Solanaceae composition, pollination and seed dispersal syndromes in Mexican Mountain Cloud Forest

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RESUMO — (Composição de Solanaceae, polinização e síndromes de dispersão de sementes em Floresta Mesófila de Montanha). Neste trabalho a hipótese é que a composição das espécies de Solanaceae e as síndromes de polinização e dispersão de sementes variam de acordo com o grau de perturbação. Assim o objetivo é analisar como a composição de espécies de Solanaceae e suas síndromes de polinização e de dispersão de sementes variam ao longo de um gradiente de perturbação. Este trabalho foi realizado nas Florestas Mesófilas de Hidalgo, México. As Solanaceae foram coletadas ao longo de transectos, dispostos em caminhos ou estradas secundárias. As síndromes de polinização e dispersão de sementes foram caracterizadas a partir das características morfológicas das flores e frutos. Das 500 amostras coletadas, 392 continham Solanaceae, pertencentes a 25 espécies. A similaridade entre as amostras mostrou dois grupos: no grupo I estavam as espécies mais freqüentemente encontradas em áreas menos perturbadas e mais úmidas, enquanto o grupo II apresentava as espécies mais frequentes em ambientes mais perturbados. A síndrome de melitofilia foi relevante nos dois grupos. No entanto, a ornitocoria (45,8%) prevaleceu sobre a chiropterocoria (37,5%) em áreas menos perturbada e mais úmida do grupo I, enquanto chiropterocoria (50%) foi maior no grupo II.

Palavras-chaves: perturbação florestal, ornitocoria, chiropterocoria, melitofilia, México

ABSTRACT — (Solanaceae composition, pollination and seed dispersal syndromes in Mexican Mountain Cloud Forest). In this work we hypothesised that Solanaceae species composition and pollination and seed dispersal syndromes change according to the degree of disturbance. Hence, the aim of this study is to analyze how the species composition of Solanaceae changes along disturbance gradients of mountain cloud forest, and to establish how Solanaceae pollination and seed dispersal syndromes vary along the same gradients. The study concentrates on the mountain cloud forests in Hidalgo, Mexico. Solanaceae species collection was carried out along transects, laid out alongside paths and secondary roads. Pollination and seed dispersal syndromes for all species were recorded based on floral and fruit morphological traits. From the 500 sample units surveyed, 392 contained 25 Solanaceae species. The (dis)similarity among sample units highlighted a major division: the first group harboured species more commonly found in less disturbed and more humid conditions, whereas the second group contained species more commonly found in contrasting conditions. Melittophilory pollination syndromes turned out to be equally relevant in the environmental conditions of both groups. With regard to seed dispersal syndromes, ornithochory (45.8%) prevailed over chiropterochory (37.5%) in group I less disturbed and more humid areas, whereas chiropterochory (50%) prevailed within group II.

Key words: forest disturbance, ornithochory, chiropterochory, melittophilory, Mexico

Introduction

The Solanaceae family comprises 90 genera, containing more than 3,500 species (D’Arcy 1986). Its cosmopolitan distribution is best represented in tropical and temperate regions, with Australia and Latin America as major dispersal centres (Barroso et al. 1991). The greatest solanaceous species diversity occurs in South America, and this area is recognised as the family’s centre of origin (Hunziker 1979). Solanaceous species are represented in most habits: trees, shrubs, herbs and occasionally as climbers, epiphytes (Markea and Juanulloa), rhizomateous herbs (Jaborosa), and thorny (Acnistus, Grabowskia and Solanum) and thornless (e.g. Cestrum) shrubs (Barroso et al. 1991). Despite the worldwide distribution and diversity of the group, some taxa are restricted to particular ecological conditions. For example, in Mexico Lycianthes monziniana is distributed at elevations above 2000 m in pine-oak forests (Williams 1993), while
others such as *Solanum iopetalum* are present only in pine forest (Rzedowski & Rzedowski 1985). Yet others are restricted to specific geographical regions (*Physalis tehuacanensis* and *P. queretaroensis*, species endemic to Mexico). Despite the considerable work carried out with this group, little research has been conducted to document its role as a light gap coloniser and coloniser of disturbed areas such as pastures, clearings, roadsides and forest edges (Bohs 1994; Da Silva et al. 1996; Miriti 1998; Nepstad et al. 1998; Tabarelli et al. 1999). Colonisation in open areas depends largely on pollination and seed dispersal processes (Murray et al. 2000). These last two processes are crucial to understanding the colonisation role of Solanaceae and, in turn, to comprehending the way colonisation takes place as part of the ecosystem function (Morellato & Leitão Filho 1992; Gorchov et al. 1993; Reis et al. 1996; Medellin & Gaona 1999).

