

## BIOTIC FACTORS ASSOCIATED WITH THE SPATIAL DISTRIBUTION OF THE MISTLETOE *PSITTACANTHUS CALYCVLATUS* IN A TROPICAL DECIDUOUS FOREST OF CENTRAL MEXICO

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**Abstract:** *Psittacanthus calyculatus* (Loranthaceae) is a neotropical hemiparasitic mistletoe and one of the most abundant and widely distributed species of the genus. Like most mistletoes, the interaction with its hosts and dispersers are directly related with its distribution and community dynamics. For the last decade, the infested areas in central México have increased, becoming a potential plant health problem. The aim of this study was to investigate three main biotic factors associated with the distribution of *P. calyculatus* in a tropical deciduous forest: (1) the plant community structure, (2) the host spatial distribution and level of association with *P. calyculatus*, and (3) bird consumers. Modified Whittaker plots were used to analyze the structure and composition of the plant community, comparing a highly infected mistletoe sites with non-infected sites. The spatial distribution and association of *P. calyculatus* with its most frequent hosts were calculated through a spatial analysis by distance indices. Study sites differed in plant diversity and species composition, showing a positive relation of mistletoe abundance with low diversity sites. The distance indices analysis presented a clumped distribution of *P. calyculatus* and *Acacia* hosts, as well as a high association with leguminous species such as *A. farnesiana* ( $X = 0.31$ ,  $P = 0.0041$ ) and *A. schaffneri* ( $X = 0.3977$ ,  $P = 0.001$ ). Three species consumed *P. calyculatus*' berries: the Northern mockingbird, the Silky-Flycatcher and the Scott's Oriole.

**Keywords:** dispersers, distance indices, host association, *Psittacanthus calyculatus*, spatial distribution.

**Resumen:** *Psittacanthus calyculatus* (Loranthaceae) es un hemiparásito neotropical y uno de los más abundantes y con mayor distribución del género. Como la mayoría de los muérdagos, las interacciones con sus hospederos y dispersores están directamente relacionadas con su distribución y dinámica en la comunidad. En la última década las áreas infectadas se han incrementado, llegando a ser un problema potencial de salud forestal. Los objetivos de este estudio fueron investigar los tres factores bióticos principales asociados a la distribución de *P. calyculatus* en un bosque tropical caducifolio en la periferia de la ciudad de Querétaro: (1) la estructura de la comunidad vegetal, (2) la distribución espacial y el nivel de asociación de *P. calyculatus* para con sus hospederos y (3) las aves que consumen los frutos del muérdago. Para analizar la estructura y composición de la comunidad vegetal, se comparó un área sin muérdago con un área con numerosos individuos de *P. calyculatus* con la ayuda de cuadrantes Whittaker. La distribución espacial y los valores de asociación fueron calculados mediante un análisis espacial por índices de distancia. Los sitios difirieron en composición de especies, mostrando una relación entre el muérdago y la importancia de sus hospederos en la comunidad. Se establecieron puntos de observación para registrar a las aves que se alimentaran de los frutos del muérdago. Se observó una distribución agregada de *P. calyculatus* y sus hospederos del género *Acacia*, así como también un nivel elevado de asociación con *A. farnesiana* ( $X = 0.31$ ,  $P = 0.0041$ ) y *A. schaffneri* ( $X = 0.3977$ ,  $P = 0.001$ ). Se registraron tres especies de aves que consumieron los frutos: el Centzonile Norteño, el Capulinero Negro y el Bolsero Tunero.

**Palabras clave:** asociación de hospederos, dispersores, distribución espacial, índices de distancia, *Psittacanthus calyculatus*.

Mistletoes are angiosperm plants from the Santalales order, characterized for adhering to a host plant's stems (Mathiasen *et al.*, 2008). Most mistletoes share an obligate hemi-parasitism lifestyle with specialized structures called haustoria. They take water and minerals from other plants

but despite being partially autotrophic, they are still dependent of their hosts (Watson, 2001; Leimu, 2010). This parasite type operates in the community as a plant, but also in a higher trophic level using resources of other plants and therefore, can be compared with herbivores (Pennings and

Callaway, 2002). Establishment and survival of mistletoe seedlings is highly dependent on host suitability (Norton and Ladley, 1998). The majority of the parasitic plants have a broad host range, but they can show a specialist behavior developing better in some hosts species in the community (Norton *et al.* 1995; Press and Phoenix, 2005). Host selection can be influenced by local conditions, such as the type and number of host species available for colonization (Hoffmann *et al.*, 1986; Medel *et al.*, 2004), host structure and characteristics like height (Sales-Teodoro *et al.*, 2009), twig size (Sargent, 1995), and bark type (Arruda *et al.*, 2006). The dynamics of the community can also influence the mistletoe-host relationship, by having more mistletoe occurrence on susceptible host individuals and increasing mistletoe densities, which in turn, increase the fruit production attracting more dispersers reinforcing the contagious distribution (Overton, 1994; Dean *et al.*, 1994; Downey *et al.*, 1997; Aukema and Martínez del Río, 2002b).

