

Population Status and Reproductive Success of an Endangered Epiphytic Orchid in a Fragmented Landscape

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ABSTRACT

Habitat fragmentation and disturbance are two of the most significant drivers of species extinctions in plant populations. The degree of impact of fragmentation on plant populations depends on the level of specificity of plant–animal interactions, as well as on the availability of suitable sites for seedling recruitment. In this study, we describe the population density and structure, pollen limitation and reproductive success of the endangered tropical orchid *Myrmecophila christinae*, an epiphytic species with a specialized pollination system. We surveyed a total of 14 populations located in a fragmented landscape. Seedling density was related to habitat disturbance and host plant density; while density of juveniles was related to density of adults. Adult and total individual densities were related to habitat affectation. We also found that fragments < 1 ha had significantly fewer seedlings, as well as an over-representation of large adults. On the other hand, fruit production was higher in fragments > 10 ha, and fruit set was significantly lower in highly disturbed fragments. Hand pollination experiments showed that *M. christinae* was pollen limited in all the studied populations, suggesting that pollen limitation is unrelated to habitat disturbance. Overall, our results suggest that fragmentation has affected key demographic features of *M. christinae*, including reproduction and recruitment.

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Key words: disturbance; habitat fragmentation; Mexico; orchid conservation; pollen limitation.

HABITAT FRAGMENTATION AND DISTURBANCE REPRESENT TWO OF THE MOST SIGNIFICANT THREATS to species conservation and ecosystem function (Ehrlich 1988, Saunders *et al.* 1991, Laurance & Bierregaard 1997). Both factors have led to the interruption of interspecific interactions, indirectly causing changes in plant demographic dynamics via reduced reproductive output (Steffan-Dewenter *et al.* 2006). Numerous studies have shown that plants in fragmented landscapes undergo a reduction in pollination efficiency and reproductive success (reviewed by Aguilar *et al.* 2006), as well as recruitment and survival rates, all of which represent relevant pathways through which fragmentation can negatively affect plant demographic dynamics (Bruna *et al.* 2009). It is likely, however, that the magnitude of fragmentation impacts on plant populations depends on plant life stage and features of the plant reproductive system. For example, early life stages of epiphytic species, which have a limited availability of suitable sites for germination and establishment, are expected to be more vulnerable to fragmentation compared with early life stages of species that do not exhibit site limitation (Calvo & Horvitz 1990; Cascante Marin *et al.* 2008, 2009). Likewise, plant species which are self-incompatible and/or have specialized pollination systems might be more negatively affected by fragmentation in terms of their reproductive output (Aizen & Feinsinger 1994, Aguilar *et al.* 2006, Jacquemyn *et al.* 2007).

Although reductions in plant reproductive success and recruitment rates have been noted to result from population fragmentation, relatively few studies have attempted to use both demographic variables and reproductive success (fruit-set) to explain the demographic status of populations in fragmented landscapes.

Myrmecophila christinae (Orchidaceae) is an epiphytic species, and as such requires host plants for seed germination and seedling establishment. It also presents a highly specific food-deceptive pollination system (Parra-Tabla *et al.* 2009). Together, these characteristics are likely to make this species susceptible to fragmentation and disturbance. Here we describe the population density and structure, as well as reproductive success and pollen limitation, for 14 populations of *M. christinae* in a fragmented landscape on the north coast of Yucatan, Mexico. Populations were found mainly along the coastal dune vegetation, which is one of the most threatened habitats in the region due to effects of fragmentation and disturbance.

The specific goals of this study were to: (1) describe the population density and age-structure of *M. christinae* populations found in fragments of different size and subject to varying levels of disturbance; (2) evaluate the influence of fragment size and degree of disturbance result on reproductive success and pollen-limitation of *M. christinae*; and (3) evaluate if *M. christinae* is pollen limited, and if the degree of limitation varies with fragment size and degree of disturbance.