Solanaceae are well known for the large quantities and variety of secondary metabolites, such as alkaloids, flavanoids and terpenes (Evans 1986). Recently, the ecological importance of *Solanum* alkaloids in limiting frugivory (Cipollini & Levey 1997a; 1997b; 1997c) and as anti-fungal agents (Cipollini & Levey 1997b) has been highlighted. These features, in addition, play a role in herbivory and seed dispersal.

Pollination and seed dispersal processes have been documented within evolutionary (e.g. Herrera 1985; Hegde et al. 1991; Tamboia et al. 1996) and ecological contexts (Vázquez-Yanes et al. 1975; Symon 1979; Howe & Smallwood 1982; Gautier-Hion et al. 1985; Fleming & Sosa 1994; Galindo-González 1998). In the present paper, the pollination and seed dispersal processes of Solanaceae are studied within a matrix of forest patches.

This study was conducted in Mexican mountain cloud forest. The vegetation is considered to be transitional, between temperate and tropical forests (Rzedowski 1996). Furthermore, this forest has been drastically disturbed, so forest gaps and openings are common. Colonisation of these forest openings by pioneer species (such as Solanaceae) may therefore play an important role in mountain cloud forest recovery. It has been well documented that disturbance drastically modifies species composition and community structure (Navarro 1992; Velázquez 1994). With this in mind, it is hypothesised that Solanaceae species composition and, consequently, pollination and seed dispersal syndromes vary according to the degree of mountain cloud forest disturbance. Among well-conserved forest patches, the diversity of syndromes may be larger and their proportion more balanced than among disturbed forest patches, where syndromes may differ significantly. Hence, the aim of this study is to analyze how the species composition of Solanaceae changes along disturbance gradients of mountain cloud forest, and to establish how Solanaceae’s pollination and seed dispersal syndromes vary along the same gradients.

**Methods**

Study area – In Mexico, mountain cloud forests reach their most septentrional geographical distribution worldwide. A high diversity (over 3,000 vascular plant species, of which many are endemic) and the remarkable predominance of vascular epiphytes and lianas (Alcantara et al. 2002) characterise these ecosystems. Their current distributions form an archipelago-like pattern and cover less than 1% of the Mexican surface (Rzedowski 1996; Luna et al. 2001). At such places, heterogeneous ecological conditions prevail (Mayorga et al. 1998), which is reflected in large floristic and physiognomic dissimilarities (Rzedowski 1996). Mexican mountain cloud forests comprise dwarf, short, medium and tall forest communities, as well as evergreen and deciduous. This vegetation is subjected to large human disturbances, which have formed a fragmented distribution pattern divided into a matrix of fragments of different sizes and split by trails, secondary roads, crops and pasture lands. Heliophyllous taxa prevail in early successional stages along edges of fragments, among which Solanaceae are conspicuous. These have been poorly studied since most vegetation surveys are biased to sample pristine conditions, so that Solanaceae are rarely found. The role of these as successional facilitators, therefore, has not been documented.

The present research was conducted in nine different areas of Mexican mountain cloud forest located in the Sierra Madre Oriental in the state of Hidalgo (Fig. 1A), within the jurisdiction of the municipalities of Molango, Lolotla, Xochicoatlán and Tlanchinol, and surrounding localities. These areas vary in elevation from 1,380 to 1,800 m. The landscapes vary from hilly to mountainous, with large differences between one slope and another in terms of soils, relief, exposure and sunlight incidence. In turn, forest physiognomy and species composition vary too. Climbers and epiphytes and tree fern types occur regularly in some areas. Table 1 synoptically describes the (dis)similarities among the nine forests studied and provides a detailed profile of the degree of disturbance observed in all areas.

The rainy season is from May to November, with
most precipitation falling from June to September. The major landscapes are predominantly mountainous, with steep straight short slopes. Dominant soil types are Cambisol, Regosol, Acrisol and Pheozem. Apart from the vegetation type studied here, pine and subtropical rainforest fragments occur in the region. Nowadays, however, most pristine vegetation types at low altitudes and on moderately steep slopes have been cleared for cropping, livestock production and timbering (Challenger 1998).

Sampling design – Intensive surveys were conducted in the region between April and November 1999 in order to select the cloud forest areas to be sampled. Two selection criteria were applied: a varying degree of disturbance, ranging from low to high, and the presence of paths and secondary roads at least 2 km long (openings) crossing the areas.

The degree of disturbance was estimated by describing the forest structure under the assumption the more pristine, the less disturbed (sensu Williams-Linera 1993). Species composition was also considered as an indicator of disturbance. Challenger (1998) provides a detailed list of tree species favoured by disturbance. The abundance of these disturbance indicator species, and their development status were reckoned as indirect measurements of the degree of disturbance. Traces of burning, timbering and grazing were also noted as indicators of the degree of disturbance. In addition, the type of secondary roads crossing each forest patch (for instance, those used by cars or those used by local people only) was also considered as an indirect index of the degree of disturbance (see Table 1).

