve based on a core and buffer area (Figure 2). The total area of the polygon is 56,394.9 ha; the core area is 6954.6 ha (12 %), surrounded by a buffer area of 49,440.3 ha (88 %). Ojo de Agua del Cuervo was included in the core area. The core area would preserve disjunct and endangered species, as well as pine, fir, oak, tropical forests, cloud forests, and the area with the largest number of endemic species for western Mexico. In addition, the important hydrologic watersheds for Talpa de Allende will be protected within the biosphere reserve. Polygon vertices were 11 and 10 for core area (Table 5).

The proposed biosphere reserve occupies the steep foothills of the Sierra de Cacoma, in the Sierra Madre del Sur, in western Jalisco. The area includes four municipalities, Talpa de Allende, Tomatlán, Mascota, and Cuautla. Approximately 70% of the polygon is located in the Talpa de Allende municipality. The main rivers are rio Talpa, rio Mascota, rio San Nicolás, and rio La Quebrada. The streams Los Tepehuajes and Paso Hondo are tributaries of rio Talpa. At the north of the polygon are streams El Zacatón, La Huerta, and Mirandilla; the last two are tributaries of rio Mascota. The stream Tescalama, La Quebrada, rio San Nicolás, and rio La Quebrada are located at the south-southwest of the polygon. Elevation ranges from 500 to 2400 m asl in the polygon. Acidic extrusive rocks from the mid-Cenozoic and acidic intrusive rocks from the Tertiary are prevalent in the area. Common soils included shallow, well-drained lime soils (Dystrict and Eutric regosols), as well as some lime secondary soils such as Haplic Phaeozem. In addition, some sandy soils (Fluvisols), Lithosols and Dystric, Humic, and Eutric cambisols, can also be found (INEGI 1974, 1976, 2001).

DISCUSSION

Species Richness and Floristic Relevance

Ojo de Agua del Cuervo is the most important forest in terms of richness and floristic composition for western Mexico. This forest is as species-rich as the one from Asia, although temperate forests from eastern Asia are richer in tree species than similar forests in most of eastern North America (Latham and Ricklefs 1993; Qian 1999). Ojo de Agua del Cuervo is floristically similar to other forests in China and Japan, which are considered to have an ancient floristic composition and extreme physiographical heterogeneity (Qian and Ricklefs 2000). The species composition that includes both tropical and temperate affinities contributes to a high richness. Other Mexican montane cloud forests are less diverse and have significantly less species richness than those in the southern portion of Central America and in South

America (Gentry 1995). Past land connections, air and sea currents, and bird dispersal are commonly used to explain floristic relationships (Qian 1999), but a detailed phytogeographic analysis would be needed to understand the observed patterns in richness for Ojo de Agua del Cuervo.

Floristic composition of Ojo de Agua del Cuervo resembles that of other forests containing disjunct and relict species. The classification of temperate and montane cloud forest tree communities based on their generic composition shows that Ojo de Agua del Cuervo in western Mexico is floristically related to forests in Mexico and Asia that contain disjunct genera (Figure 1). None of the other montane cloud forests from western Mexico were in this cluster. Forests in this cluster share genera such as Acer and Fagus. These species have disjunct distributions in Mexico and are considered relict elements in the Mexican flora that were previously more widely distributed during the Pleistocene Epoch. The forests in this cluster contain an important proportion of genera established at different times during the Neogene Period. Climate conditions during the Pleistocene reduced the distribution of these genera to the currently known fragmented pattern. In this sense, the montane cloud forests in Ojo de Agua del Cuervo contain a floristic composition that might resemble the one before major climate changes of the Pleistocene, providing another reason for conservation priority.

Species Protection Status in Montane Cloud Forests of Western Mexico

Ojo de Agua del Cuervo, which has the largest number of species currently under protection status in western Mexico, lacks legal protection and is not included in any protected area. The montane forests in Ojo de Agua del Cuervo include an array of endangered species–for instance, *Acer saccharum* subsp. *skutchi*i, designated by MESA because of its fragmented distribution across Mexico and low stem densities at most known sites. This species should also be included in the RLTS (Vargas-Rodriguez 2005). Currently, only *Abies guatemalensis* var. *jaliscana* Martínez is listed as endangered in the MESA, CITES, and RLTS. Based on the criteria used to assign protection categories, species such as *Magnolia pacifica* var. *pacifica* A. Vázquez and *Osmanthus americana* Benth. & Hook. also should be considered as vulnerable (RLTS) or threatened (MESA) in Mexico.