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METHODS

STUDY SPECIES.—*M. christinae* (Orchidaceae; synonyms *Schomburgkia tibicinis*, *Myrmecophila tibicinis*; Carnevali *et al.* 2001) is an epiphytic orchid found in the coastal shrub vegetation of Yucatan, Mexico. It is generally found growing on the trunks of palms (*Coccothrinax readii* and *Thrinax radiata* 1 and 2–5 m high, respectively) and on branches of small shrubs (Rico-Gray & Thien 1987). *M. christinae* plants produce one or two pseudobulbs per year, and plants with > 40 pseudobulbs have been reported in some cases (Rico-Gray & Thien 1987). *M. christinae* is self-compatible with a specialized nonmodel food-deception pollination system based on the production of floral scents and mediated by two large solitary bee species, *Eulaema polychroma* and *Xylocopa* sp., which are necessary for fruit-set (Rico-Gray & Thien 1987). Nonetheless, during several consecutive flowering seasons only *Xylocopa* sp. has been observed visiting flowers of this species (see Parra-Tabla *et al.* 2009). Flowers are located at the tip of 1.5–2.0-m-long inflorescences, and each plant annually produces a median of 0.9 (range 0–3.2) inflorescences ($N = 115$). Each inflorescence produces between six and 15 flowers (8–9 cm diam), which vary in color from creamy yellow to purplish rose. Inflorescences remain attached to pseudobulbs after the reproductive season. Flowers are receptive from the first day of anthesis, and floral longevity ranges from 6 to 10 days, although flowers close 24 h after being pollinated (Parra-Tabla *et al.* 2009). The flowering season extends from March to June, while fruit production takes place from May to July (Rico-Gray & Thien 1987). Pollinator limitation has been shown for this species, and the percentage of fruit-set can be as low as 2.3 percent per population (Rico-Gray & Thien 1987). Importantly, *M. christinae* populations in Yucatan have suffered from illegal extraction of individuals for

ornamental purposes, and especially from an accelerated fragmentation process due to the development of tourist infrastructure.

STUDY SITES.—Coastal areas in Yucatan remained relatively undisturbed before 1970 (Espejel 1984). During the last four decades, however, terrestrial coastal ecosystems have been strongly impacted by the intensive cultivation of *Cocos nucifera* palm trees, and more recently due to the construction of tourist infrastructure and access roads (Meyer 1999). A marked decrease in disturbance can be observed from west to east along the Yucatan coast, with western sites close to Puerto Progreso and Chuburna being the most disturbed (Fig. S1). Historical data indicate that western sites have suffered from disturbance for > 40 yr, while those to the east have been exposed to human impacts for 20 yr or less (Vargas *et al.* 2006). Illegal extraction for ornamental purposes of specimens from several species represents a significant impact on plant populations, especially in the case of *M. christinae* and *C. readii*.

From January 2000 to March 2002 we studied 14 populations of *M. christinae* found in fragments of vegetation along a ca 60 km transect from the town of Chuburna (21° 15' N, 89° 49' W) to Telchac (21° 17' N and 89° 16' W; Fig. S1). Mean annual rainfall and temperature in the region are 469 mm and 25.4°C, respectively (Espejel 1984). The coastal shrub vegetation at the study sites constitutes a 200–500-m-wide strip, bordered by mangroves to the south and the coastline to the north. Such spatial configuration of the landscape facilitated the identification, location and size estimation of fragments. The minimum distance between populations was 0.2 km and the maximum was 48.75 km, and fragment sizes ranged from 0.03 to 40 ha (Table 1).

We used the following criteria to categorize fragment disturbance: (a) the percentage of the total area covered by disturbance

TABLE 1. General description of study sites and *Myrmecophila christinae* study populations found in a fragmented landscape in Yucatan, Mexico.

Population name	Fragment size (ha)	Disturbance category	Number of individuals			Mean fruit-set (%) (range)	Host plant density (individuals/m ²)
			Seedlings	Juveniles	A/R ^a		
Pargo	0.03	High	0	2	4/2	9 (5.5–12.5)	0.615
Trillizas	0.044	High	0	1	6/2	3.2 (0–6.4)	0.248
Reef	0.882	High	0	4	19/13	1.3 (0–5)	0.615
Mr. Bú	0.128	High	0	3	5/3	1.1 (0–3.4)	0.234
Aruba	3.1	Low	11	24	35/18	1.1 (0–9.6)	0.366
Calin ha	6.0	High	3	12	46/24	2.9 (0–18)	0.141
Nuevo Yucatán	7.0	High	5	2	15/9	14 (0–28)	0.1362
Chicxulub	8.02	Medium	3	3	51/22	18 (0–50)	0.0083
Uaymitun	9.0	High	16	2	28/11	5.4 (0–17)	0.120
San Benito	12.0	Low	101	11	176/59	3.2 (0–40)	1.793
Bufo	13.2	Medium	2	1	5/5	1.0 (0–5)	0.6
SAM	21.1	Low	38	5	31/17	27.3 (0–66.6)	0.165
Alcocer	21.0	Low	19	4	16/8	42.5 (25–66.6)	0.3911
Telchac	40.0	Low	79	1	48/22	11.7 (0–50)	0.2888