Overall, nine forest areas were chosen (from different localities). Solanaceae species collection took place along transects (each 1200 m long) lying alongside paths and secondary roads. These nine forest areas were grouped into two disturbance classes, so that transect number was evenly sampled in each group. Each transect was divided into 20 sample units (10 m long and 3 m wide) 50 m apart (Fig. 1B). In total, 25
Table 1. Synoptic characteristics of the nine forest areas (localities) surveyed in Mexican mountain cloud forest in the Sierra Madre Oriental, Hidalgo (Mexico). AMT = mean annual temperature; AMP = mean annual precipitation. Sources: ¹CONABIO/ESTADIGRAFIA (1997a) and Garcia (1981); ²CONABIO/ESTADIGRAFIA (1997b); ³SSP (1983).

| Forest areas (localities) | Location | Altitude (m) | Climate | AMT¹ (°C) | AMP² (mm) | Soil type(s)² |
|---------------------------|----------|--------------|---------|-----------|-----------|---------------|
| (1) Lontla (road), Highway Pachuca-Tampico. Municipality of Tlanchinol. Pristine forest typified by a canopy 40 m high. Pteridophytes reaching up to 10 m high are abundant. Disturbance: one path used as a walking trail for indigenous people only; no traces of timbering, burning and grazing. The largest area and considered the most conserved. | 21°01'34.2"N 98°38'24"W | 1380 to 1450 | Semi-warm humid (A)(C)(fm)(i')gw² Slope exposure: East | 18-22 | 2500 | Lithosol-Feozem Rendzina, loamy texture |
| (2) Road to Apantlazol, Highway Pachuca-Tampico 7 km. Municipality of Tlanchinol. Dense forest has a canopy 40 m high. Pteridophyte communities are abundant and short. Disturbance: one secondary road and a path cross the area; traces of timbering, burning and grazing for subsistence purposes were observed. The second largest area and considered well conserved. | 20°58'55"N 98°37'1"W | 1450 to 1520 | Semi-warm humid (A)(C)(fm)(i')gw² Slope exposure: East | 18-22 | 2500 | Lithosol-Feozem-Rendzina, loamy texture |
| (3) Molango (road chapel, old iron mine), Highway Pachuca-Tampico 130 km. Municipality of Molango. Secondary forest characterised by a canopy 20 m high. Disturbance: an abandoned path used for mining purposes 50 years ago; surrounded by open pasturelands; mowing and grazing were observed along path. No signs of recent timbering or burning were detected. Area of relatively small size. | 20°46'41"N 98°43'33"W | 1670 | Temperate subhumid C(w2) Slope exposure: Southwest | 12-18 | 1500 | Luvisol-Cambisol, loamy texture |
| (4) Road to Eloxochitlán. Municipality of Molango. Remnants of secondary forest with canopy 20 m high Disturbance: a secondary road frequently used by trucks; surrounded by open pasturelands. Area of relatively small size. | 20°45'04"N 98°45'00"W | 1660 | Mild humid, with long fresh 5-12 summer Cb'(m)(f)(i')g Slope exposure: Southwest/Northeast | 12-18 | 1500 | Luvisol-Cambisol, loamy texture |
| (5) Road to Jalameco. Municipality of Xochicoatlán. Secondary forest with canopy 20 m high. Disturbance: one secondary road and a path crossing the area. Relatively medium-size area, considered little disturbed. | 20°47'46"N 98°41'48"W | 1680 | Temperate humid C(m)(f)(e)g Slope exposure: Northeast | 12-18 | 2000 | Regosol-Cambisol-Acrisol, deep litic phase, lime texture |
| (6) Mo-Xo (Molango–Xochicoatlán), Highway Pachuca-Tampico 122 km. Municipality of Molango. The forest varies from dense to semi-dense, with trees reaching from 20 to 30 m. Disturbance: only small trails were observed; traces of timbering, grazing and burning were recorded. The size of the area is medium. | 20°44'42"N 98°42'19"W | 1450 | Temperate subhumid C(w2) Slope exposure: Southeast | 12-18 | 1800 | Luvisol-Cambisol, loamy texture |
| (7) Naopa. Municipality of Lolotla. Open secondary forest with trees from 10 to 20 m. Disturbance: only a secondary road surrounded by pasturelands; traces of mowing, grazing and burning were observed. The size of the area is relatively small. |
| (8) Road to Tianguistengo. Municipality of Xochicoatlán. Secondary forest with trees from 10 to 20 m. Disturbance: a secondary road heavily transited, surrounded by pasturelands; mowing, grazing and patches of orchards were observed. The size of the area is relatively medium. | 20°51'03"N 98°43'22"W | 1650 | Temperate humid C(fm)(i')gw² Slope exposure: Southwest/Northeast | 12-18 | 2000 | Regosol-Cambisol-Acrisol, deep litic phase, loamy texture |
| (9) Lolotla (Highway Pachuca-Tampico, 140 km). Municipality of Lolotla. Open secondary forest with trees from 10 to 20 m. Disturbance: numerous trails surrounded by pasturelands; grazing, timbering, burning and corn crops were observed. |

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transects (including 500 sample units) were surveyed covering the gradient of disturbance. Each sample unit was first characterised on the basis of its environmental condition (degree of disturbance and slope exposure). Then, a complete inventory of all Solanaceae species was carried out at each sample unit. Finally, all individuals per species were counted, their heights measured and their phenological status recorded.