The montane cloud forest in Ojo de Agua del Cuervo is susceptible to the effects of disturbance and fragmentation. Cloud forest sugar maple seedlings establish in the low light environment present in the understory, and their numbers decrease with increased light levels along forest edges (Vargas-Rodriguez et al. 2006). In addition, soil and environmental moisture conditions change along forest edges, reducing survival of seedlings of several other tree species restricted to montane cloud forests (Gascon et al. 2000). Therefore, deforestation, which is currently taking place in surrounding areas, and associated edge effects resulting from logging may well change environmental conditions in montane cloud forests, diminishing tree germination and establishment (Williams-Linera 2002).

Deforestation, illegal logging, and the creation of new roads are the major threats at Ojo de Agua del Cuervo. The logging of *Abies guatemalensis* var. *jaliscana* occurs frequently in the area, although the species is included in the MESA, CITES, and RLTS. In addition, species such as the arborescent fern, *Cyathea costaricensis* Domin., have been extracted illegally for commercial purposes. Finally, a new road has been created to connect the towns of Talpa de Allende and Llano Grande, cutting through the adjacent montane cloud forests. This road might decrease species connectivity by preventing larger and cohesively-protected zones. Alternatively, the road could provide access for invasive species. Increased separation of the forest from adjacent areas and subsequent reduction in the unfragmented area might reduce the conservation of wide-ranging mobile animal species (Crist et al. 2005).

Endemic Species in Montane Cloud Forests of Western Mexico

Montane cloud forests at the Ojo de Agua del Cuervo and surroundings had the highest number of endemic species (28). This first assessment of the number of endemic species present in montane cloud forests from western Mexico points out the relevance of the Ojo de Agua del Cuervo in terms of endemic species, which supports the creation of a protected area (Stattersfield et al. 1998; Myers et al. 2000). In contrast, northern Jalisco, despite its large surface and diverse climatic and geographic conditions, only contains 11 endemic species (Hernández 1999). Future botanical explorations in western Mexico will help to determine more accurately the proportion of endemic species in western Mexico.

The dominance of endemic species belonging to the Asteraceae in montane cloud forests in western Mexico was consistent with findings of Delgadillo et al. (2003). At the national level, the largest numbers of endemic Asteraceae occur in Jalisco and Michoacán (in western Mexico), the Pacific Mexican state of Oaxaca, as well as in the northern state of Durango (Delgadillo et al. 2003). In addition, Asteraceae contained the largest number of endemic vascular plants at Sierra de Manantlán (Hernández 1995). Sixty-five percent of Asteraceae species in Mexico are endemic, and an important proportion of these endemics are present in montane cloud forests (Delgadillo et al. 2003). Thus, the number of endemic Asteraceae species in Mexican montane cloud forests can be used to delimitate areas for conservation purposes (Rzedowski 1991; Myers et al. 2000; Lamoreux et al. 2005). On the other hand, Fabaceae is the most species-rich family among endemic trees in Mexico. The number of endemic species of Fabaceae is also important in the montane cloud forests studied, and they significantly contribute to the proportion of the endemic trees in Colima state (Padilla-Velarde et al. 2006.

Montane floras have generally higher levels of endemism than lowland tropical floras (Gentry 1995). Accordingly, the montane

Table 3. Protection status of trees present at 10 sites in western Mexico. It indicates the protection category of each species at occurrence locality. Abbre Flora; RLTS, IUCN Red List of Threatened Species. According to MESA, P=In risk of extinction, A=Endangered, Pr=Under special protection. Accord

