Reproduction of *Byrsonima sericea* (Malpighiaceae) in *Restinga* Fragmented Habitats in Southeastern Brazil

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ABSTRACT

Habitat fragmentation may affect the reproductive success of plant populations in many different ways. Thus, negative, neutral, or positive plant responses can be observed, according to the balance of the different interactions. Variables related to mutualistic and antagonistic interactions (pollinator activity and gall occurrence, respectively) were measured on *Byrsonima sericea* populations of a fragmented seashore area (*restinga*) in southeastern Brazil. Pollinator visits to the oil-bearing flowers, insect gall occurrence on stems and inflorescences, and fruit set of *B. sericea* were compared between three small (up to 0.3 ha) and three large (14.0–99.0 ha) fragments. MANOVA showed differences between fragment classes. Nevertheless, *a posteriori* univariate ANOVA showed that the pollinator visit frequency was more than twofold higher in small fragments, and that gall occurrence and fruit set did not show significant differences between small and large fragments. These results suggest that the habitat fragmentation does not affect the female reproductive success of *B. sericea* in the studied *restinga* areas because resource availability seems to be a more important factor for fruit set than pollen limitation due to pollination failure. This is the first work assessing the effects of habitat fragmentation in *restinga* areas, which are intensely impacted by urbanization, so that no generalization about the fragmentation consequences can still be made for this ecosystem.

Abstract in Spanish is available at http://www.blackwell-synergy.com/loi/btp

Key words: habitat fragmentation; insect galls; phenology; plant–animal interaction; pollination; solitary bees.

HABITAT LOSS AND FRAGMENTATION, MAINLY CAUSED BY AGRICULTURE, urbanization, and exploitation of wood resources, constitute the major threat to interactions among organisms in ecosystems (Fahrig 2003, Hoffmeister *et al.* 2005). Concerning plant–pollinator interactions, the effects of habitat fragmentation can lead to negative consequences on plant reproduction, and some authors have reported causes of lower plant reproductive output in small fragments (SFs; detected by seed and fruit set), such as the increase of exotic pollinators and/or the reduction of native pollinators visiting flowers and lower stigmatic pollen loads (*e.g.*, Aizen & Feinsinger 1994, Bosch *et al.* 2002, Aguilar & Galetto 2004). On a wider scale, among the several plant traits that supposedly would indicate higher susceptibility to habitat fragmentation (see Aizen *et al.* 2002), a broad review found that the reproductive success of most self-incompatible plants is, on average, negatively affected by fragmentation (Aguilar *et al.* 2006). On the other hand, many studies found no significant differences or higher reproductive output in plants in fragmented and disturbed habitats (*e.g.*, Aldrich & Hamrick 1998, Dick 2001, Lopes & Buzato 2007, Aguirre & Dirzo 2008). Moreover, there are other trends related to positive effects of fragmentation on plant reproduction, such as the reduced richness of monophagous herbivore insects (Zabel & Tscharntke 1998) and the increased occurrence of parasitoid predators of galling insects (*e.g.*, Gathmann *et al.* 1994, Kruess & Tscharntke 1994) in smaller areas.

Because the ecological effects of habitat fragmentation are complex, exhibiting thresholds where they are unexpected (Bissonette & Storch 2002), new studies considering two or more plant–animal interactions may hopeful help to integrate and better understand plant reproduction in fragmented habitats (Aguilar *et al.* 2006). Except for mutualistic pollinators, most plant–insect interactions can affect the plant reproductive success negatively, such as those related to insect galls. Although several papers analyzed the effects of insect galls on plant reproduction (Silva *et al.* 1996, Ngakan & Yukawa 2004, Gonzáles *et al.* 2005), data on the occurrence of galls are scarce for fragmented habitats (Chust *et al.* 2007). Moreover, as far as we know, the only study that analyzed the crossed effects of fragmentation, plant reproduction and galls was that carried out by Wang *et al.* (2005), which provided a case study of the peculiar interactions between figs and their pollinating and nonpollinating Chalcidoidea wasps. It would be expected that fragmentation would induce declines in insect-gall populations due to both area and isolation effects on local extinction and dispersal (Hanski 1994) and microenvironment influence on the establishment and relative reproductive success of gallers (Boukill *et al.* 2007). However, the mean number of fig galls increased in highly fragmented forests (Wang *et al.* 2005), and similar results were found for three of seven species of cork oak galls (Chust *et al.* 2007).