^aA, total number reproductive adults; R, reproductive adults sampled.

indicator species for this type of vegetation (e.g., *Bravaisia tubiflora*, *Ernodea littoralis*, *Cyperus articulatus*, *Bouteloua repens* and *Agave angustifolia*); and (b) the characteristics of the surrounding matrix (e.g., presence of beach houses) and frequency of fires. Relatively undisturbed fragments had a low percentage of area covered by disturbance indicator species (< 25%), had no houses bordering or within them, and rarely exhibited evidence of fires (no fire recorded in at least 10 yr); intermediately disturbed fragments had 25–50 percent of their area covered by disturbance indicator species, had houses located alongside the fragments, and were subject to occasional fires (the last fire recorded in a period between 3 and 5 yr); and highly disturbed fragments were characterized by over 50 percent of their area covered by disturbance indicator species, houses both bordering and within fragments, as well as frequent fires (at least one fire recorded per year). The estimation of disturbance indicator species cover for each fragment was done by visual inspection of each site; for fragments smaller than 1 ha the entire site was examined, while for fragments > 1 ha disturbance indicator species cover was estimated based on permanent quadrants. Fire frequency is driven mainly by human activity along the coast, as people usually start fires to remove the vegetation and construct buildings, or to burn waste.

M. CHRISTINAE POPULATION SURVEYS.—In small fragments (< 1 ha) all *M. christinae* plants were located and marked, based on a careful examination of branches and trunks of potential host plants, as well as of the bare sandy substrate. For fragments > 1 ha, *M. christinae* plants were identified and marked within four permanent 20 × 20 m quadrants established inside the fragment in a random manner. We categorized *M. christinae* individuals as: (a) seedlings: that is individuals with pseudobulbs ≤ 10 cm in length; (b) juveniles: individuals with pseudobulbs > 10 cm in length and with no evidence of inflorescence production; and (c) adults: individuals with evidence of inflorescence production (previous or current reproductive events). We also further classified adults based on the number of pseudobulbs, and for all fragments we estimated the density of all host species.

REPRODUCTIVE SUCCESS AND POLLEN LIMITATION.—The number of flowers and mature fruits for each study plant were recorded during weekly censuses throughout the reproductive season. Pollen limitation was assessed through hand-pollination experiments conducted at all the fragments except Pargo and Trillizas because of the low number of reproductive plants at these sites. The same situation was present at Mr. Bú and Aruba populations, but we were able to locate and mark enough individuals surrounding the fragment (< 10 m away). Within each fragment, we selected three to eight individuals for the hand-pollination experiment. These individuals were different from those used to measure reproductive success. For each plant, one inflorescence was selected and a plastic tape was used to mark a single recently opened flower, which was not manipulated (open pollination treatment). A neighboring flower was marked with a different color tape and hand-pollinated with pollinia from nearby (> 5 m away) individuals. The response variable recorded for each flower was either success (if the fruit matured) or

failure (if it did not). The pollen limitation experiment was conducted at the 'flower level' and not at the whole plant level, and it is therefore possible that resource reallocation between flowers within an individual might have influenced the results. Fruit production is, however, typically low in orchids and because resource limitation has not been reported within or between consecutive reproductive seasons (Calvo 1993, but see Ackerman & Montalvo 1990), we assumed that the estimation of pollen limitation at the flower level was a good estimator of limitation of the whole plant (Parra-Tabla & Vargas 2007).

ANALYSIS OF POPULATION DENSITY AND STRUCTURE.—Density of seedlings, juveniles, and adults, as well as total plant density, were analyzed with general linear models (GLM). Because of the apparent dependence between fragment size and fragment disturbance (see Table 1), for this analysis we used both variables to create a new variable, which we denominated 'habitat affectation', defined as the ratio between the category of disturbance and fragment size. This ratio was log-transformed, and so negative values indicate low affectation, while positive values indicate high affectation. Independent variables included in the models were: (a) habitat affectation; (b) density of host plants; and (c) density of adult *M. christinae* plants. Models were optimized using step-wise backward removal of non-significant factors ($P > 0.05$).