Family	*Species*	*Sites*			
		Milpillas	La Bulera	Ojo de Agua del Cuervo	La Moza
Pinaceae	*Abies guatemalensis* Rehder var. *jaliscana* Martínez			MESA: P	
				CITES: I	
				RLTS: VUAld	
Pinaceae	*Abies religiosa* Lindl. var. *religiosa* Loock & Martinez				
Sapindaceae	*Acer saccharum* subsp. *skutchii* (Rehder) Murray			MESA: P	MESA: P
Guttiferae	*Calophyllum brasiliense* Cambess. var. *rekoi* (Standl.) Standl.		MESA: A		
Betulaceae	*Carpinus caroliniana* Walt.			MESA: A	MESA: A
Cecropiaceae	*Cecropia obtusifolia* Bertol.		RLTS: LR/lc		
Meliaceae	*Cedrela odorata* L.	RLTS: VUAlcd+2cd			
Ericaceae	*Comarostaphylis discolor* (Hook.) Diggs subsp. *discolor*				
Cornaceae	*Cornus disciflora* DC.	RLTS: VUAlcd		RLTS: VUAlcd	RLTS: VUAlcd
Cyatheaceae	*Cyathea costarricensis* (Kuhn) Domin			MESA: P	
Lauraceae	*Litsea glaucescens* H.B.K.			MESA: P	
Magnoliaceae	*Magnolia iltisiana* A. Vázquez				MESA: A
					RLTS: VUB1+2c
Hamamelidaceae	*Matudea trinervia* Lundell				
Araliaceae	*Oreopanax echinops* Decne. & Planch.				
Betulaceae	*Ostrya virginiana* (Mill.) K. Koch.			MESA: Pr	MESA: Pr
	Pinus maximinoi H.E.Moore			RLTS: LR/1c	
Pinaceae	*Pinus pseudostrobus* Lindl.				RLTS: LR/lc
Fagaceae	*Quercus uxoris* McVaugh			RLTS: VUAlc	
Fagaceae	*Quercus xalapensis* Humb. et Bonpl.			RLTS: VUAlc	
Actinidiaceae	*Saurauia serrata* DC.			MESA: Pr	
				RLTS: EN B1+2c	
Apocynaceae	*Stemmadenia tomentosa* Greenm.				
Tiliaceae	*Tilia mexicana* Schltdl.				
Celastraceae	*Zinowiewia concinna* Lundell	MESA: P		MESA: P	MESA: P

viations are as follows: MESA, Mexican Endangered Species Act; CITES, Convention on International Trade in Endangered Species of Wild Fauna and ing to RLTS, VU=Vulnerable, LR=Lower risk, EN=Endangered. According to CITES, I=Included in appendix I.

Sites (Continued)

Las Joyas	Quince Ocotes	Cerro Grande 2000 m a.s.l.	Cerro Grande 2100 m a.s.l.	Cerro Grande 2200 m a.s.l.	Cerro Grande 2300 m a.s.l.
			RLTS: LR/lc		
MESA: A	MESA: A				
					MESA: Pr
	RLTS: VUAlcd				
MESA: A	MESA: A				
RLTS: VUB1+2c	RLTS: VUB1+2c				
	MESA: A				
	RLTS: VUB1+2c				
RLTS: VUAlc	RLTS: VUAlc				
	MESA: Pr				
		RLTS: LR/lc			
MESA: P					
MESA: P	MESA: P	MESA: P	MESA: P	MESA: P	MESA: P

Table 4. Endemic vascular plants in western Mexico occurring at the 10 sites studied and their surrounding areas. The number 1 indicates presence.

