Comparison of a common and rare species of *Mimosa* (Mimosaceae) in Central Brazil

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**Abstract**

The aim of this study was to verify differences in the biology of a common widespread species (*Mimosa claussenii* Benth.) and three rare endemics (*Mimosa decorticans* Barneby, *M. heringeri* Barneby, and *M. setosissima* Taub.). We studied three populations of *M. claussenii* and one population of each rare species at four localities in central Brazil. We compared the population structure, phenology, fruit set, seed predation, germination, establishment and root/shoot ratio in these six populations. The endemic species occurred in higher densities and smaller individuals were more abundant. When in sympatry, the rare and common species showed a significant negative correlation of density. *Mimosa claussenii* occurred in drier and rocky environments, whereas *M. decorticans* and *M. setosissima* occurred in moister habitats. Rare species had higher levels of fruit set, more viable seeds per individual, and heavier seeds. *Mimosa setosissima* had the highest level of germination and establishment rate, but did not survive away from its endemism centre. The common species had a higher root/shoot ratio. Overall, the biological aspects studied indicated an advantage in reproductive biology for the rare in relation to the common species. The small geographical range of the rare species may be related to edaphic isolation and climatic changes in the Quaternary.

**Key words:** cerrado, conservation, demography, endemism, fruit set, germination, rarity, reproductive biology, root/shoot ratio, seed predation.

**INTRODUCTION**

Rarity is a concept that can be studied in a number of ways, depending on how it is defined (Gaston 1997). Despite some confusion over definitions, the usual methods of study are based on two variables: abundance and geographical distribution (Fiedler & Ahouse 1992; Gaston 1997).

Endemism is a relative concept, referring to the geographical range of organisms. Species that are endemic to small areas are often considered rare, and this form of rarity is usually termed local endemism or, more recently, range-restricted rarity (Cowling 2001). Endemism in plants may be associated with environmental factors such as altitude, climate or soil, as reported in the Cape region of South Africa and southwest Australia (Cowling et al. 1994; McDonald & Cowling 1995), and in the Mediterranean region of southern Europe (Ojeda et al. 1995).

The fact that many species have a very restricted geographical distribution has led to the formulation of several hypotheses to explain endemism (Stebbins 1980; Rabinowitz 1981; Fiedler 1986; Fiedler & Ahouse 1992; Kunin & Gaston 1997). Aside from historical and evolutionary events, numerous biological parameters may be related to the origin, maintenance and adaptation of this kind of rarity. Recently, some theoretical predictions have been tested in empirical studies that compare traits of rare and common species. These rare–common comparisons are often based on studies of congeneric species in order to reduce phylogenetic effects (Kunin & Gaston 1997; Bevill & Louda 1999). Some generalizations have been raised with respect to reproductive characteristics that distinguish rare from common species, because endemic species usually tend to be self-compatible, have inferior dispersal abilities and lower investment in reproduction (Cowling 2001).

The cerrado biome is a tropical savanna that covers approximately 2 million km² in central Brazil and is characterized by strong seasonality and natural fires (Ratter et al. 1997), with a dry season between May and October and mean annual precipitation of 1500 mm (Ribeiro & Walter 1998). Recently, the cerrado region was included as one of the world’s hotspots of biological diversity, indicating that it has a large and exclusive biodiversity, especially in its flora, with approximately 44% of its 10 000 species considered to be endemic, although it is suffering a great loss of natural habitats (Myers et al. 2000). The same pattern repeats on a local scale, with several studies...
indicating a high degree of endemism at higher elevation sites with acidic, nutrient-poor soils, such as the Chapada dos Veadeiros, in the state of Goiás (Munhoz & Proença 1998; Simon & Proença 2000), the Serra de Espinhaço complex in the state of Minas Gerais, with studies from the Serra do Cipó (Giulietti et al. 1987; Giulietti & Pirani 1988) and from the region of São João del Rei (Alves & Kolbek 1994), and the Chapada Diamantina in the state of Bahia (Harley 1995). For the flora of the Cerrado region, the studies of Mendonça and Lins (2000), and Simon and Proença (2000) are two of the few concerned with the conservation and status of endangered plant species. Simon and Proença (2000) studied the geographical distribution of species of *Mimosa* in the cerrado, showing a high degree of endemism in their patterns of distribution. Their centres of endemism were mainly concentrated in high altitude locations (>1000 m), where the vegetation is called a rocky field (*campo rupestre* in Portuguese, see Eiten 1978).

