PHENOLOGY OF HERBACEOUS SPECIES IN "CERRADO": COMPARISONS BETWEEN INTACT, BURNT, AND REFORESTED AREAS

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ABSTRACT

Vegetative and reproductive phenology was described for a sample of herbaceous species at sites covered by intact and disturbed "cerrado" in Southeastern Brazil. Herbaceous species showed three flowering strategies – continual, episodic and seasonal – as well as three fruiting strategies – continual, lengthy and seasonal. The phenological patterns were largely influenced by meteorological variables, but some differences between intact, reforested and burnt sites were recorded. Recent studies pointed out the major importance of the herbaceous component in "cerrado" community studies as well as the lack of substantial data on this stratum that could lead to generalizations. The present study pointed out the existence of some phenological differences of herbs growing in disturbed and undisturbed "cerrado", and the need of carrying out comparative studies to verify if these differences are due to the site conditions or the species composition.

KEY WORDS: vegetative phenology, reproductive phenology, seasonality, Brazil.

INTRODUCTION

It is well known that viable populations of most plants are maintained by means of seed formation, a process that involves both efficient flower pollination and seed dispersing (Proctor *et al*. 1996; Silvertown and Charlesworth, 2001). Therefore, it is important to carry on research on vegetal reproduction episodes to increase general understanding on nature's ecological balance, adaptation modes of plants and survival habits of animals that feed on their fruit and seeds.

The "cerrado" – neotropical savanna – is characterized by vegetal growth on acidy soils lacking in chemical components (Eiten 1972; Ferri 1980). The "cerrado" may comprise areas with varying quantities of trees and shrubs, ranging from a "campo sujo" (mainly grassy "cerrado") to a "cerradão" (thickly forested "cerrado") (Eilten 1979), but it is most commonly structured in two strata: (1) a level with shrubs and sparse twisted trees, and (2) a level with grasses and herbs. Since this description corresponds to the largest area within the biome, it is considered to be the most typical and will be herein referred as "stricto sensu cerrado".

The "cerrado" is widely acknowledged as a preservation hotspot for the world's biodiversity. Nevertheless, nearly one million square kilometres of it have so far been devastated and turned into grazing and agricultural fields, and only 2.2% of its area is currently under protection as forest reserves (Klink and Machado 2005). Most of the "cerrado" is scattered around the country, and these fragments are continuously threatened by urban and rural developments, introduction of exotic species, and anthropic fires (Durigan *et al*. 2007).

Due to the extensive heterogeneity of the "cerrado" biome, there have not been enough studies to allow for sound generalizations about its ecological management. Hence, this study seeks to contribute to the understanding of the vegetative and reproductive phenology of herbaceous species of the stricto sensu "cerrado". Its goal is to characterize the vegetative phenology (budding and fall of leaves) and reproductive phenology (flowering and fruiting) of a sample of herbaceous plants in an area of stricto sensu "cerrado", and verify whether there are differences between an intact "cerrado" area, a former "cerrado" area now reforested with arboreal specimens and a burnt "cerrado" area.

MATERIAL AND METHODS

The study site – part of the Federal University of São Carlos (UFSCar) *campus* – is located in one of the cerrado areas of São Paulo State (Brazil) that has suffered the most damage in the last decades. According to Kronka *et al.* (1998), this region has lost over 115,000 hectares of several cerrado physiognomies, corresponding to 93% of its original coverage. Most of native cerrado vegetation has given way to sugar cane, orange and paper crops.

UFSCar is situated in São Carlos, São Paulo State, Brazil, on the grounds of a former farm (21°58'- 22°00'S and 47°51'- 47°52'W, 870m altitude). In this area there is a 130ha reserve of vegetation classified as stricto sensu cerrado. Besides this intact cerrado reserve, there is a former grassy field that was reforested from 2003 to 2005. The region has a warm temperate climate with dry winters and rainy summers, classified as Cwa according to Köppen's system (1948).