Mistletoes also show close interactions with their pollinators and seed vectors, associations that could be considered as a true mutualism. Therefore, mistletoes can act as hemiparasites (for plant hosts) and mutualists (for dispersers and pollinators) simultaneously in natural communities (Watson, 2001). Species of the genus *Psittacanthus* Mart. are typically dispersed by birds feeding on its fruits that then fly to another tree, voiding the seed on a suitable branch initiating infection. Incubation and production of the first flowers require several years and once established, however, the infection is perennial, and the mistletoe produces large haustoria with many long branches (Vázquez-Collazo and Geils, 2002).

Vázquez-Collazo and Geils (2002) reviewed several reports of *Psittacanthus calyculatus* (DC.) G. Don having a wide distribution in different climate, vegetation types, and multiple hosts. Huerta-Martínez and Cházaro-Basañez (1997) documented the presence of *P. calyculatus* in a tropical deciduous forest (TDF) with a distribution from 1,300 to 2,350 m altitude, and found 20 host species. Besides temperate forests and subtropical scrublands, *P. calyculatus* can occur on hillsides, flat terrain, road edges, irrigation channels, and disturbed areas (Bello-González, 1984), suggesting that the presence mistletoe can be directly or indirectly influenced by human activities (Donohue, 1995), and that high densities of the parasite could indicate a disturbance in the ecosystem.

Although mistletoes can cause adverse effects to hosts by taking essential resources for growth and reproduction or competing for pollinators (Medel, 2000; Sinha and Bawa, 2002; Ollerton *et al.*, 2007), they may also act as keystone resources in forest ecosystems, providing food or nesting sites to a wide range of vertebrates (Watson, 2001). Therefore, we cannot contemplate long-term mistletoe management as pests or threatened plants without considering their ecosystem context (Norton *et al.*, 1997). The objectives of this study were: (1) to determine differences in species composition between a TDF with high density populations

of *Psittacanthus calyculatus* compared to a TDF lacking mistletoe presence, (2) to determine the spatial patterns of mistletoe and its hosts and quantify mistletoe-host association using spatial analysis, and (3) to record avian frugivores in order to establish plausible disperser species in TDF.

## Methods

**Study site.** The study was conducted in a tropical deciduous forest (TDF) located at the urban fringe of Queretaro City, Mexico (20° 30' and 20° 56' N, 100° 17' and 100° 36' W; elevation 1,700 to 2,800 m a.s.l.) (INEGI 2005) from May 2011 to February 2012. Mean annual temperature is 17.6 °C and mean annual precipitation range from 549.3 mm (Baltazar-Ramírez *et al.*, 2004). The climate is typically Aw type of Köppen classification system, with a six-month rainy season from May to October (Zamudio *et al.*, 1992). The families better represented in the arboreal vegetation are Leguminosae and Burseraceae (Zamudio *et al.*, 1992). The first study site (1) was located Northeast of Queretaro City at the border of Fray Junipero Serra beltway (20° 39' 40" N, 100° 21' 40" W), exhibited disturbance resulting from highway construction and wood extraction and a clear high density of *Psittacanthus calyculatus* (personal observation). The second site (2) (20° 40' 38.83" N, 100° 25' 16.75" W) was located at the same altitude, west from the first site and exhibited a much lower disturbance than the first site. The third site (3) "El Tángano" (20° 32' 37.41" N, 100° 20' 22.32" W) was found southeast from the city and the area has been considered a natural protected area with the lowest level of disturbance and lacking mistletoe populations.

**Diversity analysis.** Tree height and canopy cover, as well as individuals of *Psittacanthus calyculatus* and cover values were taken from the spatial analysis plots (a single 50 × 50 m plot divided in 5 × 5 m subplots) then we computed this data to obtain Shannon and Simpson diversity indices.

**Plant community composition.** Individuals, species and canopy cover were recorded for all trees measuring > 10 cm DBH inside the 20 × 50 m plot (D). A 100 m<sup>2</sup> subplot (5 × 20 m) (C) is centered inside the main plot, all trees > 5 cm DBH were measured and identified. Two 10 m<sup>2</sup> and 1 m<sup>2</sup> plots were arranged systematically inside the perimeter of main plot. For the two 10 m<sup>2</sup> subplots (B) all small trees > 1 cm DBH were measured as well. In 1 m<sup>2</sup> subplots only herbaceous plants were identified and coverage measured in percentage. This Modified-Whittaker nested vegetation plot design is described graphically in Stohlgren *et al.* (1995). Using Biomon software designed by the Smithsonian Institute for the modified Whittaker plots, dominance and density were computed for each tree species. Relative dominance, density and frequency were calculated and added in order to obtain importance value index (Stohlgren *et al.* 1997).

**Spatial Analysis.** For the spatial analysis only two contrasting sites were considered using the spatial analysis plots for site “1” with high densities of mistletoe population and site “3”, which was an unaffected site in a protected area. One plot of 50 × 50 m divided in 5 × 5 m subplots were used per site. Within each subplot, the presence and absence of tree species and mistletoe were recorded.

Pattern analyses were conducted using the method of spatial analysis by distance indices (SADIE), developed by Perry (1998). The basis of SADIE is to quantify the spatial pattern in a mapped population by measuring the total effort (in terms of distance moved “D”) that the individuals

in the observed sample must experience to move to extreme arrangements, in which the individuals are either spaced as uniformly or are as aggregated as possible. The degree of non-randomness within a set of data is quantified by comparing the observed spatial pattern with rearrangements in which the sampled counts are randomly redistributed among the units (Perry, 1998). Division of “D” by the average value obtained from permutations where the values of the variable under study are randomly arranged among the sampling locations gives an index of aggregation,  $I_a$ , which quantifies the spatial pattern. An aggregated sample has an  $I_a > 1$ ; a random sample has an  $I_a = 1$ ; and a regularly distributed sample has an  $I_a < 1$ . The higher the  $I_a$ , the more spatially aggregated the community under study. SADIE generates an aggregation index  $I_a$ , which is the quotient between observed D and expected D, which is the mean of the data permutations.