Species composition of Solanaceae — In total, 156 plant specimens were collected in order to verify identification. All specimens were identified at species level in the Herbarium MEXU (Universidad Nacional Autónoma de México) and were deposited in the Herbarium of the Faculty of Sciences (FCME). Bibliographical support from Standley (1924), Standley & Williams (1973), Waterfall (1967), Hunziker (1969), Knapp (1985), Nee (1986; 1993) and Martínez & Hernandez (1999) was needed to achieve the identification process.

Characterisation of pollination and seed dispersal syndromes — In this research, all Solanaceae species were grouped in a pollination (sensu Faegri & Van der Pijl 1980) and a seed dispersal syndrome (sensu Van der Pijl 1972), based on morphological traits (colour, shape and size) obtained from field observations and herbarium verification. Fruit size was compiled from Waterfall (1967), Hunziker (1969), Knapp (1985), Nee (1986; 1993) and Martínez & Hernandez (1999) and was completed by field observations. Wilson et al. (1989) and Akwood et al. (1993) alike have conducted comparative studies in other tropical and subtropical regions.

The pollination syndromes characterised in the present study were defined as follows:

- a. melittophily: flowers small; white, pale or green in colour; sweet-scented; floral reward mainly pollen;
- b. ornithophily: bright reddish-coloured flowers; odourless and tubular corolla; nectar as floral reward;
- c. sphingophily: white to pale-yellow colour of flowers; deep corolla tubes; sweet-scented; flowers open late afternoon or just after dark; nectar as floral reward.

The seed dispersal syndromes typified included the following:

- d. mammaliochory (non-flying mammals): in this study fleshy berries (with smell, inconspicuous colours, in general dropping to the ground at maturity) and fruits with seeds that have to be either protected by a hard coat or by bitter taste or toxic substances. Also fruits inaccessible for bats but likely to be consumed by terrestrial mammals such as rodents and marsupials;
- e. chiropterochory: fleshy berries usually pale green, brown, yellow or black; varying in size and chiefly scented; in addition, some fruits weakly protected;
- f. autochory: dry, dehiscent fruits (capsules).

Data analysis – Field observations on Solanaceae species, their abundance and the number of individuals per area were entered in a database. First, a complete inventory was made of the species identified, together with their abundance values per sample unit. The abundance value (Ab) was estimated as follows: Abundance (of species \( x \) present in locality \( y \)) = (total number of individuals of species \( x \) present in locality \( y \))/total number of individuals of all species in locality \( y \)\(^{100} \).

Species were then organised in order to detect sample units with similar species composition and the abundance values of the same species. The species were then sorted in a table to depict groups of taxa sharing similar statistical performance. The first group comprised differential species, which included exclusive species (defined as those that differentiate one area from the others) and characteristic species (those that show a distinct maximum abundance in certain areas). The second group included constant taxa (defined as those recorded in most sample units; sensu Velázquez 1994). This allowed us to depict preliminary groups of sample units sharing comparable species composition. This suggests that these groups share similar ecological conditions (Waite 2000).

In order to quantify the species performance statistically, we used an algorithm of correspondence (TWINSPLAN; Hill 1979). Five cut levels were considered sufficient to detect significant differences among groups of sample units. The results were presented in a dendrogram to show the distribution of species groups. These types of multivariate techniques have been recommended for studies of this kind, in order to evenly assess the weight of all species (Terborgh & Robinson 1986). Correspondence analysis (TWINSPLAN) performs simultaneously “R” and “Q” classification, giving equal chance to all species and sites to cluster on basis of resemblance index (Waite 2000).

It was expected that species groups would be distributed along a gradient of disturbance. Detrended correspondence analysis (DCA) (McCune & Mefford 1995) was therefore used to statistically relate the results obtained in the dendrogram in order to infer potential attributes that explain the distribution of species groups.
Groups of species (depicting different environmental conditions) detected in the previous analysis were also compared on the basis of their pollination and seed dispersal syndromes. Using G tests (Sokal & Rohlf 1998), significance among group differences was measured from a contingency table (number of groups versus pollination and seed dispersal syndromes). A level of P<0.05 was considered as significant throughout the analysis.