Ecological studies of the fragmentation effects in Brazilian rain forests have been conducted; however, nothing is known on this topic for seashore areas named *restingas* (Constantino *et al.* 2003). *Restinga* constitutes a singular ecosystem under stressful salinity and relative dryness conditions (Araujo 1997), which has been affected

by human action for *ca* 8000 yr, but human occupation for housing, tourism, and land speculation has recently increased such that there is a great need for conservation of remnant patches and restoration of degraded areas throughout the Brazilian coast (Zamith & Scarano 2006). Concerning pollinator fauna in *restingas*, many of the solitary bee species belonging to Apidae require pollen and oil from Malpighiaceae flowers to supplement larvae nourishment and to waterproof their nests (see Costa *et al.* 2006). One of the Malpighiaceae species is *Byrsonima sericea* DC, which constitutes an interesting study object for at least three reasons: (1) it is a frequent and abundant species in *restinga* areas (Araujo 2000, Pereira *et al.* 2001); (2) its oil-bearing flowers restrict the potential pollinator spectrum to specialized oil-collecting bees (see Vogel 1990); and (3) its leaves, flowers, and stems serve as hosts to gall-producing Diptera: Cecidomyiidae and Lepidoptera species (Flinte *et al.* 2006). In this study, we compared *B. sericea* individuals in *restinga* fragments of two different size classes considering the parameters of a mutualistic animal–plant interaction (frequency of pollinator visits) and of an antagonistic interaction (number of insect galls/plant) to analyze female reproductive efforts (fruit set after natural pollination).

METHODS

STUDY SYSTEM.—This study was carried out in fragmented areas of shrub vegetation in the *Restinga de Massambaba* area located near the cities of Arraial do Cabo and Cabo Frio (22°56′32″ S, 42°03′04″ W), State of Rio de Janeiro, Brazil. Six *restinga* fragments were selected and grouped into two size classes. SFs ranged from 0.07 to 0.28 ha and large fragments (LFs) from 14.0 to 99.0 ha. These fragments are delineated by matrix areas (salt marshes, urban nuclei, pastures, and water streams) or by interruption lines (streets, roads, and artificial water channels; Table 1). The age of fragments was *ca* 50 yr, except for SF2 and SF3, which were *ca* 20–30 yr (B. S. Dunley, unpubl. data).

Brazilian *restingas* are the result of the accumulation of marine sand sediments subjected to intense eolic activity and usually low rainfalls, which may lead to a semiarid condition (Araujo 2000). Because of both the irregular topography and the gradual salinity variation, they shelter a high variety of microhabitats in small areas (Araujo *et al.* 1998). These areas are composed of more or less flooded depressions, dunes of variable height (> 10 m in some cases), and extensive sandy plains covered by thickets more or less

isolated among them (Araujo *et al.* 1998). Their vegetation is mainly characterized by xerophytic and halophytic shrubs and herbs (Fig. S1), whose conservation is essentially threatened by urbanization activity and salt marshes (Araujo 1997).

Byrsonima sericea is well represented in *restinga*s (Araujo 2000, Pereira *et al.* 2001), where it grows as a shrub that may reach 3 m in height, although this species occurs as a tree in coastal rain forests and *cerrados* (Teixeira & Machado 2000). Each plant regularly matures hundreds of showy flowers in terminal racemes. Flowers are yellow, monoclinous, bear oil-secreting elaiophores on their sepals, and remain open for only 1 d. Its stigma presents a covering epidermis (*operculum*) that hinders spontaneous self-pollination, because a friction with the bee body and legs is necessary to expose the receptive surface (L. F. M. Rodrigues, unpubl. data). *Byrsonima sericea* has been previously classified as self-incompatible (Costa *et al.* 2006).