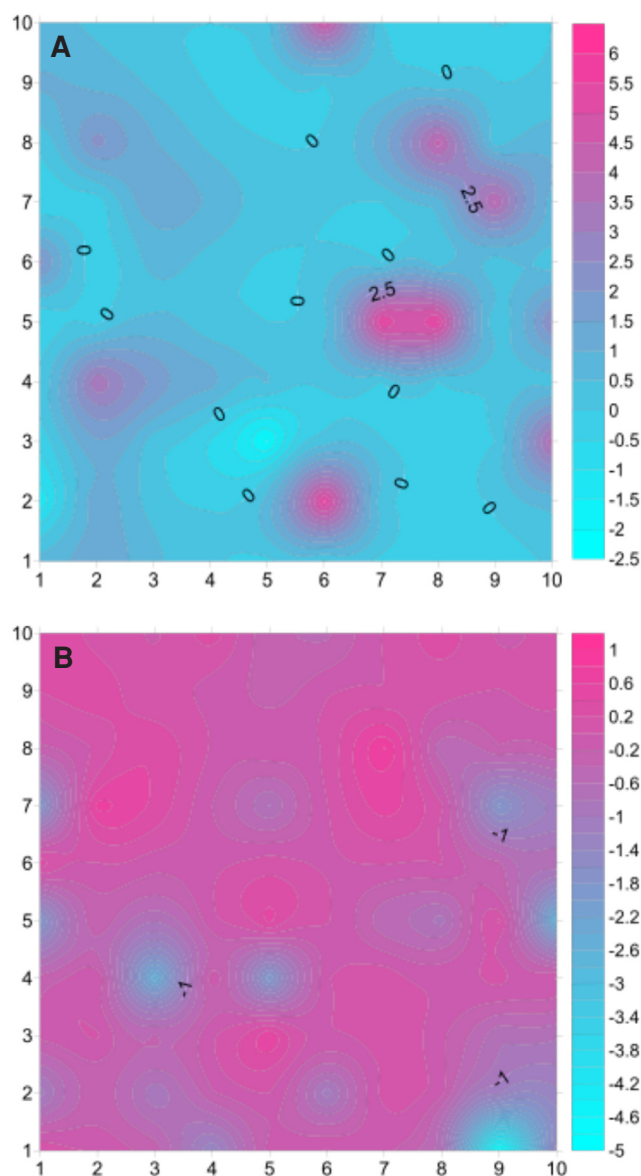
SADIE methods also provide an association index, high values of local association are indicated by the coincidence of a patch cluster for one set with a patch cluster for the other, or by the coincidence of two gaps whereas dissociation is indicated by a patch coinciding with a gap. The randomization method allows the construction of a test and critical values. Because the method allows for the spatial pattern of each of the two component populations by conditioning on the cluster indices, there should be no relationship between spatial pattern and spatial association (Perry and Dixon, 2002). The dimensionless indices for clustering,  $V_i$  and  $V_j$  quantify the degree to which the count for each sample unit contributes towards the overall degree of clustering, as part of a patch or as a gap. Their overall mean values ( $\bar{v}_i$ ,  $\bar{v}_j$ ) may be used to formally test for clustering within one set, and compare informally different sets of data (Perry *et al.*, 1999). SADIE analyses were conducted with SADIEShell v 1.22 (© Kelvin F. Conrad and IACR-Rothamstead). Indices  $I_a$ ,  $\bar{v}_i$ ,  $\bar{v}_j$  and association index with their probabilities were calculated for tree species and *Psittacanthus calyculatus*. Local aggregation indices ( $\bar{v}_i$  and  $\bar{v}_j$ ) and the association index or spatial covariation among pair of variables (X) defined by Perry (1998) were used to depict association maps with the software SURFER v. 8.02-Oct 2001 (Surface Mapping System © 1993-2002, Golden Software, Inc.).

In order to obtain cover values we measured maximum canopy diameter and a second diameter in perpendicular position, then we calculated canopy area using the formula for the area of an ellipse, i.e.,

$$\text{Area} = \pi \times r_1 \times r_2$$

Where  $r_1$  and  $r_2$  are the two radii.

**Bird feeding survey.** In order to find plausible dispersers of *Psittacanthus calyculatus* seeds, observation points were established at site 1 where high incidences of mistletoe were observed. Observations were made from 8,000 h to 1,200 h



**Figure 1.** Spatial associations maps of *P. calyculatus* with (A) *Acaia schaffneri*  $X_i=0.6325$  and (B) *Bursera fagaroides*  $X_i=-0.3208$  in a 2500 m<sup>2</sup> plot of a Seasonally Dry Tropical Forests in central México. Association values are represented from the lowest (blue) to the highest (magenta).

during January and February 2012 (a total of 44 h), when ripe fruits were available. Bird species and fruit interaction behavior were recorded, as well as the tree species where birds perched.