		Along ravine of Ojo de Agua del Cuervo	*Milpillas-Bulera-San Sebastián del Oeste*	*La Moza-Quince Ocotes-Las Joyas*	*Cerro Grande*
Malvaceae	*Abutilon jaliscanum* Standley		1		
Euphorbiaceae	*Acalypha langiana* Mull. Arg. var. *vigens* McVaugh	1	1		
Poaceae	*Aristida tuitensis* Sánchez-Ken & P. Dávila	1		1	
Mimosaceae	*Calliandra anomala* (Kunth) Macbr. var. *longepedicellata* McVaugh			1	1
Scrophulariaceae	*Castilleja pterocaulon* N. H. Holmgren		1	1	
Asteraceae	*Cosmos sessilis* Sherff		1		
Fabaceae	*Dalea mexiae* Barneby		1		
Fabaceae	*Desmodium occidentale* (Morton) Standl.	1	1	1	
Fabaceae	*Desmodium skinneri* Benth. ex Hemsl. var. *flavovirens* Schubert & McVaugh	1	1		
Apiaceae	*Eryngium jaliscense* Mathias & Constance	1		1	
Asteraceae	*Eupatorium ceriferum* McVaugh			1	
Asteraceae	*Eupatorium misellum* McVaugh	1			
Euphorbiaceae	*Euphorbia soobyi* McVaugh	1			
Asteraceae	*Galinsoga mollis* McVaugh	1			
Orchidaceae	*Hagsatera rosilloi* R. González	1	1		
Fabaceae	*Indigofera incompta* McVaugh	1			
Orchidaceae	*Laelia bancalarii* R. González & Hágsater	1	1		
Onagraceae	*Lopezia laciniata* (Rose) Jones subsp. *laciniata* Plitmann, Raven & Breedlove	1	1		
Fabaceae	*Marina dispansa* (Rydb.) Barneby	1			
Asteraceae	*Microspermum gonzalezii* Rzedowski	1			
Poaceae	*Muhlenbergia iridifolia* Soderstr.	1			
Apiaceae	*Neogoezia macvaughii* Constance	1			
Asteraceae	*Otopappus jaliscensis* McVaugh	1		1	
Euphorbiaceae	*Pedilanthus connatus* Dressler et Sacamano	1			

Continued

Table 4. (Contd) Endemic vascular plants in western Mexico occurring at the 10 sites studied and their surrounding areas. The number 1 indicates presence.