DENSITY AND COVER OF *B. SERICEA* IN THE FRAGMENTS.—The plant density and coverage of each population were quantified with a linear density index (ID = N/L; N, total number of sampled individuals; L, total length of all sampled transects) and a linear coverage index (IC = l/L; l, sum of the intercept lengths for individuals), respectively (Brower & Zar 1984, Pereira *et al.* 2001), using a total of 400 m per fragment (20 transect-lines of 20 m, spaced 10 m apart). In the SF2 site, a total of 200 m was used due to the reduced area of this fragment. The linear density (ID) and linear coverage (IC) indexes between fragments were compared according to Brower and Zar (1984) to determine whether these population traits influence the reproductive output.

REPRODUCTIVE PHENOLOGY AND POLLINATOR AGENTS.—The Fournier method was adopted to compare the flowering intensity and fruiting phenology between fragments (Fournier 1974). This is a semi-quantitative method that classifies phenophases considering intensity intervals of 25 percent (*i.e.*, value range of 0–4). Three reproductive individuals per fragment were used to characterize these reproductive phenophases. Data were monthly collected between May 2004 and June 2005 and fortnightly on the months with the highest flowering and fruiting intensity (November–January). These data were obtained to determine whether phenological traits influence the reproductive output.

Observations of floral visitors were carried out on three focal individuals (the same as those used for phenological and galls

TABLE 1. *Location, size, distance to nearest neighboring fragment, and minimal distance among Byrsonima sericea individuals in restinga fragments in Massambaba, southeastern Brazil. Frg, fragment; SFs, small fragments; LFs, large fragments.*

Frg	Coordinates	Site	Total area (ha)	Frg minimal distance (m)	Individual minimal distance (m)
SF1	22°58′07″ S 42°01′58″ W	Praia Grande	0.22	1100.0	13.0
SF2	22°56′44″ S 42°06′37″ W	Monte Alto	0.07	120.0	10.5
SF3	22°56′48″ S 42°06′37″ W	Monte Alto	0.28	350.0	10.0
LF1	22°56′58″ S 42°02′15″ W	*Restinga* do Pórtico	36.00	100.0	11.0
LF2	22°55′47″ S 42°02′31″ W	*Restinga* do Foguete	14.00	100.0	9.5
LF3	22°57′08″ S 42°04′08″ W	Reserva das Orquídeas	99.00	60.0	10.0

observations) per fragment, between October 2004 and February 2005. Whenever the flowering of a focal individual ended or intensely declined before the final observation period, its nearest neighbor at the flowering peak was selected to continue our observations on floral visitors. Consequently, up to six individuals per fragment were monitored to determine the pollinator composition and visit frequency. Previous data on *B. sericea* indicate that pollinator visits occur mainly in the morning (Teixeira & Machado 2000); thus, our observations on pollinator activity were made at 0530–1300 h. Flower visits and pollinator behavior were recorded for 20 min per individual. The observation periods were equally distributed (quantity of sections and timetable range) among the six fragments, totaling 160 min per fragment.

REPRODUCTIVE SYSTEM AND FRUIT SET.—The following data were obtained from each fragment using six additional individuals other than those used for phenological, pollinator, and galls observations: three plants for hand-pollinations (three racemes/individual) and three for natural-pollination. Some of the individuals were removed by local persons during the experimental period. The following treatments were applied in different racemes from the same individual: (1) allogamy: buds were isolated with voile bags, and newly opened flowers were hand-pollinated with pollen obtained from flowers of other individuals (a total of 246 flowers [fl] of 41 racemes [rc], of 14 individuals [in]); (2) spontaneous self-pollination: unaltered flowers were kept bagged since bud until fruit ripening (357 fl of 51 rc, of 17 in); (3) hand self-pollination: buds were isolated with bags, and newly opened flowers were pollinated with pollen from their own anthers (174 fl of 29 rc, of 15 in); and (4) agamospermy: mature buds were emasculated and then bagged (306 fl of 51 rc, of 17 in). After 40–50 d, the bags were removed and matured fruits were counted. These data were obtained to discuss plant reproductive output. Hand-crossed fruit set was compared with the natural fruit set to determine whether the plant is pollination limited.