In August 2006 a major fire of anthropic origin devastated part of the stricto sensu cerrado area. Three sub-areas were demarcated in the study site: (a) Area 1, covered with intact stricto sensu cerrado vegetation; (b) Area 2, covered by heterogeneous reforestation; and (c) Area 3, covered with cerrado vegetation that has suffered severe scorching. A sample comprising ten herbaceous species was delimited in each of these sub-areas.

Reproductive and vegetative phenology of populations was verified by means of observation of five individuals of each sampled species from September 2006 to August 2007. The phenological leaf-budding state was defined as the observed existence of individuals bearing at least one new leaf, and the leaf-shedding state as that of individuals bearing at least one senescent leaf. The beginning of the flowering state was defined as the observed occurrence of at least one individual of the species bearing flower buds and the end as when no individuals of a given species would bear flowers in anthesis. The fruiting state was defined as starting when at least one individual would bear unripe fruit and ending when individuals of the same species would bear no ripe fruit.

The specific-level flowering strategies were defined as (Morellato 1991, Newstrom et al. 1994): (1) continual – at least one individual of a given species flowering constantly throughout the year, with up to 2-month intervals without flowers in anthesis; (2) episodic – individuals flowering in different periods throughout the year, separated by months sans flowers in anthesis; (3) seasonal – individuals flowering once at different times during the year, lasting up to four months. On the other hand, the fruiting strategies were defined as (Morellato 1991): (1) continual – species presenting fruiting individuals throughout the entire year, fruitless periods lasting up to two months; (2) lengthy – species displaying fruiting individuals for more than four months in a year; and (3) seasonal: fruiting of a given species lasting up to five months per year.

The reproductive and vegetative phenology of species found in the three sub-areas was correlated with rain and temperature (data provided by Embrapa Pecuária Sudeste, whose climatologic station is located at 21°57'S and 47°50'W, 10km away from the study site). Spearman correlation coefficient (r_s) was used to verify the correlation significance between phenological events and climate variables (Zar 1996).

RESULTS

The observation of flowering and fruiting events for the species sampled in each one of the sub-areas enabled the analysis of their reproductive phenology at the community level. This showed that the number of species in the reproductive and vegetative phenological state varied along the period of data collection. It was possible to find species flowering, fruiting, budding and shedding leaves (Figure 1) throughout data collecting.

Using rain precipitation and average temperature data for the region during the study period (Figure 2), a strong positive correlation was found between the number of species flowering and the rain precipitation rate ($r_s = 0.81$, $p<0.05$) and the average temperature ($r_s = 0.72$, $p<0.05$) in the intact cerrado sub-area. The correlation was equally strong, however not statistically significant ($r_s = 0.79$, $0.05<p<0.1$ for rain precipitation, and $r_s = 0.67$, $0.05<p<0.1$ for average temperature) in the burnt sub-area. Correlation was weak and not statistically significant for both rain precipitation ($r_s = 0.35$, $0.20<p<0.25$) and average temperature ($r_s = 0.33$, $0.20<p<0.25$) in the reforested sub-area.