We conducted simple linear regressions to evaluate changes in the ratio of individuals belonging to each age category relative to the following age category and to fragment size. To estimate the significance of the habitat affectation we used the resampling Bootstrap method with 1000 repetitions (SYSTAT 2000). Likewise, we evaluated whether the change in frequency of individuals of each age category was independent of fragment size; in this case, fragments were grouped in three categories for analysis: small (< 1 ha), intermediate (1–10 ha) and large fragments (> 10 ha). This analysis was based on χ^2 values, and the probabilities associated with these values were obtained through the random generation of frequency tables; this method has the advantage of not assuming minimum expected frequencies (Romesburg & Marshall 1985).

REPRODUCTIVE SUCCESS AND POLLEN LIMITATION.—The effects of fragment size category and degree of disturbance on *M. christinae* fruit-set (number of mature fruits/total number of flowers) were evaluated with GLM. The study species has a highly skewed distribution of fruit production, with most plants not producing fruits, so the computation of the significance of F -values for fragment size and disturbance effects was based on the Bootstrap resampling method using 1000 repetitions (SYSTAT 2000). Using this method, we also calculated 95% confidence interval (CI) for significant F -values. Fruit-set data were arcsine transformed using the Freeman–Tukey modification (Zar 1996). Accepted P -values for all GLM models were based on type III sums of squares.

Pollinator limitation data were analyzed using binary logistic regression models (Steinberg & Colla 2000). Binary logistic regression analysis evaluates the effect of continuous and categorical independent variables on a binary response variable (fruit maturation success or failure). In this case, pollination treatment (hand-

pollination vs. open pollination), disturbance level, and fragment size category were the independent variables selected as predictors of the pollination success odds ratios. Regression coefficients (β) were calculated and represent the rate of change in odds ratio logarithms with respect to changes in the explanatory factors. Statistical adjustment of the binary logistic regressions can be estimated with an approximated χ^2 value, as well as with the McFadden ρ^2 value (Steinberg & Colla 2000). Initially, a saturated logistic model was used which included all the predictor variables; subsequently, nonsignificant predictor variables were eliminated in a step-wise backward fashion (factors retained only if $P \leq 0.05$). All values presented are means \pm SD unless otherwise stated.

RESULTS

POPULATION DENSITY AND STRUCTURE.—Seedling density was significantly affected by habitat affectation and host plant density (Table 2). The regression coefficient for habitat affectation was negative for seedling density and positive for host plant density (Table 2), suggesting that although affectation reduces recruitment rates, it also results in greater host availability (Figs. 1A and B). Juvenile density was also positively influenced by adult density (Table 2; Fig. 1C) but not by habitat affectation or host plant density (Table 2). Finally, both the density of adults and the total density of plants were significantly influenced by habitat affectation (Table 2; Figs. 1D and E). In this case, the coefficient value was positive due to the high number of adult individuals present in highly affected habitats, and this clearly had an effect on population structure. Host plant density varied considerably across fragments, but was not significantly affected by habitat affectation ($P = 0.5$).

A large proportion of adults was observed in small fragments (< 1 ha), as well as a considerable increase in the proportion of seedlings in medium size (1–10 ha) to large fragments (> 10 ha) (Fig. 2A). A χ^2 -test showed a lack of independence in the frequency of individuals belonging to each age stage across fragment size cat-

egories ($\chi^2_4 = 50.4$, $P < 0.001$). Specifically, juveniles and adults were over represented and seedlings under represented in small fragments (< 10 ha) (Fig. 2A), while seedlings were over represented in large fragments (> 10 ha) (Fig. 2A).

Linear regressions showed a significant and positive relationship between the ratio of seedlings/juveniles, seedlings/adults, and juveniles/adults with respect to habitat affectation (Table 3). In the first two cases, the regression coefficient was negative, suggesting a greater amount of seedlings relative to other size categories in large and relatively undisturbed fragments (Fig. 2A). In contrast, the regression coefficient for juveniles/adults was positive, suggesting a greater number of juveniles relative to adults in large and disturbed fragments (Fig. 2A).

The frequency of individuals belonging to each adult size category also varied across fragments (Fig. 2B); the χ^2 -test showed a lack of independence in the frequency of individuals of each adult size category across fragment size categories ($\chi^2_4 = 10.25$, $P = 0.03$). Small fragments showed an over-representation of individuals belonging to the largest adult size category, and an under-representation of individuals in the smallest adult size category (Fig. 2B). In contrast, fragments > 1 ha exhibited an over-representation of individuals of the smaller size category, and an under-representation of individuals from the intermediate and largest size categories (Fig. 2B). Regression analyses did not, however, reveal a significant relationship between the ratio of one individual size category relative to the following individual size category and habitat affectation ($r \leq 0.17$, $P \geq 0.1$ in all cases).