Fruit set under natural conditions was quantified on inflorescences exposed to pollinators for 7–10 d. All buds and flowers from each marked raceme were counted, totaling 39 racemes from 15 individuals. A total of 822 bagged flowers were monitored until the end of the flower lifetime. Only well-developed fruits (*i.e.*, > 6 mm diam) were recorded.

OCCURRENCE OF INSECT GALLS.—The presence of both floral and stem galls was recorded on three individuals/fragment (the same individuals for phenological observations) during November 2005. This collection date overlaps the period (October–December) of the highest frequency of galls on *B. sericea*, according to Flinte *et al*. (2006). Gall occurrence was either quantified by direct counting, or globally estimated when it was too intense (> 100/plant). The number of galls per individual was recorded by counting the galls on 10 racemes or branches; then the mean number of galls per raceme/branch was multiplied by the total of racemes/branches of each sampled individual. Data for the SF2 fragment could not be obtained because it was occupied by new habitations during the study and the vegetation was suppressed before the gall measurements. To maintain this site within the whole analysis (*i.e.*, MANOVA), data of mean insect galls per plant were obtained

for this fragment as the mean number of galls per individual of the other two SFs.

STATISTICAL ANALYSIS.—Data on fruit set, visit frequency per individual (transformed into logarithm), and gall occurrence were associated and analyzed with MANOVA, considering fragment size class as the main factor (Zar 1999). Sampled individuals were nested within each fragment. Multivariate normality and homogeneity of variance–covariance matrixes were considered according to Tabachnick and Fidell (1996) using SPSS 10.0 (1999). The comparison between fruit set under natural and hand-cross conditions was made with a chi-square test. All tests were run using SPSS 10.0 (1999). To explore additional sources of variation before run data analysis, some population parameters for each fragment (*i.e.*, plant population density and reproductive phenology) were considered. Thus, these variables for SFs and LFs were compared through *t*-tests (plant linear density and coverage) or Mann–Whitney tests (plant reproductive phenology).

RESULTS

DENSITY AND COVERAGE OF *B. SERICEA* INDIVIDUALS IN THE FRAGMENTS.—Plant population parameters were comparable between SF and LF size classes. The plant ID and IC indexes did not differ between SFs and LFs (mean ± SE; ID SFs = 0.031 ± 0.004; LFs = 0.059 ± 0.020, $t = -2.51$, $P = 0.066$; IC SFs = 0.081 ± 0.01; LFs = 0.110 ± 0.05, $t = -0.98$, $P = 0.38$). Thus, when comparing reproductive output, we assumed that these population traits were factors of less importance, and they were not considered in order to simplify data analyses. During the study, SF2 was intensely disturbed by the surrounding population. By the end of field data collection, four of the seven sampled individuals had been removed for building.

REPRODUCTIVE PHENOLOGY.—Flowering occurred between September 2004 and May 2005 (peaking in December) and fruiting started in January and finished during May (peaking between mid-March and mid-April; Fig. 1). No significant differences in monthly flowering and fruiting intensity were detected between the fragment classes (Mann–Whitney *U*-tests, $P > 0.05$). Thus, we did not consider these population traits in data analyses as we did in plant density and coverage.