The objective of the present study was to compare characteristics of *Mimosa claussenii* Benth., a species with a wide geographical distribution, with those of three highland endemic species, *M. decorticans* Barneby, *M. heringeri* Barneby, and *M. setosissima* Taub. Our hypothesis was that the broader geographical range of *M. claussenii* is related to a higher reproductive output than in the rare species, and to its ability to colonize different habitats.

**METHODS**

**Species and study sites**

In 1999 and 2000 we studied populations of *Mimosa claussenii*, *M. decorticans*, *M. heringeri* and *M. setosissima* at four sites in central Brazil (Fig. 1). These species belong to the series *Pachycarpae* (Barneby 1991), an infrageneric group with 40 species restricted to the cerrado biome, and characterized by a high level of endemism, being found mainly in the Chapada dos Veadeiros (Simon & Proença 2000). Closely related species were used to minimize the effects of phylogeny. The species studied are dioecious shrubs or small trees, 1–5 m in height, that produce capitulate inflorescences. Fertilized inflorescences produce one or more fruits that open and remain on the plant after maturing. *Mimosa claussenii* is widespread in central Brazil, occurring in several environments and soil types, ranging from open grasslands to woody savanna (cerrado sensu stricto), at altitudes ranging from 300 to over 1400 m a.s.l. (Simon & Proença 2000). *Mimosa decorticans* and *M. setosissima* occur mainly in humid and open habitats, on lithosols at altitudes over 1000 m a.s.l. (*campo rupestre*). The former is restricted to the Cristalina region (Goiás State) whereas *M. setosissima* is endemic to the Serra dos Pirineus in Pirenópolis (Goiás State). *Mimosa heringeri* occurs in moist habitats with open vegetation on latosols near the southern boundary of the Distrito Federal. These three endemic species belong to a vicariant complex that occurs at higher elevations in central Brazil and probably originated from a direct common ancestor (Barneby 1991). We studied three populations of *M. claussenii* and one population of each of the endemic species (Table 1). Voucher specimens

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**Table 1.** Location and description of study sites of the *Mimosa* species studied in central Brazil:

<table>
<thead>
<tr>
<th>Study site</th>
<th>Location</th>
<th>Area (ha)</th>
<th>Altitude (m a.s.l.)</th>
<th>Studied species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parque Nacional de Brasilia (PNB)</td>
<td>15°43' S, 47°57' W</td>
<td>30 000</td>
<td>1120</td>
<td><em>M. claussenii</em></td>
</tr>
<tr>
<td>RPPN* Linda Serra dos Topáios</td>
<td>16°44' S, 47°42' W</td>
<td>500</td>
<td>1180</td>
<td><em>M. claussenii</em> and <em>M. decorticans</em></td>
</tr>
<tr>
<td>(Cristalina)</td>
<td></td>
<td></td>
<td></td>
<td><em>M. heringeri</em></td>
</tr>
<tr>
<td>Parque Ecológico do Gama (Gama)</td>
<td>16°02' S, 48°03' W</td>
<td>136</td>
<td>1090</td>
<td><em>M. claussenii</em></td>
</tr>
<tr>
<td>Serra dos Pirineus (Pirenópolis)</td>
<td>15°50' S, 48°54' W</td>
<td>50 000</td>
<td>1200</td>
<td><em>M. setosissima</em></td>
</tr>
</tbody>
</table>

*Private permanent reserve.*
were collected and deposited in the herbarium of the University of Brasilia (UB).

Density and population structure

To obtain data on density and population structure we established three 50 m × 50 m plots in areas representative of the average density of the Mimosa species present at the site. These plots were then subdivided into 10 m × 10 m quadrats and 11 of the 25 quadrats in each plot were randomly selected for sampling. In each quadrat we counted all individuals of each species of Mimosa and measured their height (m) and circumference at 10 cm height (cm). When the height was less than 20 cm, the circumference was measured at the base of the stem. The presence of current or past reproductive structures (peduncle and replum) was also recorded for each individual.

Reproductive phenology and fruit production

For four of the populations, M. claussenii at Parque Nacional de Brasília (PNB) and Cristalina, M. decoricans and M. heringeri, we marked one reproductive branch on 28 individuals in each population and recorded their reproductive phenology monthly between March and November of 2000. The phenological categories adopted were bud, opened flower, old flower, immature fruit and mature fruit. On each marked branch we recorded the total number of buds produced and the final number of developed fruits. To verify differences among phenological patterns based on the period of fruit production, we used the method described by Estabrook et al. (1982), and adopted $P < 0.01$ as the significance level.