Results

Species richness – A clear gradient of disturbance (Table 1) was detected among areas and was reflected in the species composition of Solanaceae. A total of 25 species of Solanaceae were identified. The species *Physalis queretaroensis*, *P. gracilis*, *P. subrepens*, *Solanum rudepannum* and *Witheringia mexicana* were reported in the region for the first time. Abundance values per species per area are shown in Table 2. The most exclusive (stenoecious) species are found at the top (e.g. *Solanum erianthum*, *S. rudepannum* and *Physalis gracilis*), whereas constant (euryecious) species are placed at the bottom (e.g. *Solanum chrysotrichum* and *S. nigrescens*). Characteristic species, represented by *Solanum aligerum*, *S. pseudocapsicum* and *Cestrum oblongifolium*, are found between exclusive and constant species groups. From Table 2, we inferred that Lolotla and Tianguistengo shared similar environmental conditions, which is reflected in the common exclusive species (e.g. *Solanum rudepannum*, *S. erianthum* and *Physalis gracilis*). However, these areas differ from Lontla and Apantlazol, where the exclusive species are *Cestrum elegans* and *Solanum appendiculatum*. Other species such as *Solanum aligerum*, *S. pseudocapsicum* and *Cestrum oblongifolium* occurred within a certain

Table 2. Species of the nine forest areas (localities) surveyed in Hidalgo (Mexico). Abundance (of species *x* present in locality *y*) = (total number of individuals of species *x* present in locality *y*)/total number of individuals of all species in locality *y*100. (Tiangui = Tianguistengo; Lolotla; Mo-Xo = Molango-Xochicoatlán; Apan = Apantlazol; Lontla; Molan = Molango; Eloxo = Eloxotitlán; Naopa; Jala = Jalameleco). Legend: □ = exclusive species; ▲ = characteristic species; ▼ = constant species.
range of environmental conditions, although not grouped in a particular set of areas.

Classification and ordination — Of the 500 sample units, 392 comprised Solanaceae species; these were compared and their (dis)similarity was measured. The dendrogram (Fig. 2A) suggests a gradient from the relatively less disturbed and more humid areas, such as Lontla and Apanatzol, towards the more disturbed and less humid areas, such as Lolotla and Tianguistengo (Fig. 2B). The abundance value per species per group was recalculated in order to depict differential species representative of certain environmental conditions (Table 3). The differential species depicting group I were *Solanum pseudocapsicum* and *S. aligerum*, whereas those for group II were *S. rudepammum* and *Cestrum oblongifolium* (Fig. 3).

These two groups were further analysed in order to measure their (dis)similarity along environmental gradients. These gradients were depicted along ordination axes, which in turn allowed us to infer potential environmental attributes that best explain the distribution and abundance of Solanaceae species. The DCA results showed that those sample units forming groups I and II split significantly along axis I ($l_1 = 0.770$; percen-

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**Figure 2.** A. Dendrogram (obtained via TWINSPAN) showing the (dis)similarities of the species sampled in the nine Mexican mountain cloud forest fragments. Full names of differential species are given in Table 2 and Figure 4. B. Number of sampling units (expressed in percentage) per area, depicting different environmental conditions represented by group I and/or group II. Group I ($\bigcirc$) = less disturbed and more humid; Group II ($\blacksquare$) = more disturbed and less humid. Lontla; Apan = Apantlazol; Molan = Molango; Eloxo = Elxotitlán; Jala = Jalameclo; Mo-Xo = Molango-Xochicoatlán; Naopa; Tiangui = Tianguistengo; Lolotla.
The results showed a major division into two groups. Group I harbours species assemblages that are better distributed in less disturbed forest areas with more humid conditions than the species assemblages from group II (Fig. 4). Along axis II ($\lambda = 0.63$; percentage of variance explained 29%), species distribution did not show clearly related environmental attributes.

Pollination and seed dispersal – Most types of Solanaceae habits were represented: shrub-like (60%), herb-like (24%), climber-like (12%, including both succulent and woody types) and tree-like (4%). Of these species, 84% were melittophilous (Table 4). This pollination syndrome was found to be equally important in both groups detected in the previous analysis and no substantial differences were found between groups (GI = 83.3% and GII = 93.8%), as shown in Fig. 5A. A detailed characterisation of all species into pollination and seed dispersal syndromes is given in Table 4.

Four seed dispersal syndromes were distinguished, clustered into two types: biotic (comprising three types: ornithochory, chiropterocory and mammaliochory) and abiotic one type (autochory). Overall, 44% of the species were categorised as ornithochoric. Fruits were small, varying in size from 7 to 15 mm, and of these 54.5% were red-orange, 27.3% black and 9.1% white. It was not possible to categorise the remaining 9.1%
as regards colour. Concerning the chiropterchoric species (36% of the total), fruit sizes varied from 8 to 35 mm, and 77.8% were green-yellow, 11% black, and the rest were categorised as any colour (Table 4). The mammaliochorous fruits were found at ground level and were usually coriaceous or had an expanded calyx. Comparing these syndromes between groups, it was found that in group I (less disturbed and more humid) ornithochory (45.8%) prevailed over the chiropterchoric (33.5%) syndrome (Fig. 5B), whereas within group II, chiropterchoric (50%) dominated ornithochory (31.3%). In spite of this, no significant differences were found between the syndromes of groups I and II (G_{adj} = 0.875 < X^2_{0.05[3]} = 7.815).