## Results

**Diversity analysis.** We recorded seven tree species in site “1”, 12 in site “2”, and 10 in site “3”. At site “1” only three species were found with mistletoe: *Acacia schaffneri*, *A. farnesiana*, and *Prosopis laevigata*. The proportion of infected host trees was 71.42 % of *A. schaffneri* (N = 7), 62 % of *A. farnesiana* (N = 10), and 16 % of *P. laevigata* trees (N = 30). A total of 165 individuals of *Psittacanthus calyculatus* were recorded. Mistletoes were distributed at 44.84 % (N = 74) in *A. schaffneri* hosts, 41.81 % (N = 69) in *A. farnesiana*, and 13.33 % (N = 22) of mistletoe plants in *P. laevigata*. The conserved TDF (site 2 and 3) had greater values in richness and diversity indices for the vegetation (Shannon = 1.68, Simpson = 0.757 and Shannon = 1.294, Simpson=0.553 respectively) compared to a disturbed TDF (site 1; Shannon = 0.987; Simpson = 0.476).

**Plant community composition.** The community composition of the study sites differs resulting from the impacts of human

activities. *Bursera fagaroides* and *Acacia schaffneri* importance values switch drastically between sites “1” to site “2” (Table 1). From being the two species with the higher values, they change to be within the last four species in the preserved TDF. *Acacia schaffneri* keeps the second place in importance in site “3”, but considering the importance value relation, the value is the half of *Senna polyantha*.

**Spatial Analysis.** The aggregation index (Table 2) indicates clearly that *Psittacanthus calyculatus* has an aggregated pattern ( $I_a = 1.408$ ) as well the main host trees: *Acacia schaffneri* ( $I_a = 1.211$ ) and *A. farnesiana* ( $I_a = 1.245$ ). Strong spatial associations of the mistletoe with both *A. schaffneri* ( $X = 0.6325$ ,  $P = 0.0001$ ) and *A. farnesiana* ( $X = 0.3977$ ,  $P = 0.0001$ ) were found, in contrast with *Ipomoea murucoides* ( $X = -0.3517$ ,  $P = 0.9996$ ) and *Bursera fagaroides* ( $X = -0.3208$ ,  $P = 0.9987$ ), which showed an evident dissociation. These data indicate that *P. calyculatus* has a narrow host range within the TDF studied.

**Bird feeding survey.** A total of 195 observations were made and 28 bird species were registered. Only ten species interacted with *Psittacanthus calyculatus* whether perching or eating the mistletoe berries. Three species were observed consuming the fruits: *Mimus polyglottos*, *Phainopepla nit-*

**Table 1.** Importance value indices (IVI) of tree species in three sites of Seasonally Dry Tropical Forests in central México.

Sites					
1. Fray Junipero Serra beltway		2. Fray Junipero Serra beltway west		3. El Tángano	
Species	IVI	Species	IVI	Species	IVI
<i>Bursera fagaroides</i> (Kunth) Engl.	79.96	<i>Opuntia arborescens</i> Engelm. In Wisl.	58.7	<i>Senna polyantha</i> (Collad.) H.S. Irwin & Barneby	106.43
<i>Acacia schaffneri</i> (S.Watson) F. J. Herm.	69.21	<i>Lysiloma microphyllum</i> Benth	37.07	<i>Acacia schaffneri</i> (S.Watson) F. J. Herm.	51.13
<i>Celtis pallida</i> Torr.	55.18	<i>Forestiera phillyreoides</i> (Benth.) Torr.	31.26	<i>Eysenhardtia polystachya</i> (Ortega) Sarg.	33.35
<i>Prosopis laevigata</i> (Humb. & Bonpl. ex Willd.) M. C. Johnst.	46.10	<i>Senna polyantha</i> (Collad.) H. S. Irwin & Barneby	30.39	<i>Forestiera phillyreoides</i> (Benth.) Torr.	18.98
<i>Opuntia</i> sp.	22.50	<i>Myrtillocactus geometrizans</i> Console	29.99	<i>Ipomoea murucoides</i> Roem. & Schult.	17.36
<i>Ipomoea murucoides</i> Roem. & Schult.	20.37	<i>Karwinskia humboldtiana</i> (Schult.) Zucc.	23.64	<i>Celtis pallida</i> Torr.	12.1
<i>Acacia farnesiana</i> (L.) Willd.	6.66	<i>Celtis pallida</i> Torr.	18.75	<i>Bernardia mexicana</i> (Hook. & Arn.) Müll. Arg.	9.42
		<i>Acacia schaffneri</i> (S. Watson)	18.75	<i>Bursera fagaroides</i> (Kunth) Engl.	9.3
		<i>Bursera fagaroides</i> (Kunth) Engl. F. J. Herm.	15.73	<i>Karwinskia humboldtiana</i> (Schult.) Zucc.	9.21
		<i>Acacia farnesiana</i> (L.) Willd.	13.68	<i>Iresine schaffneri</i> S. Watson	8.01
		<i>Ipomoea murucoides</i> Roem. & Schult.	8.03		
		<i>Prosopis laevigata</i> (Humb. & Bonpl. ex Willd.) M. C. Johnst.	7.01		



**Table 2.** Aggregation and association indices of *Psittacanthus calyculatus* and main tree species in a 2,500 m<sup>2</sup> plot in a Tropical deciduous forests in central Mexico. Indices indicate Aggregated distributions when  $I_a > 1$ , random distributions if  $I_a = 1$  and regular distributions if  $I_a < 1$ ;  $V_i$  = patches,  $V_j$  = gaps.  $X$  = association index.  $P$  = two tail test  $\alpha = 0.05$ . Associated  $X = > 0$ ; Dissociated  $X = < 0$ ; random arrangement  $X = 1$ .