FLORAL VISITORS.—The most frequent pollinators were the solitary bees *Epicharis nigrita* Friese and *Centris caxiensis* Ducke (Apidae: Centridini; Table 2). *Centris* (*Xanthemisia*) aff. *lutea* Friese, *Centris spilopoda* Moure, and *Augochloropsis* sp. (Halictidae: Augochlorini) were rare visitors. Nests of *E. nigrita* and *C. caxiensis* were found immediately below or a few meters away from some *B. sericea* individuals. Visits of this bee species to flowers started at 0545–0600 h and most of them occurred at 0800–1200 h (with a mid-morning peak; Fig. 2). The composition and relative frequency of pollinators in SFs and LFs were similar, except for *C. spilopoda*, which was only observed in LFs (Table 2).

COMPATIBILITY SYSTEM.—Fruit set after manual alogamic crossings and open pollinations did not differ (Fig. 3) in both SFs and LFs ($\chi^2 = 0.001$, $P = 0.97$ for SF; $\chi^2 = 0.82$, $P = 0.36$ for LF). Eleven of the 15 individuals did not set fruits after self-pollination. The production
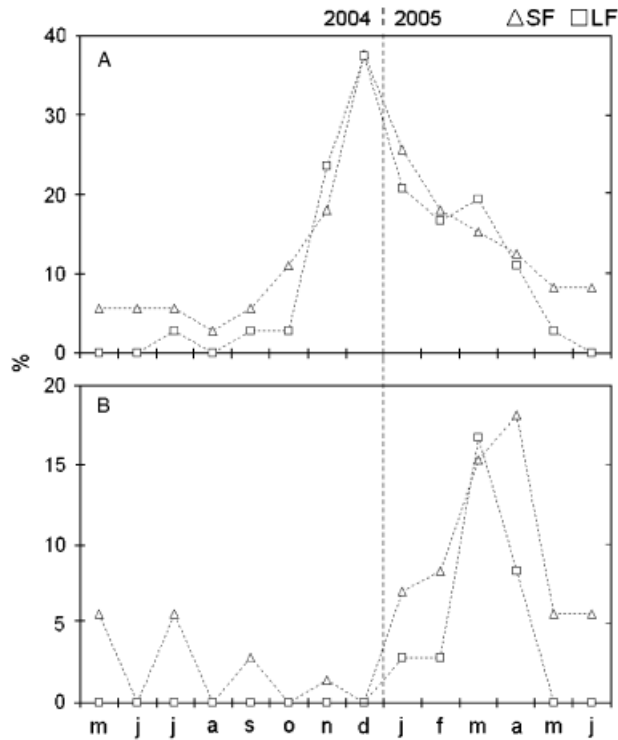
FIGURE 1. Reproductive phenology (flowers [A] and ripe fruits [B]) of *Byrsonima sericea* in small and large fragments (SFs and LFs), between May 2004 and June 2005, in Restinga de Massambaba, southeastern Brazil.

of fruits after self-pollination ranged from 8 to 17 percent in the other four plants. Thus, the populations studied can be characterized as self-incompatible.

THE REPRODUCTION OF *B. SERICEA* IN FRAGMENTED HABITATS.—MANOVA showed differences between fragment classes (Wilks' $\lambda = 0.008$, $F_{2, 18} = 78.0$, $P = 0.01$). Nevertheless, results of *a posteriori* univariate ANOVAs showed that the frequency of pollinator visits was

TABLE 2. *Visiting bee species for Byrsonima sericea in Massambaba, southeastern Brazil. Number of individuals and relative percentage of visits to fragment size class (in parentheses). SFs, small fragments; LFs, large fragments; O, oil; P, pollen.*