REPRODUCTIVE SUCCESS AND POLLEN LIMITATION.—The global average of fruit-set for all the studied populations was 0.09 ± 0.13 , although means varied strongly both within and between populations (range 0–0.66, Table 1). A nonsignificant relationship was observed between fruit-set and fragment size ($\beta = 0.006 \pm 0.004$, SE; $t = 1.94$, $P = 0.07$; 95% CI: 0.0012–0.017) and between fruit-set and flower density (number of flowers/m²) ($\beta = -0.7 \pm 0.37$, SE; $t = -1.8$, $P = 0.09$; 95% CI: 1.49–0.07). Although fragments of intermediate (1–10 ha) and large size (> 10 ha) showed an average fruit-set value four to six times greater than that observed at small fragments (< 1 ha) (Fig. 3A), the GLM analysis did not show a significant effect of fragment size on fruit-set ($F_{1,210} = 1.2$, $P = 0.36$; CI for significant F -value at 95% CI: 1.9–2.1). There was, however, a significant effect of disturbance ($F_{1,210} = 4.1$, $P = 0.02$; CI for significant F -value at 95% CI: 3.8–4.3); low and intermediately disturbed fragments showed, on average, twice as much fruit-set compared with highly disturbed fragments (Fig. 3B).

Only 21 flowers from the 214 flowers marked for the open pollination treatment (controls) set fruit, compared with 168 flowers from the 225 hand-pollinated flowers. The logistic binary regression showed a significant effect of the hand pollination treatment ($\chi^2_1 = 36.1$, $P < 0.001$, McFadden's $\rho^2 = 0.34$), for which the regression coefficient was positive and significant ($\beta = 3.3 \pm 0.27$ [SE]) ($z = 11.94$, $P < 0.0001$, 95% CI: 2.9–4.6); the odds ratio showed that hand-pollinated flowers were on average *ca* 27 times more likely to set fruit than open-pollinated flowers: odds ratio 27.01 ± 7.5 (SE) (95% CI: 15.7–46.5). The effects of disturbance,

TABLE 2. General linear model results for main effects on densities of seedlings, juveniles, adults and total density (individuals/ha) of the epiphytic orchid *Myrmecophila christinae* in a fragmented landscape in Yucatan, Mexico. Significant effects are shown in bold.

Dependent variable	Independent variables	Coefficient (\pm EE)	<i>t</i>	<i>P</i>
Seedling density	Habitat affectation	-0.3 (0.13)	-2.34	< 0.001
	Adult density	0.004 (0.016)	0.25	0.8
	Host density	3.16 (0.8)	4.36	0.04
Juvenile density	Habitat affectation	1.81 (2.01)	0.9	0.38
	Adult density	0.33 (0.05)	5.76	< 0.001
	Host density	2.07 (6.7)	0.09	0.76
Adult density	Habitat affectation	14.12 (2.5)	5.62	< 0.001
	Host density	14.57 (16.1)	0.9	0.38
Total density	Habitat affectation	19.1 (3.3)	5.78	< 0.001
	Host density	24.1 (20.7)	1.16	0.27