Species	$I_a$	$V_i$	$P(V_i)$	$V_j$	$P(V_j)$	(X)	P
<i>Psittacanthus calyculatus</i>	1.408	1.218	0.1047	-1.416	0.0221	-	-
<i>Acacia schaffneri</i>	1.211	1.211	0.0871	-1.214	0.0907	0.6325	0.0001
<i>Ipomoea murucoides</i>	1.301	1.330	0.0422	-1.301	0.0528	-0.3517	0.9996
<i>Acacia farnesiana</i>	1.245	0.999	0.8658	-1.265	0.0503	0.3977	0.0001
<i>Prosopis laevigata</i>	0.905	0.881	0.8089	-0.904	0.7297	0.0132	0.4490
<i>Bursera fagaroides</i>	1.071	1.075	0.2725	-1.076	0.2658	-0.3208	0.9987

*tens*, and *Icterus parisorum*, the first two regurgitated the seed in one occasion. *Mimus polyglottos* had the higher perching frequency. Disperser candidates were considered by feeding habits, size and for being reported as mistletoe fruit consumers (Table 3).

## Discussion

**Differences in plant communities.** The results show a narrow host range for *Psittacanthus calyculatus* in the tropical deciduous forest (TDF) of the present study, with three host species in the Leguminosae family: *Acacia schaffneri*, *A. farnesiana*, and *Prosopis laevigata*. These results contrast to hosts species reported by Huerta-Martínez and Cházaro-Basañez (1997) who found 20 host species in a TDF and a *Quercus* forest in Sierra de Tapalpa, Jalisco, where the most frequent hosts belonged to three families, which included Leguminosae, and the host species present in this study: *Acacia* spp. and *P. laevigata*.

Most parasite populations depend on the availability of the host (Donohue, 1995). The changes in importance val-

ues of the hosts between the infested and non-infested TDF, suggests a link in the presence of *Psittacanthus calyculatus* and the composition of tree community. Roxburgh and Nicolson (2005) found that the infection prevalence of the mistletoe *Plicosepalus kalachariensis* which had high host specificity, was related with host abundance. The impact of parasitic plants on a community may be widespread, especially if the most parasitized plant species are dominant (Press and Phoenix, 2005). This suggests that communities where mistletoe hosts have high importance values can be more vulnerable to colonization and mistletoe spreading.

**Spatial aggregation and association of *Psittacanthus calyculatus* and hosts.** Aggregation in mistletoes on their hosts is very common and this clumped distribution have been detected in other mistletoe species, such as *Phoradendron* (Larson, 1996; Aukema and Martínez del Río, 2002a; Aukema, 2004), *Tristerix aphyllus* (Medel *et al.*, 2004), *Tristerix corymbosus* (García *et al.*, 2009), and *Tristerix verticillatus* (Lemaitre *et al.*, 2011). As expected, *P. calyculatus* has an aggregated pattern among its hosts in the present studies. The

**Table 3.** *Psittacanthus calyculatus*' disperser candidate's abundance and direct interactions with it, such as perching, feeding and regurgitation in a Tropical deciduous forests in central Mexico. A = abundance, P = perching, F = feeding, R = regurgitation. \*Ehrlich *et al.* (1988).

Species Common name	Behavior				Feeding habit*	References of feeding on other mistletoe species
	A	P	F	R		
<i>Mimus polyglottos</i>	56	13	2	1	Insects, fruits and nectar	Walsberg, 1975; Overton, 1994; Larson 2001.
<i>Icterus parisorum</i>	1	1	1	0	Arthropods and fruits	
<i>Phainopepla nitens</i>	17	2	2	1	Berries and flying insects	Walsberg, 1975; Overton, 1994; Watson, 2001; Aukema, 2003.
<i>Campylorhynchus brunneicapillus</i>	13	2			Insects, small vertebrates, fruits and seeds.	Overton, 1994; Larson, 2011.
<i>Icterus pustulatus</i>	1	0				
<i>Melanerpes aurifrons</i>	1	0			Insects, nuts and fruits	Lopez-De Buen and Ornelas, 2002.
<i>Myiarchus cinerascens</i>	10	2			Insects and berries	Overton, 1994;
<i>Toxostoma curvirostre</i>	1	1			Insects and fruit.	
<i>Tyrannus vociferans</i>	15	6			Insects and berries	

aggregated spatial arrangement can be found in other *Psittacanthus* species like *P. robustus* in South East Brazil, (Ferreira-Monteiro *et al.*, 1998; Sales-Teodoro *et al.*, 2010), *P. biternatus*, *P. plagiophyllus* and *P. eucalyptifolius* in North Brazil (Fadini and Lima, 2012).

Bird vector can have an important influence in favoring an aggregated distribution of mistletoe (Aukema and Martínez del Río, 2002b). According to Sales-Teodoro *et al.* (2010), host distribution and behavioral patterns of seed dispersers are directly responsible of mistletoe distribution patterns. Vectors are attracted by the presence of mistletoe increasing the parasite aggregation, then a group of mistletoes with different origins could share the same host, subsequently increasing the visibility to other birds (Larson, 1996; Medel *et al.*, 2004), reinforcing a spatial mistletoe-disperser interaction cycle, whereby infected trees receive an escalating number of seeds (Overton, 1994).