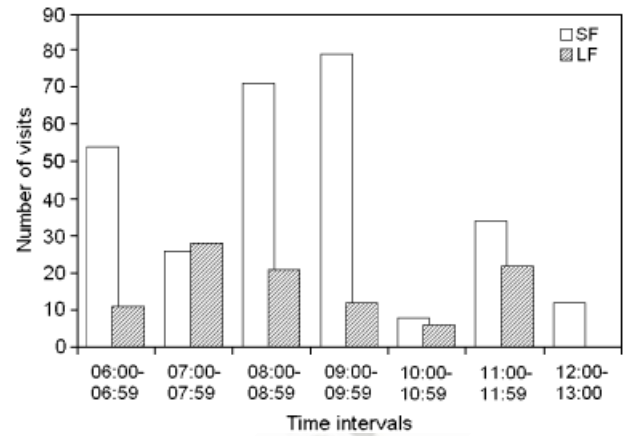| Visitor	Captured individuals	Number of visits		Collected resource
		SFs	LFs	
Apidae: Centridini				
Epicharis nigrita	75	204 (74.7%)	72 (73.5%)	O/P
Centris caxiensis	20	66 (24.2%)	13 (13.3%)	O/P
C. aff. *lutea*	2	2 (0.7%)	1 (1.0%)	O/P
C. spilopoda	2	0	5 (5.1%)	O/P
Halictidae: Augochlorini				
Augochloropsis sp.	2	1 (0.4%)	7 (7.1%)	P
Total	101	273	98	

FIGURE 2. Cumulative frequency of pollinator visits per observation intervals to *Byrsonima sericea* flowers, in small and large fragments (SFs and LFs).

significant and more than twofold higher in SFs (mean ± SD; SFs = 1.16 ± 0.16; LFs = 0.54 ± 0.19; $F = 18.6$, $P = 0.01$). Fruit set under natural conditions (SFs = 34.7 ± 9.3%; LFs = 26.7 ± 15.2%; $F = 0.6$, $P = 0.48$) and gall occurrence (SFs = 136 ± 99; LFs = 531 ± 359; $F = 3.37$, $P = 0.14$) did not show significant differences between SFs and LFs.

DISCUSSION

Contrasting results have been reported for the effects of habitat fragmentation on plant sexual reproduction. Several studies have found negative effects of fragmentation and other anthropogenic disturbances on fruit and/or seed set—supposedly mediated by
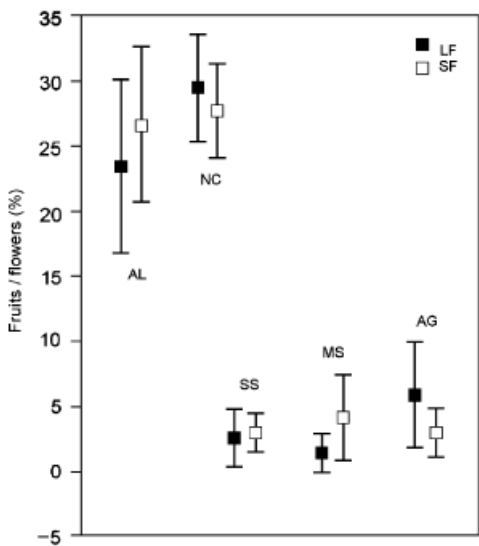

FIGURE 3. Mean and SE of manual crosses treatments of *Byrsonima sericea* in small and large fragments (SFs and LFs). AL, cross-pollination; NC, natural conditions; SS, spontaneous self-pollination; MS, manual self-pollination; AG, agamospermy.