**Discussion**

Solanaceae composition and disturbance – In the present study, the 25 Solanaceae species reported exceeded the number forecast. Other studies recently conducted in the region recorded between 12 and 20 species, representing 3.6 to 4.6% of all vascular plants in the region (Luna et al. 1994; Mayorga et al. 1998). Solanaceae therefore represent 7.5% of the vascular plants in the region, which indicates the need for more detailed inventories covering both well-conserved and disturbed areas.

Most of the Solanaceae species in the study area have predominately shrub-like (60%) and herb-like (24%) habits. These species constitute part of the understory, confirming that these layers in the Mexican cloud forest are of Neotropical origin. This understory is shared with the Acanthaceae, Piperaceae, Rubiaceae, Myrsinaceae, Melastomataceae families, as well as with epiphytes and monocotyledonous taxa, coming from low elevations in the Andean region (Gentry 1982; Rzedowski 1978).

Despite the common origin, clear floristic differences in Solanaceae species were observed among the mountain cloud forest areas studied. Table 2 and Fig. 2A show that Solanaceae species were significantly split up to cut level 4, as seen from the large eigenvalues (l) obtained from the classification analysis. Similar floristic patterns have been observed in other groups, so changes in composition may indicate different environmental and ecological conditions (Luna et al. 1994; Mayorga et al. 1998). In addition to floristic differences, physiognomic discrepancies were also found among the areas. To illustrate this further, the Lontla and Apantlazol areas still retain most of their pristine character, comprising tall tree species (up to ca. 40 m in height) of Magnolia schiedeana, Liquidambar macrophylla, Podocarpus reichei, Pinus patula and Cyathea spp. (Luna et al. 1994). The rest of the areas comprised lower tree layers (up to 30 m in height) of Liquidambar macrophylla, Cercis canadensis, Pinus patula, Dalbergia palo escrito and Podocarpus reichei (Mayorga et al. 1998).

Likely environmental attributes to explain Solanaceae composition differences among areas were sought in this study. Of these, degree of disturbance was hypothesised as the major attribute governing Solanaceae species distribution. In this study, the ordination diagram (Fig. 4) showed clear distributions of species along axis I; this was inferred to be related to the degree of disturbance. The species Solanum aligerum, S. pseudocapsicum and Cestrum elegans were placed on the left side of the ordination diagram and are the differential species in the areas considered well conserved (Lontla and Apantlazol). In contrast, Solanum rudemannum, S. schlechtendalianum and Cestrum oblongifolium are the differential species in the areas categorised as largely disturbed (Lolotla and Tianguistengo) (Table 1) and these were placed on the right side of axis I. This axis, therefore, represents a clear gradient of disturbance.

It was observed that axis I (degree of disturbance) was closely related to a humidity gradient. As disturbance increased, relative humidity decreased, and vice versa. Disturbance (mainly man-made) favours changes in vegetation coverage and species abundance, implying microclimatic changes. Thus, more disturbed areas receive more sunlight and wind exposure, increasing evapotranspiration (Laurance et al. 1998), so that relatively less humidity remains. This depends on slope exposure since eastern slopes receive substantially more humidity than western slopes (Luna et al. 2001). In brief, both degrees of disturbance and relative humidity explain (48% of variance) the present distribution of Solanaceae in the study area. However, no attribute proved significantly correlated with axis II, so further research is recommended in order to gain insight into the current environmental attributes determining Solanaceae species distribution.

Pollination syndromes – As stated by Faegri & Van der Pijl (1980) and Dafni & Kevan (1997), floral morphological traits such as colour, shape, size and floral rewards are associated with the pollination syndrome and therefore with pollinator type. From the morphological floral traits of the Solanaceae species reported in this study, it was found that melittophily was the main pollination syndrome in all areas (Fig. 5A
The prevalence of melittophily as the dominant pollination syndrome in this tropically dominated ecosystem is similar to the results reported in the cloud forests of Michoacán (Hernández & Carreón 1987) and Sierra Madre Oriental (L.M. Godínez, data not published). This corresponds with most tropically dominated environments where 94% of all pollinators are zoophilous (Reis et al. 1996; Murray et al. 2000).

In descending order, the pollination syndromes melittophily, sphingophily and ornithophily were present in all studied areas, among which no differences were observed (Fig. 5A). Similar pollinator assemblages have been reported elsewhere for Solanaceae (Endress 1994). Pollinators, in general, may influence reproductive success by determining the percentage of seeds set, and eventually influencing the effective size genetically (Fleming & Sosa 1994). It has been widely accepted that this kind of mutualism plays an important role in maintaining the ecosystem function (Hove & Smallwood 1982; Morellato & Leitão Filho 1992; Murray et al. 2000).