Both *Acacia* species showed an aggregated arrangement. If host trees are considered as living patches and they are only substrate where mistletoe population can inhabit (Overton, 1994), a host-clumped distribution will facilitate dispersion providing a continuous substrate and subsequently enhancing mistletoe spatial aggregation. Also, tree spatial patterns can influence frugivore foraging decisions, in Carlo and Morales (2008) model when fruiting plants become aggregated, unevenness in fruit-removal rates increases and seed dispersal distance decreases, due to birds moving shorter distance in high density neighborhoods. This can be a balancing factor between aggregated distribution and dispersion efficiency.

*Acacia schaffneri* was the host with higher index of association with *Psittacanthus calyculatus*. Dean (1994) registered 24 mistletoes species as parasites of the genus *Acacia* considering it the most important host in South Africa. Species of the genus are usually described as the main host (Bowie and Ward, 1994; Donohue, 1995; Roxburgh and Nicolson, 2005) or as frequent hosts (Barlow and Wiens, 1977; López de Buen and Ornelas, 2002; Dzerefos *et al.*, 2003). On the other hand, *Acacia* species are an integral component of plant communities in semiarid climates (Zamudio *et al.*, 1992) with drought tolerance (Clemens and Jones, 1978) that permits individuals to resist the six to seven months of the dry season of the TDF. Since mistletoes of Loranthaceae family have a higher transpiration rates than their hosts (Ulman *et al.*, 1985), *Acacia* and *Prosopis* trees can be convenient hosts because are phreatophytic species capable of providing water throughout the year due to an extensive root system that extends both deep and wide (Ludwig *et al.*, 2003).

**Bird feeding survey.** *Psittacanthus* seeds are dispersed by several species of birds, especially fly-catchers, thrushes, and tanagers (Genini *et al.*, 2012). *Psittacanthus calyculatus* fruit production starts primarily during the dry season

(Vázquez-Collazo and Geils, 2002) and begins in January and extends to May when most of TDF tree species remain leafless (Zamudio *et al.*, 1992) and insect abundance is low. This is very convenient for insectivore-frugivorous birds. López de Buen and Ornelas (2001) studied the synchrony between abundance of *P. schiedeanus* ripe fruits and abundance in fruit eating birds, where the fruit phenology was very important for birds with generalist feeding habits. This can also benefit neotropical migrants such as *Icterus* spp. López de Buen and Ornelas (2002) observed *Icterus galbula* consuming *P. schiedeanus* fruits. *Phainopepla nitens* a Silky-flycatcher from Central Mexico is well known as the main disperser of the desert mistletoe *Phoradendron californicum* (Walsberg, 1975; Larson, 1996; Aukema and Martínez del Río, 2002a). The *Phainopepla*'s intestinal tract is highly adapted for processing mistletoe seeds (Walsberg, 1975). However, there are no studies documenting *P. nitens* consuming *Psittacanthus calyculatus* fruits. It seems that *P. nitens* can benefit from *P. calyculatus* spatial aggregation, because this species defines territories in function of resource agglomeration and defends mistletoe clumps from other foraging species (Walsberg, 1975).

*Mimus polyglottos* the Northern mockingbird is considered part of the generalist assemblage of birds feeding on *Phoradendron californicum*, which can provide appropriate dispersal for some seeds (Larson, 1996). The high territorialism in *M. polyglottos* (Farnsworth, 2011) and an apparent fearless behavior towards man, could explain the numerous sights of perching in *P. calyculatus*. Like *P. nitens*, Northern mockingbirds haven't been considered as a *Psittacanthus* disperser.

The interactions of *Psittacanthus calyculatus* with hosts plants and avian vectors data shows that host availability and spatial arrangement are important factors shaping mistletoe distribution; also low tree diversity is related to high mistletoe densities and a strong dominance by hosts can lead to a greater rate of infection (Press and Phoenix, 2005). Distribution of host species can partially determine mistletoe distribution patterns (Overton, 1994) and host aggregation can further aggregate mistletoe on a greater spatial scale. Although *P. calyculatus* has been reported to have multiple hosts throughout different vegetation types, the species was highly associated with only two trees: *Acacia schaffneri* and *A. farnesiana*. Of the bird species observed, *M. polyglottos* and *P. nittens* frequent *P. calyculatus* using it as a food resource, behavioral observations and background with other mistletoe species, indicate that both can be efficient seed dispersers. Further analyses are needed to establish dispersion roles on the *P. calyculatus* vector ensemble in TDF.