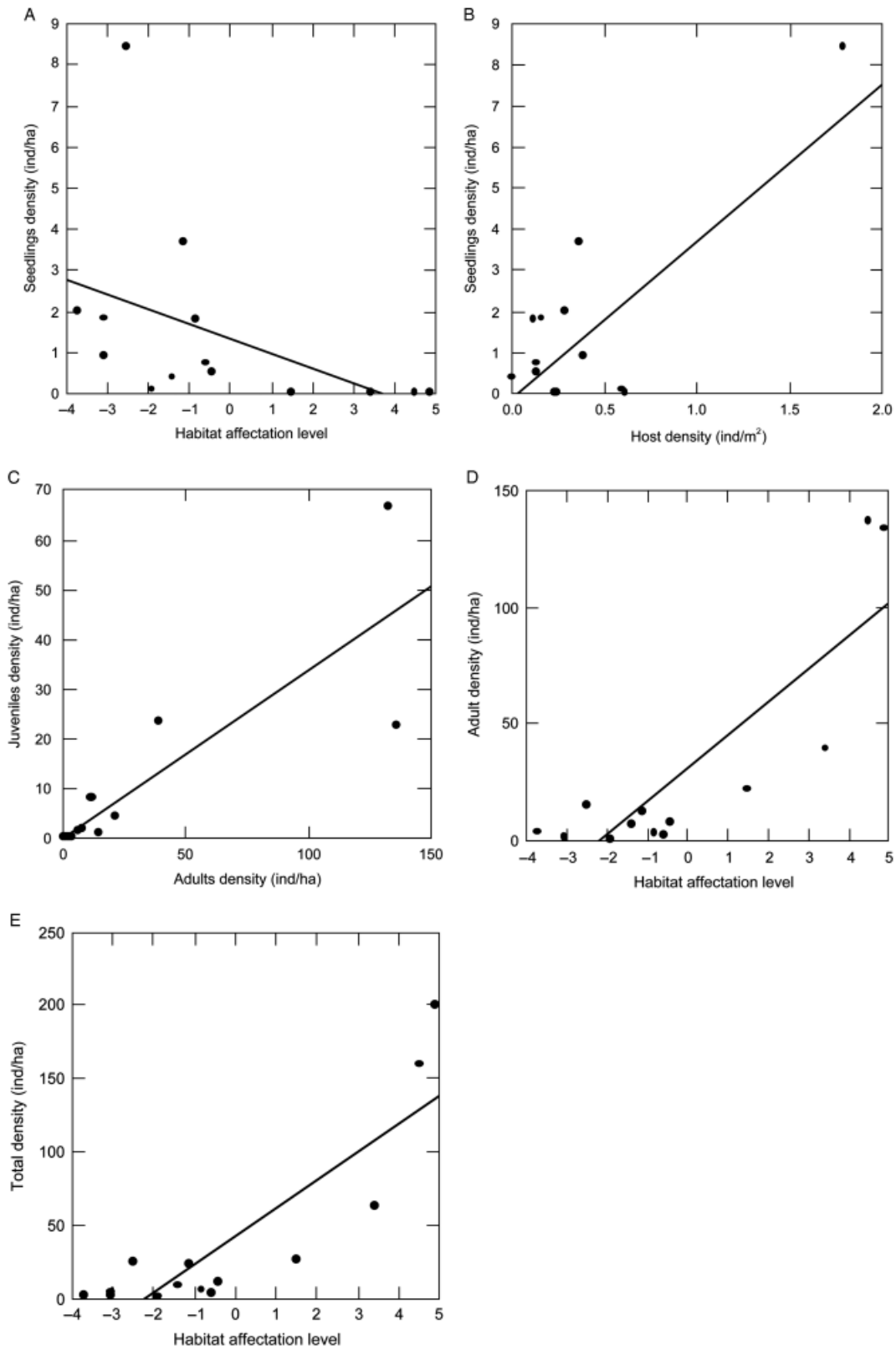


FIGURE 1. Relationship between (A) Seedling density and habitat affection (logarithmic scale), (B) Seedling density and host density, (C) Juvenile density and adult density, (D) Adult density and habitat affection, and (E) Total density and habitat affection, using the 14 study populations of *Myrmecophila christinae* found in a fragmented landscape on the north coast of Yucatan, Mexico.