changes in pollinator frequency and foraging behavior—in some tropical and subtropical species (*e.g.*, Aizen & Feinsinger 1994, Nason & Hamrick 1997, Ghazoul *et al.* 1998, Gigord *et al.* 1999, Cunningham 2000, Parra-Tabla *et al.* 2000, Quesada *et al.* 2003, Aguilar & Galetto 2004). Results of as many studies showed no significant differences or higher reproductive output for plants in fragmented and disturbed habitats (Aizen & Feinsinger 1994, Aldrich & Hamrick 1998, Dick 2001, Herrerías-Diego *et al.* 2006, Ramos & Santos 2006, Lopes & Buzato 2007, Aguirre & Dirzo 2008). Several explanations may account for these neutral or positive fragmentation effects on reproductive success, for instance, heavy visitation by feral honeybees as compensation for a decline in visits by native pollinators (Aizen & Feinsinger 1994, Dick 2001); plant size, since larger individuals produce more offspring (Aldrich & Hamrick 1998, Herrerías-Diego *et al.* 2006); and both the high pollen/ovule ratio and the high abundance of the remaining pollinators (Aguirre & Dirzo 2008). In fact, the fragmentation effects are very complex, exhibiting thresholds where they are unexpected, and some of the responses are characterized by time lags that may be unpredictable and influenced by structural differences between the matrix and the patches and by the temporal and spatial scales of observation (Bissonette & Storch 2002). This makes the putative causes of plant population responses to fragmentation very difficult to identify. Nevertheless, the absence of differences in the natural fruit set of *B. sericea* between SFs and LFs may be related to a combination of plant and pollinator characteristics, and to some particularities of the habitat fragmentation process in the *restingas*.

Concerning plant population parameters, some differences in the population density and distribution of *B. sericea* are expected between LFs and SFs in Massambaba *restinga*; however, the results were comparable. This homogeneous pattern for the *B. sericea* populations can be explained by plant and habitat characteristics. For example, low rates of seed germination and seedling establishment have been reported for *restinga* areas compared with other habitats of occurrence of this species (Zamith & Scarano 2004). During regeneration, *B. sericea* usually shows higher densities at initial stages compared with later stages (Assumpção & Nascimento 2000, Sá 2002). The *restinga* vegetation fragments in Massambaba apparently share a similar structure and land-use history, and are not under a regeneration process. Thus, *B. sericea* plant density in SFs seems to be the original, with fewer individuals but of similar conspecific density as that of LFs, and this is a possible explanation for similar results on the fruit set of *B. sericea*.

Concerning pollinator traits, Centridini bees are certainly important to the fruit set of *B. sericea* in Massambaba, mainly because these populations are self-incompatible, a trait that, in theory, makes this species more susceptible to fragmentation (after Aguilar *et al.* 2006). The presence of nests of the main pollinator species of *B. sericea* in SFs shows that these bees live and use such areas. Fragment quality seems to be more important for the maintenance of bee populations than size or isolation (see Gathmann *et al.* 1994, Tscharntke *et al.* 1998). In addition, mobility of bees is less susceptible to fragment arrangement than of other insect groups (Cane 2001). In the case of *B. sericea*, Centridini bees are medium sized and usually show high-flying autonomy and the potential to forage

on isolated plants that may mitigate population disruption after fragmentation (Ghazoul & Shaanker 2004).

In many animal-pollinated plant species, two main factors determine that only a fraction of flowers produces fruits with viable seeds: (1) resource limitation for fruit development and (2) pollen limitation through pollination failure (Bierzychudek 1981). Pollen limitation seems to be a less important factor for *B. sericea* in Massambaba because the fruit set did not differ between manual crosses and natural conditions. Thus, if the lower pollinator activity registered in LFs is sufficient to reach the maximum fruit set of *B. sericea* plants, it could explain why the higher frequency of floral visitors did not imply a higher fruit set under natural conditions in SFs. Similar results were found for the self-incompatible *Psychotria suterella* in fragmented rain forests in southeastern Brazil (Lopes & Buzato 2007). Although many authors have highlighted pollen limitation as one of the main factors determining lower reproductive success in fragmented areas (Wilcock & Neiland 2002, Ashman *et al.* 2004), only a few studies of the fragmentation effects on plant reproduction have estimated pollen limitation by the differences in fruit/seed set in natural conditions and after manual crosses. Results have shown that reproductive output is negatively affected in plants that naturally suffer pollen limitation (Ghazoul *et al.* 1998, Gigord *et al.* 1999, Cunningham 2000, Wolf & Harrison 2001, Ward & Johnson 2005, Meyer *et al.* 2007; but see Aizen & Feinsinger 1994). This supports Aguilar *et al.* (2006), who concluded that pollen limitation (in quality or quantity) might be the main cause or the most proximate cause of reduced reproductive success in plant populations in fragmented habitats.