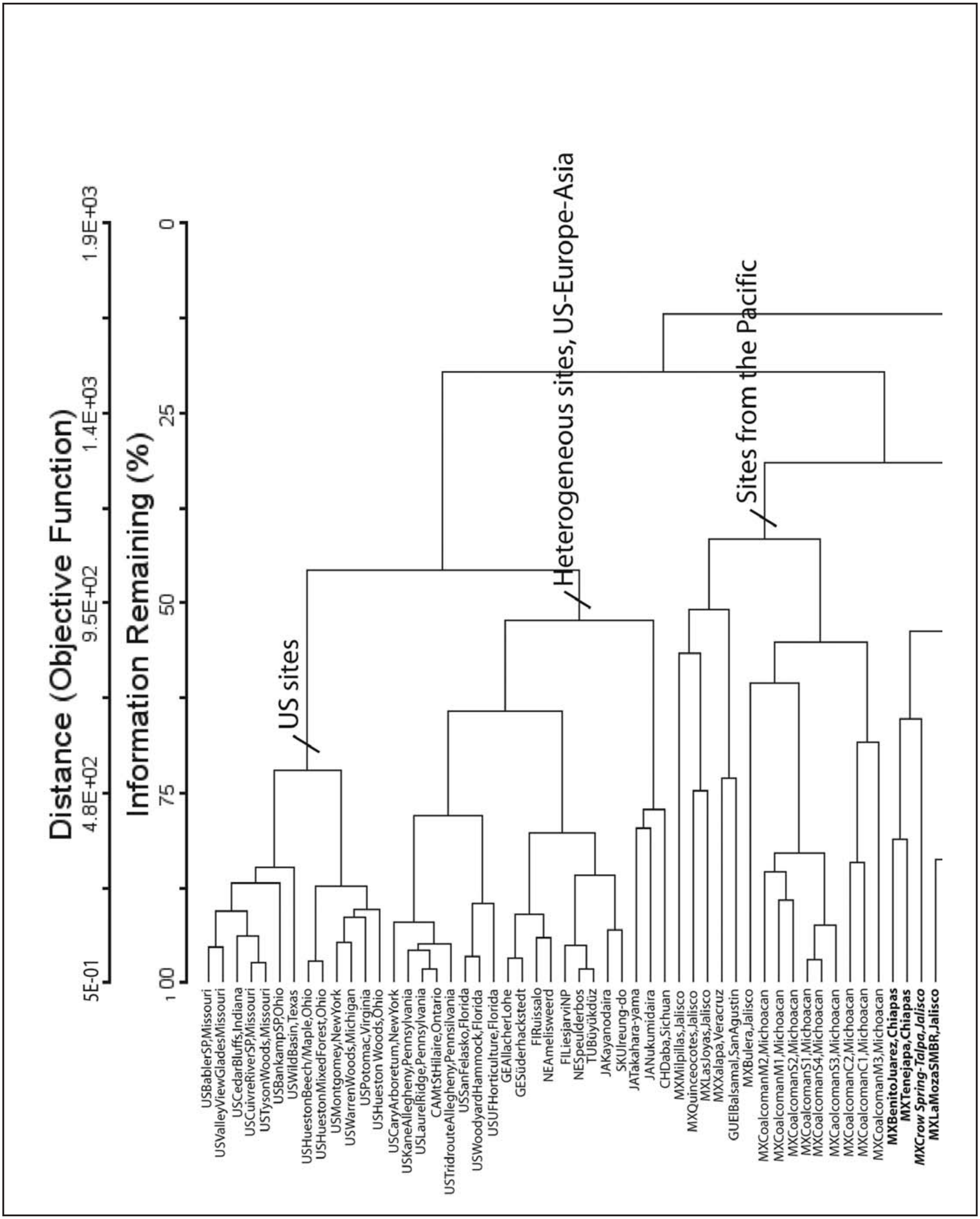
		Along ravine of Ojo de Agua del Cuervo	Milpillas-Bulera-San Sebastián del Oeste	La Moza-Quince Ocotes-Las Joyas	Cerro Grande
Asteraceae	*Perezia nelsonii* B. L. Rob.	1	1		
Solanaceae	*Physalis longiloba* Vargas, M. Martínez & Dávila			1	
Solanaceae	*Physalis longipedicellata* Waterfall			1	
Solanaceae	*Physalis mcvaughii* Waterf.	1			
Lentibulariaceae	*Pinguicula parvifolia* B. L. Rob.			1	
Pinaceae	*Pinus jaliscana* Pérez de la Rosa	1	1		
Asteraceae	*Piptothrix jaliscensis* B. L. Rob.	1	1		
Asteraceae	*Polymnia mcvaughii* Wells	1		1	
Asteraceae	*Psacalium pentaflorum* B. L. Turner	1	1	1	
Acanthaceae	*Ruellia jaliscana* Standl.	1	1	1	
Asteraceae	*Stevia urceolata* Grashoff		1		
Fabaceae	*Tephrosia platyphylla* (Rose) Standl.		1		
Iridaceae	*Tigridia pugana* Aaron Rodr. & L. Ortiz-Catedral			1	
Tiliaceae	*Triumfetta indurata* W. W. Thomas & McVaugh	1	1		
Asteraceae	*Verbesina culminicola* McVaugh	1			
Asteraceae	*Vernonia autumnalis* McVaugh	1			
Total		28	18	14	1

cloud forests in Veracruz contain the largest number of endemic species with a very restricted distribution (Castillo-Campos et al. 2005). Cooler areas are usually high in number of endemics (Delgadillo et al. 2003). Species in montane cloud forests might be narrowly adapted to the humid conditions found along the ravines where this vegetation persists. In addition, vicariant speciation, resulting from habitat isolation and the fragmented pattern of montane cloud forests, might result in the elevated number of endemic species contained in western Mexico (Rzedowski 1996). Endemic species must be a target of conservation since they are important in understanding patterns of species origin and evolution, which reflects the diversification history of an area (Qian 2001).

Montane Cloud Forest Protection in Western Mexico and the Biosphere Reserve Proposal

Biosphere reserves in Mexico can be effective for protecting natural areas. Effectiveness of management and maintenance of ecological integrity are achieved in 65% of the biosphere reserves in Mexico, indicating that might be an adequate category for conservation success (Figueroa and Sánchez-Cordero 2008). This category had the greatest effectiveness for preventing vegetation loss compared with the other protected areas categories recognized by Mexican legislation: national parks and flora and fauna protection areas (Figueroa and Sánchez-Cordero 2008).