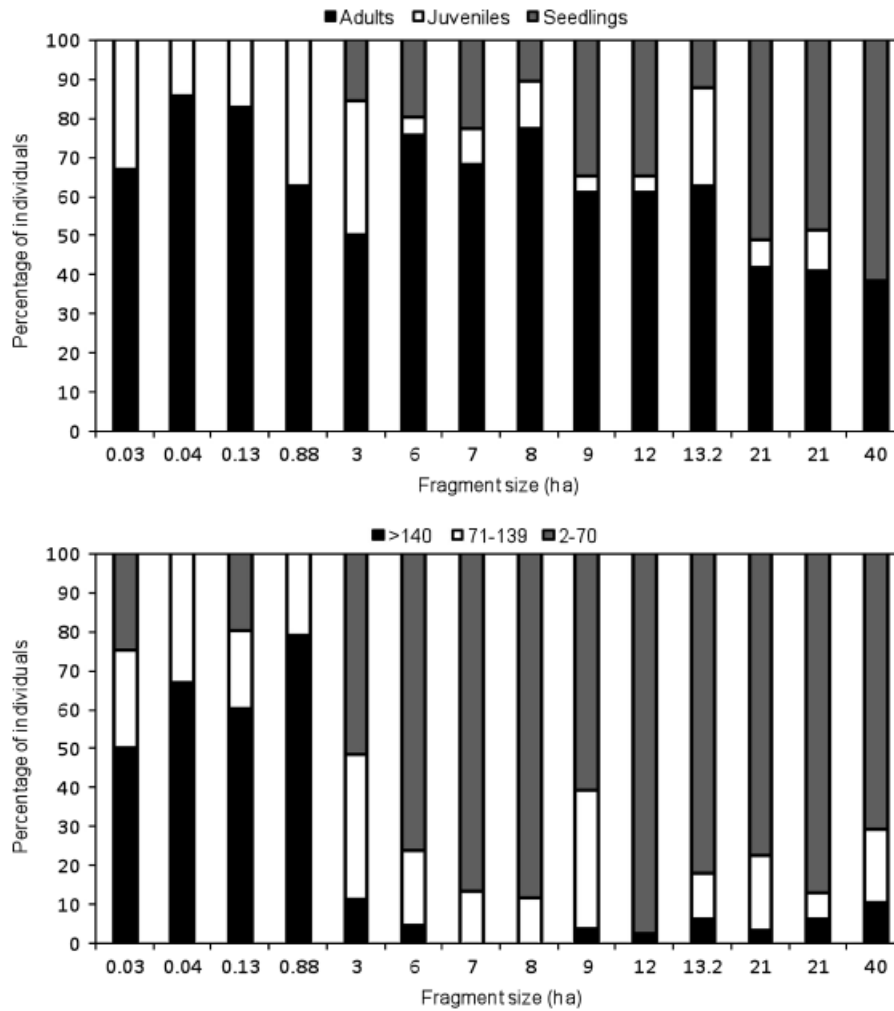


FIGURE 2. (A) Percentage of individuals of different age classes, and (B) proportion of adult individuals of different size (number of pseudobulbs) for the 14 study populations of *Myrmecophila christinae* found in a fragmented landscape on the north coast of Yucatan, Mexico.

fragment size category, and their interactions with pollination treatment were not significant (β coefficients ≤ 0.94 , $z \leq 0.7$, $P \geq 0.22$ in all cases) indicating that pollen limitation is not affected by fragment size category and/or disturbance level.

DISCUSSION

Based on a description of population density and age structure, as well as reproductive success and pollen limitation, the present study

has found that key aspects of the population ecology of *M. christinae* are affected in fragmented landscapes. Our data suggest that fragmentation of the coastal dune vegetation is leading to changes in the population structure of this species.

POPULATION DENSITY AND STRUCTURE.—Seedling density was affected both by the habitat affectation and density of host plants. The lack of significant habitat affectation on the density of host plants, however, and the presence of host plants at sites where

TABLE 3. Linear regression results to evaluate changes in the ratio of *Myrmecophila christinae* individuals belonging to each age stage category across populations found in a fragmented landscape in Yucatan, Mexico. Regression coefficients, β (\pm SE) estimated by bootstrap resampling, and their 95% confidence interval (CI) are shown.

Dependent variable	Independent variable	$F_{1,12}$	P	R^2	β	CI
Seedlings/juveniles	Habitat affectation	6.22	0.02	0.34	-7.01(3.2)	-16.7, -2.16
Seedlings/adults	Habitat affectation	14.9	0.002	0.55	-0.15 (0.04)	-0.25, -0.08
Juveniles/adults	Habitat affectation	5.45	0.03	0.55	0.03 (0.01)	0.03, 0.002

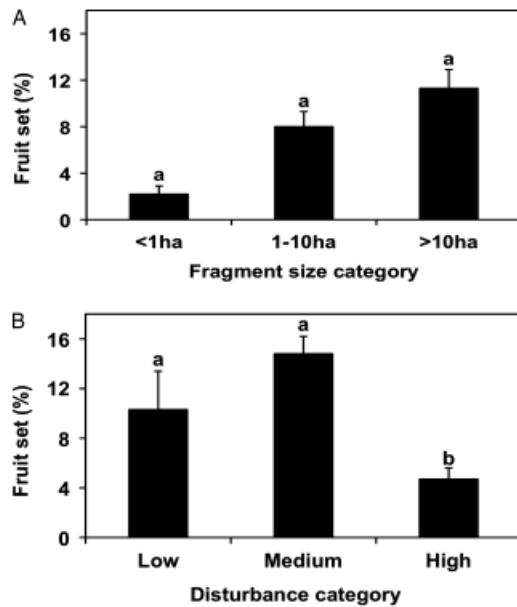


FIGURE 3. Effect of (A) fragment size category and (B) disturbance category on fruit-set using 14 populations of *Myrmecophila christinae* found in a fragmented landscape on the north coast of Yucatan, Mexico.