Aspects not assessed in this study are ~~the possible~~ fragmentation effects on the mating system of *B. sericea*. For example, fragmentation frequently reduces the number of reproductive individuals in a population, which can experience a reduction in outcrossing rates (Dick *et al.* 2003, Fuchs *et al.* 2003), even in situations where pollinator activity and fruit set are not affected (Cascante *et al.* 2002). However, such effects vary in the function of the species; outcrossing rates may be equivalent among populations even when the pollinator frequency of visits is higher in forest than in fragments, as observed for *Ceiba grandiflora* (Bombacaceae) in Mexico (Quesada *et al.* 2004), or the fruit and seed set is higher in continuous forests than in pastures, as for *Enterolobium cyclocarpum* in Costa Rica (Rocha & Aguilar 2001). Moreover, although widespread loss of genetic diversity from drift and inbreeding is expected following habitat fragmentation, empirical support is still scarce and there are some caveats on the assumption that fragments contain isolated tree populations to which the genetic theory of small populations applies (Kramer *et al.* 2008).

Population dynamics of galling-inducing insects seem to be influenced by several environmental factors (Goolsby *et al.* 2000, Boukill *et al.* 2007). The number of galls per plant, for instance, is positively correlated with leaf sclerophylly (Price *et al.* 1998), xeric habitats (Fernandes & Price 1992, Cuevas-Reyes *et al.* 2004a) and availability of young leaves and shoots (Yukawa 2000, Cuevas-Reyes *et al.* 2006, Boukill *et al.* 2007), and negatively correlated with plant age (Cuevas-Reyes *et al.* 2004a, 2006) and phosphorus availability in the soil (Cuevas-Reyes *et al.* 2004b). Moreover,

gall-inducing insects suffer frequent attacks from parasitoids and inquilines, being also predated by birds and mammals (Price & Clancy 1986, Chust *et al.* 2007). Thus, in this system, direct effects of fragmentation on both host plants and predators may lead to changes in the population structure and dynamic of gall insects.

Hence, we have assumed that the microenvironment has the potential to alter the outcomes of interspecific interactions by changing the acquisition of resources, movement, and survival (Boukill *et al.* 2007) and that habitat fragmentation, in particular due to edge effects on humidity, wind speed, temperature, and soil nutrients, may affect the immediate environment surrounding each *B. sericea* individual. Thus, we expected to find some difference in *B. sericea* gall frequency between LFs and SFs, the latter showing either a decrease or an increase in the number of galls. However, gall occurrence was not related to fragment size in *B. sericea* at Massambaba. This is comparable to the results found by Chust *et al.* (2007), who found that although the abundance of three species of oak gall wasps was significantly related to forest fragmentation at particular ranges of spatial scales, the other four gall species were unrelated at all analyzed scales. Moreover, the variation coefficient of gall occurrence in *B. sericea* was high, suggesting that additional sampling effort is required for a more robust evaluation of *restinga* fragmentation effects on gall populations of this plant species.

Byrsonima sericea populations and their main pollinators can apparently be preserved with the current fragmentation and disturbance level in Massambaba *restinga*, because the sexual reproduction of *B. sericea* does not seem to be affected by habitat fragmentation in Massambaba. Nevertheless, to our knowledge, the present study is the first to quantify ecological traits in different-sized *restinga* fragments; thus, it is not yet possible to extrapolate about the effects of fragmentation for other species or plant–animal interactions in this ecosystem.

ACKNOWLEDGMENTS

SUPPORTING INFORMATION

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

FIGURE S1. *Restinga* vegetation in Massambaba, southeastern Brazil. (A) Open shrubby, in area with plain topography. (B) Shrubby-herbaceous vegetation in more irregular topography, with elevated dunes and swampy depressions.

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