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## Literature cited

- Arruda R., Carvalho L.N. and Del-Claro K. 2006. Host specificity of a Brazilian mistletoe, *Struthanthus* aff. *polyanthus* (Loranthaceae), in Cerrado tropical savanna. *Flora* **201**:127-134.
- Aukema J.E. 2004. Distribution and dispersal of desert mistletoe is scale-dependent, hierarchically nested. *Ecography* **27**:137-144.
- Aukema J. and Martínez-Del-Río C. 2002a. Where does a fruit-eating bird deposit mistletoe seeds? Seed deposition patterns and an experiment. *Ecology* **83**:3489-3496.
- Aukema J.E. and Martínez-Del-Río C. 2002b. Mistletoes as parasites and seed dispersing birds as disease vectors: current understanding challenges and opportunities. *Seed dispersal and frugivory: ecology, evolution, and conservation*. CABI International, Wallingford, UK (2002): 99-110.
- Baltazar-Ramírez J., Martínez M. and Hernández-Sandoval L. 2004. Guía de Plantas Comunes del Parque Nacional "El Cimatario" y sus Alrededores. Universidad Autónoma de Querétaro, Querétaro.
- Barlow B.A. and Wiens D. 1977. Host-parasite resemblance in australian mistletoes: the case for cryptic mimicry. *Evolution* **31**:69-84.
- Bello-González M.A. 1984. Estudio de muérdagos (Loranthaceae) en la región Tarasca, Michoacán. Boletín Técnico 102. Secretaría de Agricultura y Recursos Hidráulicos, Instituto Nacional de Investigaciones Forestales, México D.F.
- Bowie, M. and D Ward. 2004. "Water and Nutrient Status of the Mistletoe *Plicosepalus Acaciae* Parasitic on Isolated Negev Desert Populations of *Acacia Raddiana* Differing in Level of Mortality." *Journal of Arid Environments* **56**:487-508.
- Carlo T.A. and Morales J.M. 2008. Inequalities in fruit-removal and seed dispersal?: consequences of bird behavior, neighborhood density and landscape aggregation. *Journal of Ecology* **96**:609-618.
- Clemens J. and Jones P.G. 1978. Modification of drought resistance by water stress conditioning in *Acacia* and *Eucalyptus*. *Experimental Botany* **29**:895-904.
- Dean W.R.J., Midgley J.J. and Stock W.D. 1994. The distribution of mistletoes in South Africa: patterns of species richness and host choice. *Journal of Biogeography* **21**:503-510.
- Donohue K. 1995. The spatial demography of mistletoe parasitism on a yemeni *Acacia*. *International Journal of Plant Sciences* **156**: 816-823.
- Downey P.O., Gill A.M. and Banks J.C.G. 1997. The influence of host attributes on mistletoe colonization: an example from Mulligan's Flat Nature Reserve, A.C.T. *The Victorian Naturalist* **114**:105-111.
- Dzerefos C.M., Witkowski E.T.F. and Shackleton C.M. 2003. Host-preference and density of woodrose-forming mistletoes (Loranthaceae) on savanna vegetation, South Africa. *Plant Ecology* **167**:163-177.
- Ehrlich P., Dobkin D.S. and Wheye D. 1988. *Birder's Handbook: A Field Guide to the Natural History of North American Birds*, Simon and Schuster Inc., New York..
- Fadini R.F. and Lima A.P. 2012. Fire and host abundance as determinants of the distribution of three congener and sympatric mistletoes in an amazonian savanna. *Biotropica* **44**:27-34.
- Farnsworth G.L., Pollock K.H., Nichols J.D., Simons T.R., Hines J.E. and Sauer J.R. 2002. A removal model for estimating detection probabilities from point-count surveys. *The Auk* **119**:414-425.
- Ferreira-Monteiro R., Parentoni-Martins R. and Yamamoto K. 1992. Host specificity and seed dispersal of *Psittacanthus robustus* (Loranthaceae) in south-east Brazil. *Journal Tropical Ecology* **8**:307-31.
- García D., Rodríguez-Cabal M.A. and Amico G.C. 2009. Seed dispersal by a frugivorous marsupial shapes the spatial scale of a mistletoe population. *Journal of Ecology* **97**:217-229.
- Genini J., Côrtes M.C., Guimarães P.R. and Galetti M. 2012. Mistletoes play different roles in a modular host – parasite network. *Biotropica* **44**:171-178.
- Huerta-Martínez F.M. and Cházaro-Basañez M. 1997. La Familia Loranthaceae (muérdagos) de la Sierra de Tapalpa, Jalisco, México. *Cactáceas y Suculentas Mexicanas* **42**:83-94.
- Hoffmann A.J., Fuentes E.R., Cortés I., Liberona F. and Costa V. 1986. *Tristerix tetrandus* (Loranthaceae) and its host plants in the chilean matorral: patterns and mechanisms. *Oecologia* **69**:202-206.
- INEGI [Instituto Nacional de Estadística y Geografía]. 2005. Marco Geoestadístico Municipal, versión 3.1. Instituto Nacional de Estadística y Geografía, Aguascalientes.
- Larson D.L. 1996. Seed dispersal by specialist versus generalist foragers: The plant's perspective. *Oikos* **76**:113-120.
- Lemaitre A.B., Troncoso A.J. and Niemeyer H.M. 2011. Host preference of a temperate mistletoe: Disproportional infection on three co-occurring host species influenced by differential success. *Austral Ecology* **37**:339-345.
- Leimu R. 2010. Habitat quality and population size as determinants of performance of two endangered hemiparasites. *Annales Botanici Fennici* **47**:1-13.
- López-de-Buen L. and Ornelas J.F. 2001. Seed dispersal of the Mistletoe *Psittacanthus schiedeana* by birds in Central Veracruz, Mexico. *Biotropica* **33**:487-494.
- López-de-Buen L. and Ornelas J.F. 2002. Host compatibility of the cloud forest mistletoe *Psittacanthus schiedeana* (Loranthaceae) in central Veracruz, Mexico. *American Journal of Botany* **89**:95-102.
- Ludwig F., Dawson T.E., de Kroon H., Berendse F. and Prins, H.H.T. 2003. Hydraulic lift in *Acacia tortilis* trees on an East african savanna. *Oecologia* **134**:293-300.
- Martínez-del-Río C., Silva A., Medel R. and Hourdequin M. 1996. Seed dispersers as disease vectors: bird transmission of mistletoe seeds to plant hosts. *Ecology* **77**:912-921.
- Mathiasen R.L., Nickrent D.L., Shaw D.C. and Watson D.M. 2008. Mistletoes: pathology, systematics, ecology, and management. *Plant Disease* **92**:988-1006.
- Medel R. 2000. Assessment of parasite-mediated selection in a host-parasite system in plants. *Ecology* **81**:1554-1564.
- Medel R., Vergara E., Silva A. and Kalin-Arroyo M. 2004. Effects of vector behavior and host resistance on mistletoe aggregation. *Ecology* **85**:120-126.
- Norton D.A., Hobbs R.J. and Atkins L. 1995. Fragmentation, disturbance, and plant distribution: mistletoes in woodland rem-