Montane cloud forests in Talpa de Allende should be the most important for preservation. In western Mexico, the Sierra de Mananatlan Biosphere Reserve (Jalisco-Colima), the Volcán Nevado de Colima National Park (Jalisco-Colima), and the Sierra de Quila Flora and Fauna protection area (Jalisco), Pico de Tancítaro National Park (Michoacán), Cerro de Garnica National Park (Michoacán), preserve montane cloud forests fragments (CONANP 2002). However, except for montane cloud forests at Sierra de Manantlán, no other site has been evaluated for area occupied by montane cloud forests and their conservation


Distance (Objective Function)
5E-01
4.8E+02
9.5E+02
1.4E+03
1.9E+03
Information Remaining (%)
100
75
50
25
0
US sites
Heterogeneous sites, US-Europe-Asia
Sites from the Pacific
USBablerSP,Missouri
USValleyViewGladesMissouri
USCedarBluffs,Indiana
USCuivreRiverSP,Missouri
USTysonWoods,Missouri
USBankampSP,Ohio
USWildBasin,Texas
USHuestonBeech/Maple,Ohio
USHuestonMixedForest,Ohio
USMontgomey,NewYork
USWarrenWoods,Michigan
USPotomac,Virginia
USHueston Woods,Ohio
USCaryArboretum,NewYork
USKaneAllegheny,Pennsylvania
USLaurelRidge,Pennsylvania
CAMtStHilaire,Ontario
USTridrouteAllegheny,Pennsilvania
USSanFelasko,Florida
USWoodyardHammock,Florida
USUFHorticulture,Florida
GEAllacherLohe
GESüderhackstedt
FIRuissalo
NEAmelisweerd
FILiesjarviNP
NESpeulderbos
TUBüyükdüz
JAKayanodaira
SKUlreung-do
JATakahara-yama
JANukumidaira
CHDaba,Sichuan
MXMilpillas,Jalisco
MXQuinceocotes,Jalisco
MXLasJoyas,Jalisco
MXXalapa,Veracruz
GUEIBalsamal,SanAgustin
MXBulera,Jalisco
MXCoalcomanM2,Michoacan
MXCoalcomanM1,Michoacan
MXCoalcomanS2,Michoacan
MXCoalcomanS1,Michoacan
MXCoalcomanS4,Michoacan
MXCaolcomanS3,Michoacan
MXCoalcomanC2,Michoacan
MXCoalcomanC1,Michoacan
MXCoalcomanM3,Michoacan
MXBenitoJuarez,Chiapas
MXTenejapa,Chiapas
MXCrow Spring-Talpa,Jalisco
MXLaMozaSMBR,Jalisco