In all six studied populations, we counted the total number of fruits (inflorescences with fruits) per individual and the number of fruits per inflorescence on individuals within and close to the 50 m × 50 m plots. For comparisons among populations we used individuals with stem circumference between 10 and 20 cm. This circumference range was chosen to reduce the effect of plant size.

Seed set, predation and seed mass

In each population, we manually collected closed mature fruits for dissection in the laboratory to verify seed set and seed predation. After opening the fruits, seeds were removed and classified as: (i) apparently intact (fully developed and without evidence of predation); (ii) predated (where any seed tissue was eaten or had fungus present); and (iii) aborted (non-fertilized ovules or undeveloped seeds). One hundred intact seeds from mature fruits from at least 20 individuals in each population were dried (40°C for 48 h) and individually weighed on an Ohaus Analytical Plus balance (precision of 0.0001 g).

Germination and establishment experiment

Germination and establishment experiments were performed to verify differences in the germination potential among species and test if there was any limitation in the capacity of seeds of the endemic species to germinate and establish away from their centre of endemism. Mimosa claussenii (PNB), M. decoricans and M. setosissima seeds were collected in 1999 from at least 15 individuals of each species, and were sown on the soil surface in natural conditions (following Oliveira & Silva 1993). Seeds of the rare species were sown in their centres of endemism and at PNB, whereas M. claussenii seeds were sown at PNB and Cristalina. In each case, 200 seeds were sown per site, divided amongst four 5-m² plots with 50 seeds each. The experiment was started at the beginning of the rainy season (October 1999). This season was selected because it is the most favourable period for germination in the cerrado (Oliveira 1998). We surveyed the plots monthly during 1 year, recording the number of seedlings (identified by cotyledon emergence). All emerged seedlings were tagged to ensure identification and avoid possible replication.

Root/shoot ratio

In each population, we collected 14 non-reproductive individuals of different sizes. In the laboratory, these individuals were separated into above- and below-ground components, dried at 80°C for 48 h and weighed separately to obtain the root/shoot ratio.

Statistical analysis

We compared the population structure with a Kolmogorov–Smirnov test, based on circumference. For the sites where the species occurred in sympatry, we performed a Spearman correlation ($r_s$) using the density of each species in the sampled quadrats. To compare the population and reproductive parameters, we used a one-way analysis of variance (ANOVA) with an a posteriori comparison (Tukey test, $\alpha = 0.05$). Data were tested for normality with the Kolmogorov–Smirnov test and when indicated, we used a Kruskal–Wallis test ($H$) with a non-parametric multiple comparison Dunn test (Zar 1999). Statistical analyses were performed using SigmaStat, version 2.0 (SPSS 1997).
RESULTS

Density and population structure

Population densities differed among populations ($F_{5,193} = 5.21, P < 0.001$), with the rare species having a higher number of individuals per 100 m$^2$ (Table 2). The population structure of M. claussenii was similar in the three sites sampled (Fig. 2), and the distribution in circumference classes was not statistically different among populations. Rare species had a population structure different from M. claussenii, with a greater number of seedlings (Fig. 2). Rare species also differed from each other: M. decorticans and M. heringeri ($D = 0.39, P < 0.0001$), M. setosissima and M. heringeri ($D = 0.15, P = 0.0013$), and M. decorticans and M. setosissima ($D = 0.28, P < 0.0001$). Because of differences in the size of the circumference classes, it was not possible to compare rare and common species. In sites where species occurred in sympatry, we found a significant negative correlation for co-occurrence between the number of individuals of rare and common species in each quadrant: $r_s = -0.38$ for M. claussenii and M. decorticans at Cristalina ($P = 0.028, n = 33$), and $r_s = -0.52$ for M. claussenii and M. setosissima at Pirenópolis ($P = 0.002, n = 33$). Mimosa claussenii occurred mainly in habitats with more closed vegetation cover, with well-drained rocky soils, whereas M. decorticans and M. setosissima occurred in open vegetation habitats, with moister and sandy soils. In these habitats, the rare species form dense stands and are the most abundant woody plants. Mean stem circumference of the reproductive individuals in these plots did not differ among populations ($F_{5,486} = 1.57, P = 0.167$), but they differed in height ($F_{5,486} = 119.15, P < 0.001$), being significantly higher for M. heringeri. Populations of M. claussenii differed statistically in height from each other.