Seed dispersal syndromes – Fruit morphological traits also play an important role in defining the type of potential disperser (Van der Pijl 1972; Gautier-Hion et al. 1985). Solanaceae species in the mountain cloud forest study areas were preferentially characterised as zoochorous (92%). Solanaceae fruits in this study varied from pendulous to erect to reflexed types; colour varied from white to red; fruits from fleshy berries to

Table 4. Morphological features of the Solanaceae species recorded in the Mexican mountain cloud forests of Hidalgo, Mexico. Hb = Habit: H = herb; S = shrub; V = vine; T = tree. Pas (pasture) = pasture edge; Ed = forest and road edges; Re = river edge. Syndromes: Meli. = Melittophily; Orni. = Ornithophily; Sph. = Sphingophily; Chiro. = Chiropterochory; Ornit. = Ornithochory; Mam. = Mammalochory and Auto = Autochory. The asterisk (*) represents the months when the species was collected with flower and fruit during fieldwork. Flower and fruit orientation: erect (E), pendulous (P), reflexed (R), indistinct (I).

| Species | Habitat | Height (cm) | Syndrome | Inflorescence |
|---------|---------|-------------|----------|---------------|
| **Brugmansia suaveolens** (Willd.) Bercht. & Presl | S x | 90-300 | Sph. | Auto | Solitary |
| **Cestrum elegans** (Brongn.) Schltdl. | S x x | 30-220 | Orni. | Ornit. | Pseudoterminal cymes |
| **Cestrum oblongifolium** Schltdl. | S x x | 20-450 | Sph. | Ornit. | Pseudoterminal cymes |
| **Cestrum sp.** | S x | 40-50 | | | |
| **Cyphomandra betacea** (Cav.) Sendtn. | S x x | 50-250 | Meli. | Chiro. | Lateral umbels |
| **Jaltomata procumbens** (Cav.) J.L. Gentry | H x x | 50-110 | Meli. | Ornit. | Lateral umbels |
| **Lycianthes aff. lenta** (Cav.) Bitter | S x | 80 | Meli. | Ornit. | Lateral fascicles |
| **Physalis gracilis** Miers | H x x | | Meli. | Mam. | Solitary |
| **Physalis subrepens** Waterf. | H x x | | Meli. | Chiro. | Solitary |
| **Physalis quere Tahoeensis** M. Martínez & L. Hernández | H x x | | Meli. | Mam. | Solitary |
| **Solanum algerum** Schltdl. | T x x | 30-1000 | Meli. | Ornit. | Pseudoterminal cymes |
| **Solanum aphyodendron** S. Knapp | S x | 10-250 | Meli. | Chiro. | Lateral |
| **Solanum appendiculatum** Dunal | V x | | Meli. | Ornit. | Pseudoterminal cymose-paniculate |
| **Solanum chrysotrichum** Schltdl. | S x x | 20-350 | Meli. | Chiro. | Lateral |
| **Solanum erianthum** D. Don | S x | 60-200 | Meli. | Chiro. | Terminal (at the beginning) |
| **Solanum jasminoides** Paxton. | V x | | | | |
| **Solanum myricacanthum** Dunal | H x x x | 20-100 | Meli. | Mam. | Lateral |
| **Solanum nigrescens** M. Mart. & Gal. | H x x | 30-100 | Meli. | Ornit. | Lateral pseudoumbels |
| **Solanum nudum** Dunal | S x | 100 | Meli. | Chiro. | Lateral |
| **Solanum pseudocapsicum** L. | S x | 20-130 | Meli. | Ornit. | Lateral |
| **Solanum rudepannum** Dunal | S x | 20-180 | Meli. | Chiro. | Pseudoterminal (at the beginning) |
| **Solanum schlechtendalianum** Wap. | S x x | 20-200 | Meli. | Chiro. | Pseudoterminal (at the beginning) |
| **Solanum skutchii** Corr. | V x x | | Meli. | Ornit. | Pseudoterminal cymose-paniculate |
| **Solanum umbellatum** Mill. | S x | 20-200 | Meli. | Chiro. | Terminal (at the beginning) |
| **Witheringia mexicana** (Rob.) Hunz. | S x | 100-180 | Meli. | Ornit. | Lateral |
capsules; sizes were generally small (<15 mm), as shown in Table 4. Van der Pijl (1972), Charles-Dominique (1986), Janson (1992) and Korine et al. (1998) have reported similar results.

Ornithochory and chiropterochory were found to be the main seed dispersal syndromes in all areas, where equivalent proportions of each were recorded (Fig. 5B). In general, Solanaceae species (e.g. most species of Cestrum and Solanum) are well known for their strong leaf scents. This has been recognised as a major bat attraction, favouring fruit consumption and in consequence seed dispersal (Nee 1993). In our study, it was frequently observed that bats dispersed green, yellow and black fruits (e.g. Solanum rudepannum, S. schlechtendalianum and S. aligerum) – colours with strong scents coming from their leaves.