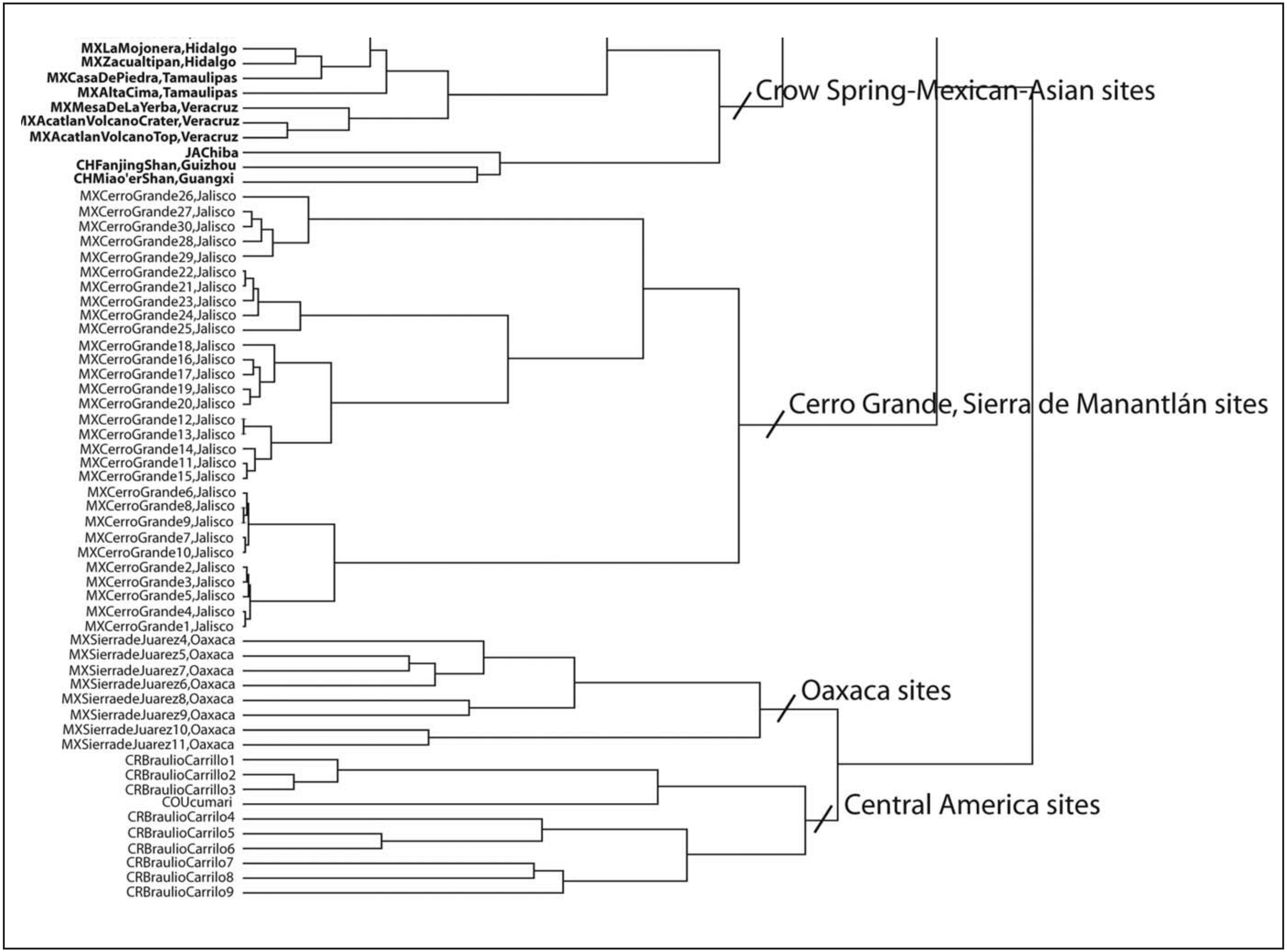


Figure 2. Classification of temperate and montane cloud forests communities based on generic composition. Cluster including Ojo de Agua del Cuervo is in bold, the forest is distinguished by bold italics. The first initials indicate the country, followed by the locality name and in some cases the state name at the end in shown. CH is China, CO is Colombia, CR is Costa Rica, FI is Finland, GE is Germany, GU is Guatemala, JA is Japan, MX is Mexico, NE is Netherlands, SK is South Korea, TU is Turkey, and US is United States.

Table 5. Vertices and their geographic coordinates to the proposed biosphere reserve in the Ojo de Agua del Cuervo, Talpa de Allende, Jalisco, Mexico.

Zone	Vertex name	Latitude	Longitude
Buffer area	Cerro Las Cebollas	104º40’30.854	20º7’51.887
	Las Conchas	104º47’37.311	20º7’26.107
	Cerro El Pachón	104º50’16.694	20º8’37.423
	El Pozo	104º50’47’03	20º11’12.469
	El Escondido	104º53’15.926	20º14’2.515
	El Aguaje	104º51’24.586	20º15’37.656
	El Tigre	104º50’12.159	20º19’57.067
	Picacho de Peña	104º45’44.125	20º22’13.0
	La Huerta	104º43’6.316	20º20’44.426
	Los Lobos	104º38’40.069	20º17’47.706
	Las Víboras	104º38’33.076	20º12’50.406
Core area	Los Picachitos	104º44'54.107	20º17'10.556
	El Jato	104º43'36.575	20º16'42.763
	Los Guajes	104º43'58.563	20º15'40.424
	El Zacatón	104º42'33.474	20º14'31.155
	La Cumbre	104º43'04.323	20º11'38.427
	Arrayán	104º46'12.364	20º11'29.039
	Cuesta de Herón	104º47'09.095	20º13'26.862
	El Refugio	104º46'32.208	20º15'30.620
	Paso Hondo	104º46'17.541	20º17'15.599
	El Cuji	104º45'03.759	20º09'57.177

status. Sierra de Manantlán and montane cloud forests at Talpa de Allende municipality, where the Ojo de Agua del Cuervo is located, appear to be the two primary locations for conservation of cloud forests. Sierra de Manantlán already is protected, and the Ojo de Agua del Cuervo and surrounding forests need to be included in a protected area. The creation of a biosphere reserve at the Ojo de Agua del Cuervo will protect the most important relict montane cloud forests in western Mexico and will be the first area created specifically to protect these forests.