![Figure 2](https://example.com/figure2.png)

**Fig. 2.** Population structure of six populations of four *Mimosa* species in central Brazil. All data are based on a total area of 0.33 ha. (a) M. claussenii at Cristalina; (b) M. decorticans at Cristalina; (c) M. claussenii at Parque Nacional de Brasilia; (d) M. heringeri at Parque Ecológico do Gama; (e) M. claussenii at Pirenópolis; (f) M. setosissima at Pirenópolis. ( ), Non-reproductive individuals; ( ), reproductive individuals.

### Table 2. Population density (mean ± SE) of four *Mimosa* species in central Brazil sampled in 33 quadrats of 10 m × 10 m

<table>
<thead>
<tr>
<th>Species</th>
<th>Site</th>
<th>Density (individuals per 100 m$^2$)</th>
<th>n (total)</th>
<th>n (reproductive)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M. claussenii</td>
<td>Cristalina</td>
<td>2.0 ± 3.4$^b$</td>
<td>65</td>
<td>18</td>
</tr>
<tr>
<td>M. claussenii</td>
<td>PNB</td>
<td>1.5 ± 3.5$^b$</td>
<td>51</td>
<td>12</td>
</tr>
<tr>
<td>M. claussenii</td>
<td>Pirenópolis</td>
<td>1.5 ± 3.1$^b$</td>
<td>52</td>
<td>8</td>
</tr>
<tr>
<td>M. decorticans</td>
<td>Cristalina</td>
<td>12.9 ± 26.7$^b$</td>
<td>427</td>
<td>17</td>
</tr>
<tr>
<td>M. heringeri</td>
<td>Gama</td>
<td>15.1 ± 24.2$^b$</td>
<td>429</td>
<td>31</td>
</tr>
<tr>
<td>M. setosissima</td>
<td>Pirenópolis</td>
<td>8.8 ± 12.2$^{ab}$</td>
<td>243</td>
<td>43</td>
</tr>
</tbody>
</table>

Values with the same letter are not significantly different ($P < 0.05$, Tukey test).
Reproductive phenology and fruit set

In all populations the majority of buds (inflorescences) did not produce fruits, ranging from 62% for *M. claussenii* (Cristalina) to 80% for *M. heringeri* (Table 3). The mean percentage of buds producing fruits differed statistically among the four populations ($H = 10.77, P = 0.013$), with *M. claussenii* (Cristalina)

Table 3. Reproductive efficiency in four populations of *Mimosa* species in central Brazil (mean ±SE)

<table>
<thead>
<tr>
<th></th>
<th><em>M. claussenii</em> (Cristalina)</th>
<th><em>M. claussenii</em> (PNB)</th>
<th><em>M. decorticans</em> (Cristalina)</th>
<th><em>M. heringeri</em> (Gama)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of buds produced</td>
<td>300</td>
<td>358</td>
<td>403</td>
<td>509</td>
</tr>
<tr>
<td>Total number of infructescences</td>
<td>107</td>
<td>67</td>
<td>90</td>
<td>102</td>
</tr>
<tr>
<td>Mean percentage of infructescences/buds</td>
<td>38.2 ± 4.6a</td>
<td>21.0 ± 3.7b</td>
<td>23.5 ± 3.2ab</td>
<td>20.7 ± 2.9b</td>
</tr>
</tbody>
</table>

Values with the same letter are not significantly different ($P < 0.05$, Dunn test); $n = 28$ plants (one reproductive branch per individual) in all cases.

Table 4. Reproductive parameters in six populations of four *Mimosa* species in central Brazil (mean ±SE)