While comparing seed dispersal syndromes among areas, no significant differences were found (Fig. 5B). Ornithochory, however, was detected as the prevailing syndrome in the less disturbed and more humid areas represented by group I (45.8% ornithochory and 33.3% chiropterochory). Conversely, in the more disturbed and less humid areas of group II chiropterochory (50%) prevailed over ornithochory (31.3%). It has been documented that a larger disturbance may be expressed as a clear dominance of chiropterochory in Solanaceae (e.g. Vázquez-Yanes et al. 1975; Fleming & Sosa 1994; Da Silva et al. 1996; Galindo-González 1998; Medellín & Gaona 1999).

This study showed that birds and bats play an important role in the distribution of Solanaceae, since these are potentially the most likely dispersers. For instance, Da Silva et al. (1996) demonstrated that ca. 40% of bird species moved some 50 to 150 m away
Solanaceae are considered as key taxa in open areas. Furthermore, Solanaceae also favour alternative fruit consumption. Once their fruits have been eaten, secondary compounds limit frugivory (Cipollini & Levey 1997a; 1997b; 1997c) and may promote the search for alternative food sources. The medium- and long-term consequences are that consumers eat and disperse a greater diversity of seeds as Solanaceae consumption increases, thus promoting seed-bank enrichment. These effects are yet to be researched in Neotropical solanaceous species.

Implications for management and conservation — Angiosperms have diversified as a consequence of seed dispersal by animals (zoochory) (Tiffney 1984). It has been proved that, compared with pollination, seed dispersal doubles genetic exchange (Hamrich & Nason 1996). Hence, current landscape patterns, to a large extent determined by vegetation communities (Farina 1998), ought to be influenced by seed dispersal (Sinha & Davidar 1992). To illustrate this further, recent studies highlight the lack of seeds in pasturelands compared with forest edges. Da Silva et al. (1996) mentioned that animals disperse seeds into small clearings, but seed dispersal decreases as clearing size increases and this retards plant succession. In addition, Tabarelli et al. (1999) found that in Atlantic forest (similar conditions to those studied here) Compositae, Euphorbiaceae, Solanaceae and Leguminosae increased as the forest area decreased. When these taxa prevail, a good chance of re-vegetation remains (Rodrigues & Gandolfi 1996). Solanaceae flowers and fruits are available throughout the year, so this family is considered as a trigger group for successional and regeneration processes (Bohs 1994; Da Silva et al. 1996; Tabarelli et al. 1999). This is especially relevant at landscape level, where birds and bats transport Solanaceae seeds across forest edges.

Birds and bats take an active part in the formation of seed dispersal corridors. Seed dispersal corridor can be defined as a narrow functional belt that limits forest edges, increases connectivity and functions as a route mainly for birds and bats where they spread seed pools within a mosaic. Hence, a seed dispersal corridor allows genetic flow and consequently maintains forest dynamics. Solanaceae in particular offer floral rewards and fruits throughout the year. In the long run, these species favour landscape stability. The threshold for reaching this stage of stability in Mexican mountain cloud forest has yet to be ascertained.

In conclusion, disturbance favours changes in vegetation coverage and species abundance, implying...
microclimatic changes, as when the disturbance increased, relative humidity decreased. Therefore, the gradients of Solanaceae species’ distribution are firstly associated to the disturbance degree and, secondarily, to the humidity gradient. Within these conditions, some species can be considered as indicative of less disturbance and more humidity conditions, as *Solanum aligera*, *S. pseudocapsicum*, *Cestrum elegans*, while others, for instance, *Cestrum oblongifolium*, *Solanum rudepannum*, *S. schlechtendalianum* are indicative of more disturbance and less humity. However, the Solanaceae pollination syndromes are not related to the disturbance degree, but to the pattern of tropical species pollination (zoophily). In relation to seed dispersal syndromes among areas, no significant differences were found, although, ornithochory was detected as the prevailing syndrome in the less disturbed and more humid areas. On the other hand, chiropterochory prevailed over ornithochory in the more disturbed and less humid areas. Besides, the tendency that larger disturbances may be expressed as a clear dominance of chiropterochory in Solanaceae has already been documented (e.g. Vázquez-Yanes et al. 1975; Fleming & Sosa 1994; Da Silva et al. 1996; Galindo-González 1998; Medellín & Gaona 1999).

To summarise, wild Solanaceae species play a relevant role by favouring the colonisation of open areas and, consequently, in forest regeneration processes. In addition, this group attracts wildlife by offering floral rewards and fruits throughout the year. Finally, this group facilitates connectivity among forest patches by means of seed dispersal corridors. Their conservation is important since a large number of species provide both known and as yet unknown services for human beings. Future research along this line is therefore recommended.

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