The biosphere reserve we propose would increase the protected area of an endangered ecosystem. Mexico has 161 federally administrated Natural Protected Areas, representing 11.54% (22.71 million ha) of the country (CONANP 2007). The proposed biosphere reserve represents 0.7% and 0.03%, respectively, of the area of Jalisco and Mexico. The biosphere reserve polygon increases the area of montane cloud forests, as well as pine and oak forests, that are currently underrepresented by the Mexican natural protected system (Cantú et al. 2001, 2004). Intermediate elevations (< 3000 m) with montane cloud forests and high productive soils are the primary gaps in the current Mexican protected areas system (Cantú et al. 2004). The opposite is true for areas located in elevations from 0 to 500 m (Cantú et al. 2004). At the state level, Sierra de Manantlán Biosphere Reserve is the only biosphere reserve preserving montane cloud forests (2066 ha, 0.025% Jalisco surface area) (INE 2000). We estimate that a similar area of montane cloud forests could be protected around Ojo de Agua del Cuervo.

The creation of a new biosphere reserve in western Mexico will facilitate development of flora and fauna corridors to other protected areas. Corridors promote the preservation of several biological processes (Damschen et al. 2006). Furthermore, a connection with Chamela-Cuixmala and Sierra de Manantlán Biosphere Reserves in western Mexico could create a network of protected areas for the region. Tropical dry forest at Chamela-Cuixmala can be connected to tropical forest in the southern portion of the proposed polygon, while temperate and montane cloud forests could connect with Sierra de Manantlán through Sierra de Cacoma.

The hydrologic region of Talpa de Allende can also be protected. Montane cloud forests have an important role in stabilizing water quality and maintaining natural flow patterns of the streams and the rivers originating from them (Bubb et al. 2004). The montane cloud forests have the unique additional value of capturing water from the condensation from clouds and fog. The amount of water intercepted by the vegetation in montane cloud forests can be 15% to 20% of the amount of direct rainfall (Bubb et al. 2004). This is relevant to the Mexican Pacific slopes where rainfall and water availability throughout the year are lower than on the Atlantic slopes.

Ojo de Agua del Cuervo is eligible for long-term protection. In an unprecedented initiative, 3000 inhabitants of Talpa de Allende signed a protection proposal for cloud forest sugar maple in 2002. Through Jalisco legislators, the proposal was sent to the Federal Mexican authorities in October 2002 and reviewed by Federal legislators in November 2004, but no response has been received yet. We urge Mexican authorities to protect the zone under the biosphere reserve category to ensure the protection and conservation of species-rich montane cloud forests in Ojo de Agua del Cuervo in Talpa de Allende. The support of conservation agencies and organizations is needed to encourage Mexican authorities to provide a protected status to the area.

Ojo de Agua del Cuervo should be incorporated into a biosphere reserve, based on unique and relictual biodiversity elements, regional hydrologic importance, tree species richness, the presence of relict and endangered species, large numbers of endemic vascular plants, floristic relationships, and a characteristic montane landscape in the area. The establishment of this protected area will preserve the most important montane cloud forest relicts in the western portion of Mexico.

ACKNOWLEDGMENTS

We are most grateful for the work of A. Gentry and those who helped him obtain data on structure and richness of cloud forests. Yalma Vargas-Rodriguez acknowledges research support provided by grants from the National Council for Science and Technology, Mexico (CONACYT-161695, Vargas-Rodriguez's fellowship), University of Guadalajara, IDEAWILD Foundation, and Louisiana State University. We thank Matthew Slocum and James Chaney for comments on this paper.

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