<table>
<thead>
<tr>
<th></th>
<th><em>M. claussenii</em> (Cristalina)</th>
<th><em>M. claussenii</em> (PNB)</th>
<th><em>M. claussenii</em> (Pirenópolis)</th>
<th><em>M. decorticans</em> (Cristalina)</th>
<th><em>M. heringeri</em> (Gama)</th>
<th><em>M. setosissima</em> (Pirenópolis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fruits per inflorescence</td>
<td>2.6 ± 0.1abc</td>
<td>2.0 ± 0.1abcd</td>
<td>2.9 ± 0.2a</td>
<td>2.0 ± 0.1bcd</td>
<td>1.5 ± 0.1d</td>
<td>2.8 ± 0.2ab</td>
</tr>
<tr>
<td>n (inflorescences)</td>
<td>72</td>
<td>98</td>
<td>99</td>
<td>101</td>
<td>101</td>
<td>101</td>
</tr>
<tr>
<td>Fruits/individual*</td>
<td>13.1 ± 1.7b</td>
<td>16.3 ± 2.4b</td>
<td>5.2 ± 0.8a</td>
<td>34.3 ± 4.4a</td>
<td>38.9 ± 5.6a</td>
<td>30.3 ± 3.5a</td>
</tr>
<tr>
<td>n (individuals)</td>
<td>67</td>
<td>58</td>
<td>28</td>
<td>37</td>
<td>42</td>
<td>86</td>
</tr>
<tr>
<td>Seeds per fruit</td>
<td>9.6 ± 0.3a</td>
<td>9.8 ± 0.3a</td>
<td>9.8 ± 0.8a</td>
<td>6.6 ± 0.2b</td>
<td>6.3 ± 0.2bc</td>
<td>5.2 ± 0.1c</td>
</tr>
<tr>
<td>n (fruits)</td>
<td>101</td>
<td>113</td>
<td>29</td>
<td>100</td>
<td>112</td>
<td>100</td>
</tr>
<tr>
<td>Seed mass (mg)</td>
<td>26.4 ± 0.5d</td>
<td>23.3 ± 0.5c</td>
<td>29.0 ± 0.6d</td>
<td>38.8 ± 0.7a</td>
<td>34.7 ± 0.6b</td>
<td>31.7 ± 0.5d</td>
</tr>
<tr>
<td>n (seeds)</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

*Fruits per individual for plants with 10–20 cm of stem circumference at 10 cm height. Values with the same letter are not significantly different ($P < 0.05$, Tukey test for seed mass, and Dunn test for others).

Fig. 3. Reproductive phenology of four populations of *Mimosa* species in central Brazil. (a) *M. claussenii* at Cristalina; (b) *M. claussenii* at Parque Nacional de Brasília; (c) *M. decorticans* at Cristalina; (d) *M. heringeri* at Parque Ecológico do Gama.
being different from *M. claussenii* (PNB) and *M. heringeri*, but not from *M. decorticans* (Table 3).

The number of fruits produced per inflorescence also differed statistically among species ($H = 45.58, P < 0.001$); however, the distinctions between rare and common species was not clear (Table 4). The number of fruits per individual with stem circumference between 10 and 20 cm differed statistically among populations ($H = 80.52, P < 0.001$). Rare species had a greater number of fruits per individual, differing statistically from *M. claussenii* (Table 4). Populations showed generally similar reproductive phenology. However, based on fruit production phenology, we found statistical differences between all populations studied ($P < 0.01$), except between *M. heringeri* and *M. decorticans*. *Mimosa claussenii* (Cristalina) differed from *M. claussenii* at PNB (Kolmogorov–Smirnov test, observed difference ($D$) = 0.282, calculated threshold ($T$) = 0.253); and from *M. decorticans* and *M. heringeri* ($D = 0.913$, $T = 0.235$; $D = 0.766$, $T = 0.225$, respectively). *Mimosa claussenii* (PNB) also differed from *M. decorticans* and *M. heringeri* ($D = 0.814$, $T = 0.263$; $D = 0.853$, $T = 0.225$, respectively). For the *M. claussenii* populations, the difference was only slightly higher than the threshold. Populations of *M. claussenii* started to reproduce approximately 1 month earlier than the other species, and had several individuals with immature fruits in March (Figs 3a,b). However, fruit development seems to be slower in *M. claussenii* than in *M. decorticans*, and especially slower than in *M. heringeri* (Figs 3c,d).

Seed set and seed predation

Seeds apparently do not have any specific adaptations for dispersal and stay in the fruit until they fall from the plant. The mean number of seeds per fruit varied among populations ($H = 206.66, P < 0.0001$), with more seeds per fruit in *M. claussenii* populations (Table 4). Mean seed mass differed among populations ($F_{5,595} = 100.01, P < 0.0001$), but despite significative differences among populations (Table 4), *M. claussenii* had lower seed mass values than the rare species. We found significative differences in the mean percentage of intact, predated and aborted seeds among populations ($H = 270.23$; $H = 258.65$; $H = 47.73$, respectively, with $P < 0.001$ in all cases). Two *M. claussenii* populations (PNB and Cristalina) showed the lowest...
percentage of intact seeds and differed statistically from the other populations (Fig. 4a). The endemic species showed the lowest pre-dispersal seed predation, ranging from 10 to 20% (Fig. 4b). The level of aborted seeds was similar in all populations, ranging from 9 to 32% (Fig. 4c). The principal pre-dispersal seed predators in all cases were Curculionidae (Coleoptera) larvae, but Bruchidae (Coleoptera) and other organisms were also found. For *M. claussenii* we found evidence of bird predation, probably by parrots, on at least one fruit in 57.1% of the marked individuals at Cristalina, and 29.6% at PNB. In the other populations we saw no evidence of bird predation.