seedlings were not observed, suggests that other factors besides host availability may limit *M. christinae* recruitment. One such factor might be differences in host species quality for this orchid's germination and establishment (Tremblay *et al.* 1998). Stressful environments such as those present in the coastal dune vegetation where *M. christinae* grows, are characterized by elevated light levels and high temperatures. In this way, *C. readii*'s reticulated stem surface and abundant foliage probably provide *M. christinae* with optimal microhabitat conditions characterized by partial shade and thus lower plant evaporative water loss, as well as a suitable surface for root anchorage. Both of these are conditions, which have been shown to favor orchid establishment (Zotz 1998, Bayman *et al.* 2002). In *M. christinae*, it would be interesting to study the differences in microhabitat quality between its different hosts species.

REPRODUCTIVE SUCCESS AND POLLEN LIMITATION.—There is increasing evidence that plant reproductive success decreases in fragmented landscapes, and that the magnitude of such reduction depends on the pollination system of the species and the degree of specificity in plant–pollinator interactions (Aguilar *et al.* 2006). Because *M. christinae* depends on only two pollinators to set fruit, we expected that fragmentation and disturbance would have strong effects on fruit production for this species. Results from this study partially supported this hypothesis, as disturbance level had a significant effect on reproductive success; fragment size, however, did not. The lack of a significant effect of fragment size on *M. christinae* might have been due to the large variance in reproductive output within each population.

Orchid species are characterized by having a strong component of stochasticity (*i.e.*, high variation both within and between

populations) governing individual reproductive output (*e.g.*, Ackerman & Montalvo 1990, O'Connell & Johnston 1998, Tremblay *et al.* 2005), and this may very well be the case for *M. christinae*. It is also important to consider that previous studies with this species have shown that traits such as floral display and floral scent production partially explain the variation in individual reproductive success (Parra-Tabla & Vargas, 2007, Parra-Tabla *et al.* 2009).

Results from the pollen limitation experiment showed that hand-pollinated flowers were *ca* 27 times more likely to set fruit compared with control flowers. Pollen limitation for *M. christinae* has been reported previously (Rico-Gray & Thien 1987, Parra-Tabla & Vargas 2007) and seems to be a common condition in tropical orchids which do not offer floral rewards for pollinators (Neiland & Wilcock 1998, Tremblay *et al.* 2005). Fragment size and disturbance, however, did not influence pollen limitation indicating that pollen limitation cannot explain the relationship between fragment size or disturbance and reproductive success of *M. christinae*.

CONCLUSION AND CONSERVATION IMPLICATIONS FOR *MYRMECOPHILA CHRISTINAE*.—One of the main effects of fragmentation on plant populations is that it promotes demographic stochasticity (*i.e.*, variable populations rates growth, reductions on effective and total population sizes). This may in turn lead to the loss of genetic variability, reduction in fitness, and finally an increase in the risk of local extinction (Soulé 1986). In the case of *M. christinae*, although there is currently no evidence of a loss in genetic variation due to fragmentation (Vargas *et al.* 2006), and the present study did not show a significantly lower fruit production for plants in small fragments, results did show a negative effect of disturbance on fruit production. Moreover, fragmentation may still have the potential to cause a reduction in recruitment within the populations. This reduction can modify the population age structure resulting in a large proportion of reproductive adults capable of significant reproductive output, but a lower proportion of seedlings, suggesting reduced recruitment levels presumably due to a lack of suitable host plants.

The evidence gathered to date suggests that anthropogenic impacts taking place along the north coast of Yucatan are affecting demographic features of *M. christinae* populations. One relatively simple strategy to increase this species' recruitment would be the reintroduction of key host plant species such as *C. readii*. This palm is not only a threatened endemic species, but has been shown to play a relevant role as nurse plant for an endemic cactus in the Yucatan peninsula (Cervera *et al.* 2006). The use of *C. readii* would have multiple effects in favor of the conservation of *M. christinae* and other species found in the coastal shrub ecosystem in Yucatan.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article.

FIGURE S1. Study sites where the 14 sampled populations of *Myrmecophila christinae* were found throughout a fragmented landscape on the north coast of Yucatan, Mexico.

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