- nants in the Western Australian wheatbelt. *Conservation Biology* **9**:426-438.
- Norton D.A., Ladley J.J. and Owen H.J. 1997. Distribution and population structure of the loranthaceous mistletoes *Alepis flavida*, *Peraxilla colensoi*, and *Peraxilla tetrapetala* within two New Zealand *Nothofagus* forests. *New Zealand Journal of Botany* **35**:323-336.
- Norton D.A. and Ladley J. 1998. Establishment and early growth of *Alepis flavida* in relation to *Nothofagus solandri* branch size. *New Zealand Journal of Botany* **36**:213-217.
- Ollerton J., Stott A., Allnutt E., Shove S., Taylor C. and Lamborn E. 2007. Pollination niche overlap between a parasitic plant and its host. *Oecologia* **151**:473-485.
- Overton J.McC. 1994. Dispersal and infection in Mistletoe meta-populations. *Journal of Ecology* **82**:711-723.
- Pennings S.C. and Callaway R.M. 2002. Parasitic plants: parallels and contrasts with herbivores. *Oecologia* **131**:479-489.
- Perry J.N. 1998. Measures of spatial pattern for counts. *Ecology* **79**:1008-1017.
- Perry J.N., Winder L., Holland J.M. and Alston R.D. 1999. Red-blue plots for detecting clusters in count data. *Ecological Letters* **2**:106-113.
- Perry J.N. and Dixon P.M. 2002. A new method to measure spatial association for ecological count data. *Ecoscience* **9**:133-141.
- Press M.C. and Phoenix G.K. 2005. Impacts of parasitic plants on natural communities. *New Phytologist* **166**:737-751.
- Roxburgh L. and Nicolson S.W. 2005. Patterns of host use in two African mistletoes: the importance of mistletoe-host compatibility and avian disperser behavior. *Functional Ecology* **19**:865-873.
- Sales-Teodoro G., van den Berg E., de Castro Nunes Santos, M., and de Freitas-Coelho F. 2010. How does a *Psittacanthus robustus* Mart. population structure relate to a *Vochysia thyrsoidea* Poh. host population? *Flora* **205**:797-801.
- Sinha A. and Bawa K.S. 2002. Harvesting techniques, hemiparasites and fruit production in two non-timber forest tree species in south India. *Forest Ecology and Management* **168**:289-300.
- Sargent S. 1995. Seed fate in a tropical Mistletoe: The importance of host twig size. *Functional Ecology* **9**:197-204.
- Stohlgren T.J., Falkner M.B. and Schell L.D. 1995. A Modified-Whittaker nested vegetation sampling method. *Vegetatio* **117**:113-121.
- Stohlgren T.J., Coughenour M.B., Chong G.W., Binkley D., Kalkhan M.A., Schell L.D., Buckley D.J. and Berry K.J. 1997. Landscape analysis of plant diversity. *Landscape Ecology* **12**:155-170.
- Ulman I., Lange O.L., Ziegler H., Ehleringer J., Schulze E.-D. and Cowan I.R. 1985. Diurnal courses of leaf conductance and transpiration of mistletoes and their hosts in Central Australia. *Oecologia* **67**:577-587.
- Vázquez-Collazo I. and Geils B.W. 2002. *Psittacanthus* in Mexico. In: Mistletoes of North American Conifers. General Technical Report, United States Department of Agriculture, Forest Service, Rocky Mountain Research Station.
- Vidal-Russell R. and Nickrent D.L. 2008. Evolutionary relationships in the showy mistletoe family (Loranthaceae). *American Journal of Botany* **95**:1015-1029.
- Walsberg G.E. 1975. Digestive adaptations of *Phainopepla nitens* associated with the eating of mistletoe berries. *The Condor* **77**:169-174.
- Watson D.M. 2001. Mistletoe—A keystone resource in forests and woodlands worldwide. *Annual Review Ecology and Systematics* **32**:219-249.
- Zamudio S., Rzedowski R., Carranza E. and Calderón de Rzedowski G. 1992. La Vegetación del estado de Querétaro. Consejo de Ciencia y Tecnología el Estado de Querétaro e Instituto de Ecología, A.C., Querétaro.

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