**Germination and establishment experiment**

In general, germination was low, ranging from 0.5 to 25.0% of sown seeds. The highest germination was observed for *M. setosissima* at PNB, away from its endemism centre, where 50 seedlings (25.0%) germinated in the first month (Fig. 5a). However, none of these seedlings established. In its endemism centre, in contrast, *M. setosissima* showed the highest establishment rate with 19 seedlings (9.5%) after 1 year (Fig. 5b), but unfortunately we do not have data for the first eight months after sowing. *Mimosa decorticans* had both the lowest germination and establishment rate, with only one seedling established at PNB and five at Cristalina. *Mimosa claussenii* had its highest germination rate at Cristalina with 21 seedlings (10.5%), and the establishment was similar to that recorded at PNB. Although an accidental fire passed through the germination experiment at PNB in July 1999, two *M. claussenii* and one *M. decorticans* seedlings survived and persisted 3 months after fire.

**Root/shoot ratio**

In general, *Mimosa claussenii* had higher root/shoot ratios than the rare species (Fig. 6), and the population at Cristalina differed statistically from the others (*H = 43.19, *P* < 0.001). Sampled individuals ranged from 0.4 to 11.6 cm in circumference and 6–120 cm in height. Mean stem circumference of the collected individuals did not differ among populations (*F*2,79 = 1.33, *P* = 0.26), so differences in the root/shoot ratio were not due to unequal individual sizes. In more than 90 excavations, we found no evidence of vegetative reproduction in the studied species. However, some individuals had roots of up to 5 m, which grew parallel to the soil surface.

**DISCUSSION**

The endemic species studied occurred in higher densities than *M. claussenii*, and can be classified as having a narrow range, and being habitat-specific and locally abundant, following Rabinowitz (1981). The population structure of rare species suggests that mortality in early life stages is greater than in *M. claussenii*, and population maintenance depends on a high density of young individuals. In fact, intact seed production is greater in these rare species, which may be related to the high seedling density. Frequency of *M. claussenii* by circumference class did not vary among populations, which may indicate a pattern of population structure independent of site. Among the rare species, the difference recorded may be due to local environmental variation or disturbance frequency. A tendency towards a higher density of young plants was evident in all rare species populations. Differences in average height among endemic species may be related to soil type. Coincidentally, *M. heringeri*, the tallest species, occurs on a richer soil than do *M. decorticans* and *M. setosissima*, which grow in sandy and nutrient-poor soils. This tendency was also found in the *M. claussenii* (Pirenópolis) population, where the individuals were shorter than in the PNB and Cristalina populations.

Despite the similarity in reproductive phenology, some patterns appeared. *Mimosa claussenii* produced buds earlier than the rare species that had a shorter reproductive period with faster fruit ripening. The higher percentage of predation observed in *M. claussenii* might be related to slower fruit development due to the longer seed retention on the plant. Overall, our results agree with the expected, with closely related populations showing more similar phenologies. Madeira and Fernandes (1999) found greater differences studying *Chamacrista* (Caesalpiniaceae), where rare species produced seeds earlier, at the end of the dry season, whereas common
species started to produce in the middle of the wet season.

Seed dispersal in the genus *Mimosa* is poorly studied. Previous studies have found dispersal by water (Lonsdale 1993), by wind and water (Camargo-Ricalde & Grether 1998), and epizoochory (van der Pijl 1982; Barneby 1991; Mori & Brown 1998). All the currently studied species are dispersed by passive autochory, the same mode of dispersal cited by Gottsberger and Silberbauer-Gottsberger (1983) for six herbaceous species of *Mimosa* in the cerrado.

Seed mass may be related to several parameters such as dispersal mode, growth form, seedling development and environmental conditions (Oakwood *et al.* 1993; Edwards & Westoby 1996; Westoby *et al.* 1996, Lord *et al.* 1997; Wright *et al.* 2000). Reduction in dispersal potential has been associated with endemism in plants growing on oceanic islands. This change in dispersal potential is a consequence of isolation that favours this trend (Cody & Overton 1996; Thompson *et al.* 1999). Despite the fact that endemic species had heavier seeds, we do not believe that this implies less efficient dispersal than for *M. claussenii*. Moreover, seed mass is not only related to dispersal, but also to resource allocation for seedling establishment. Mustart and Cowling (1992) studied species pairs of Proteaceae, and found that seed mass was greater for species growing on sandy, nutrient-poor soils. In the species of *Mimosa* studied we also found heavier seeds in the rare species, which occur on poor and sandy soils. This may be an adaptation to the hostile conditions for seedling development.

Bird predation of *M. claussenii* fruits presents a possible case of seed dispersal, because the embryos are not destroyed when eaten, and remain viable after passage through the digestive tract (M. F. Simon and J. D. Hay, pers. obs.). At PNB, predation of *M. claussenii* fruits by the parrot *Amazona xanthops* was observed (M. F. Amaral, pers. comm.). This parrot is widely distributed in the cerrado (Sick 1997), and this relationship merits additional study to verify: (i) if bird dispersal occurs; (ii) if it is restricted to *M. claussenii*; and (iii) if this greater dispersal potential is related to a wider geographical distribution, because plants dispersed by birds have a larger range than species dispersed by other agents (Oakwood *et al.* 1993; Westoby *et al.* 1996).

Fig. 7. Diagram comparing reproductive output in six populations of four *Mimosa* species in central Brazil. (a) *M. claussenii* (Cristalina); (b) *M. decorticans*; (c) *M. claussenii* (PNB); (d) *M. heringeri*; (e) *M. claussenii* (Pirenópolis); (f) *M. setosissima*. Values shown were based on the data from Tables 2–4, and Fig. 4. For *M. claussenii* (Pirenópolis), we calculated the flower loss ratio as the mean between the two other populations of *M. claussenii*, and for *M. setosissima*, we used the mean between *M. decorticans* and *M. heringeri*.  

Seed predation in legumes has been closely associated with beetle larvae (Johnson 1981). At PNB, predation of *M. claussenii* (J. D. Hay, pers. obs.). At PNB, predation of *M. claussenii* by beetle larvae (Johnson 1981). In the cerrado, there are records of seed predation by Curculionidae in *Chamaecrista* (Madeira & Fernandes 1999) and *Syagrus* (J. D. Hay, unpubl. data). The results we obtained contradict the hypothesis that rare species have a higher percentage of predated or aborted seeds. Madeira and Fernandes (1999) did not find differences in seed predation among rare and common species of *Chamaecrista*. Fiedler (1987) studied rare and common species of *Calochortus* (Liliaceae), but also found no differences in percentage of seed predation and herbivory.

Overall, we did not find advantages in reproductive potential between *M. claussenii* and the rare species. *Mimosa claussenii* was superior to rare species only in the number of fructified buds (at Cristalina), and in the mean number of seeds per fruit. However, if we consider both the greater individual fruit production and the higher percentage of intact seeds, the rare species have a larger reproductive potential than *M. claussenii*. The absence of vegetative reproduction reinforces the importance of seed production for the maintenance of these populations. Estimating the total number of intact seeds per individual or per hectare, populations of *M. claussenii* were surpassed by three to 17 times by the rare species (Fig. 7). This disagrees with the hypothesis that rarity is associated with an inferior reproductive potential, as proposed by Fiedler and Ahouse (1992). Fiedler (1987) studied rarity in the genus *Calochortus* and found no differences in the number of seeds per capsule in rare and common species, despite the fact that the common species appeared to have a greater potential to produce flowers, fruits and seeds than did the rare species. Byers and Meagher (1997) found a higher level of sexual reproduction in a common species of *Eupatorium* (Asteraceae) than in a rare one. In other studies of rarity, sexual reproduction (fruit and seed production) was not a critical parameter that could explain the endemism (Giblin & Hamilton 1999; Kaye 1999), which is contrary to the hypothesis that rare species are associated with reproductive constraints, as found by DeMauro (1993).

For these rare species, occurrence in high density and high reproductive output may be related to the maintenance of small geographical range. In a spatially limited habitat, rare species would require high reproductive growth rates to persist. However, common species would not have to invest in high reproductive output because of their broader habitat tolerance and wider geographical distribution. This may be an example of an 'entry rule' (Kunin 1997) in the sense that plants adapted to geographically restricted habitats, and hence occurring in small populations, require high reproductive rates to avoid extinction.
Results of the germination and establishment trials suggest that *M. setosissima* is an edaphic specialist, because it germinated out of its habitat but its seedlings did not survive. The low establishment rate at PNB, where soil type is a latosol, may be associated with the endemism of *M. setosissima*, which is restricted to lithosols at Pirenópolis. Nevertheless, this trend was not so clear for *M. decorticans*, which showed low germination and establishment at both sites. *Mimosa claussenii* did not exhibit a notable advantage over *M. decorticans*, and germinated relatively well in both soil types. This may indicate that it is a habitat generalist and better adapted than the endemic species. Other studies did not find significant differences in the germination and establishment of rare and common species (Westoby *et al*. 1996; Baskin *et al*. 1997; Walck *et al*. 1998).

Root/shoot ratio is an important parameter for cerrado plants, because the seedlings of woody species depend on a well-developed root system that allows survival during the dry season and eventual fires (Oliveira 1998). *Mimosa claussenii* had a greater root/shoot ratio, which may be an advantage for seedling survival in the hostile conditions of the cerrado. During an accidental fire at PNB, the aerial biomass of the seedlings was completely destroyed; however, several seedlings resprouted and produced new leaves 1 month after the fire.

In general, we did not find large differences in the biological parameters studied that could be associated with the rarity of *M. decorticans*, *M. heringeri* and *M. setosissima* when compared with *M. claussenii*. The rare species’ advantage in reproduction is indisputable as shown by total seed output. The only parameters for which *M. claussenii* was better than rare species were the greater allocation to underground biomass, and moderate germination and establishment in two distinct habitats. Nevertheless, the biological importance of these parameters must be investigated in more detail to confirm if they are indeed relevant in explaining the different geographical ranges of the studied species.

Other studies concerning rare and common congeners have not found differences that could explain the endemism, and argue that extrinsic factors, such as historical events, could influence rarity (Snyder *et al*. 1994; Baskin *et al*. 1997). Historical events also may explain the rarity of *Mimosa* species in central Brazil, as suggested by Simon and Proença (2000), because highland endemism can be related to climatic fluctuations and glacial periods that occurred in the Quaternary (van der Hammen 1982; Ledru *et al*. 1996; Salgado-Labouriau *et al*. 1998). The three rare species studied herein are closely related and probably originated from a common ancestor that was widespread in central Brazil (Barneby 1991; Simon & Proença 2000). Afterwards, perhaps because of climatic changes, this ancestral species may have had its geographical range reduced, which resulted in isolated populations, restricted to highlands where the climate was cooler and moister. As a consequence of this isolation, these populations began to differentiate to become the different species found at present. Today, these species form a vicariant complex, which occurs mainly in highlands with poor and sandy soils, as do *M. decorticans*, *M. setosissima* and *M. densa* (at Chapada dos Veadeiros, Goiás State). In these cases, endemism is strongly related to a combination of particular conditions and isolation by the surrounding vegetation, which prevents dispersal and colonization. Nevertheless, *M. heringeri* is an exception because it does not occur in these specific habitats, but in a typical cerrado environment on a latosol. This species may be a relict population of the common widespread ancestor that at present survives in marginal habitat and is unable to expand its geographical range.

**Conservation**

Although occurring in high densities, the rare species studied have a very restricted geographical distribution, which makes them more susceptible to extinction. *Mimosa heringeri* is essentially restricted to the Parque Ecológico do Gama (136 ha) and surrounding areas, and urban expansion is a great threat to this species. Even within the ecological reserve, this species is not protected, because of the absence of adequate infrastructure and site protection. *Mimosa decorticans* also has a small area for its preservation, the private natural reserve Linda Serra dos Topáziós (500 ha), where the present study was done. Clearing for crop production or mining has destroyed the surrounding native vegetation in the Cristalina region. At Pirenópolis, *M. setosissima* is losing suitable habitats by conversion to pasture and by rock extraction. This region has a large State Park, the Serra dos Pirenéus (50 000 ha), but in reality it is not adequately protected.

At present, *M. decorticans* and *M. setosissima* are less threatened because they occur in rocky environments that are inappropriate for agriculture, and should be considered as ‘vulnerable’ according IUCN threatened categories (Davis *et al*. 1986), whereas *M. heringeri* can be classified as ‘threatened’ because of its critical habitat loss. More intensive population studies are needed to provide a better knowledge of conservation status and management of these rare species. Expansion and improvement of the extant protected areas are essential to provide for the conservation not only of these rare *Mimosa* species, but also for several other species restricted to these endemism centres (Proença *et al*. 2000; Simon & Proença 2000).

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