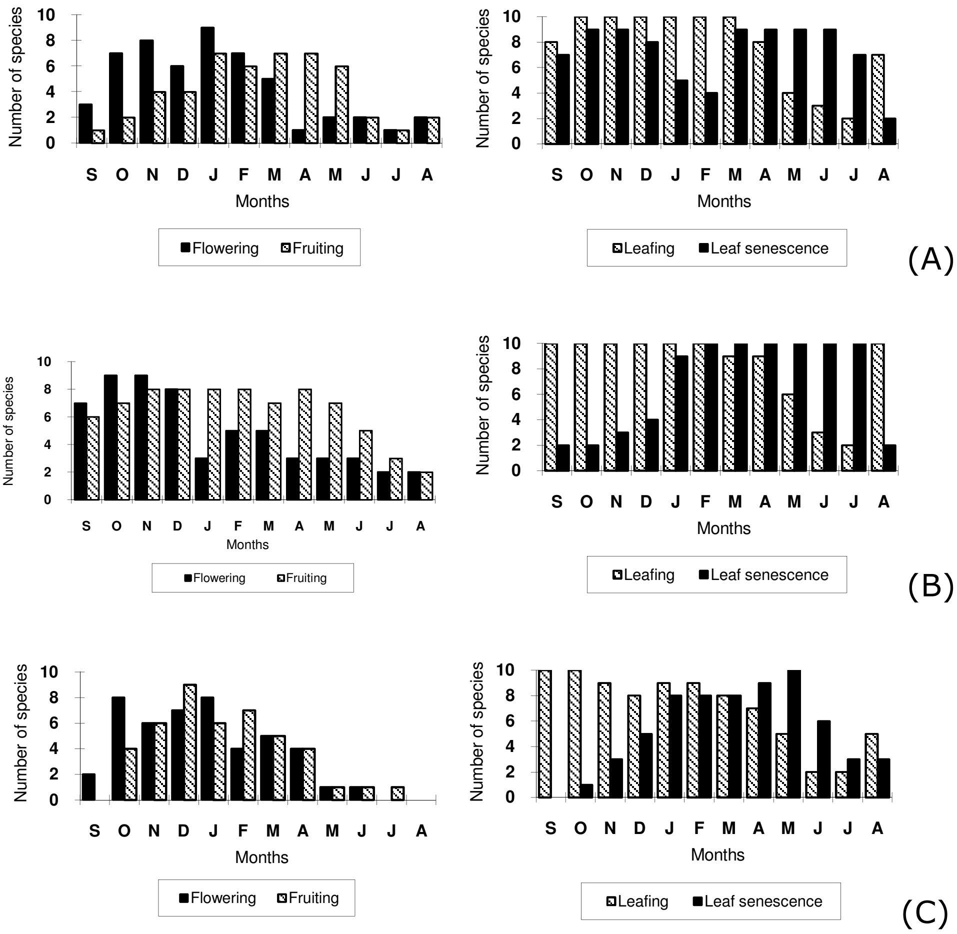

Figure 1 - Phenological events of herbaceous species in intact cerrado (A), reforested cerrado (B), and burnt cerrado (C). J = January, F = February... N = November, and D = December.

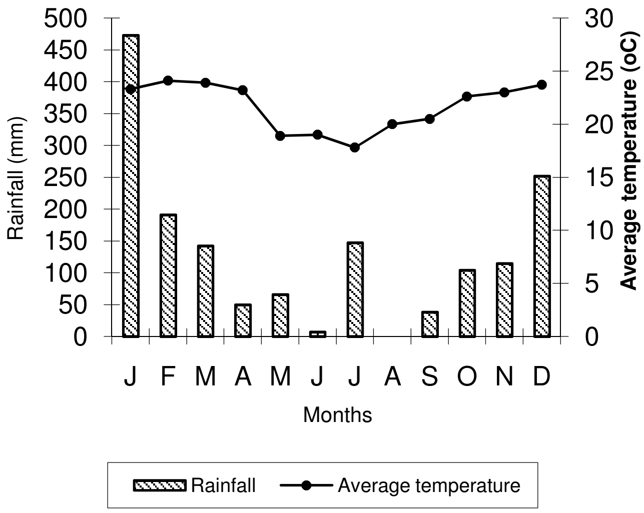

Figure 2 - Rainfall and average temperature for the study area in Southeastern Brazil (21°58’-22°00’S and 47°51’-47°52’W).

Strong correlation between fruiting of species and rain precipitation was only found in the burnt sub-area ($r_s = 0.88$, $p<0.01$). Correlation between fruiting and rain precipitation was weak for the intact cerrado sub-area ($r_s = 0.59$, $0.1<p<0.2$) as well as for the reforested sub-area ($r_s = 0.55$, $0.1<p<0.2$). As regards average temperature, correlations with fruiting were strong for all of the three sub-areas, however only statistically significant for the burnt sub-area ($r_s = 0.68$, $0.05<p<0.1$ for the intact cerrado sub-area; $r_s = 0.68$, $0.05<p<0.1$ for the reforested sub-area; and $r_s = 0.84$, $p<0.01$ for the burnt sub-area).

With respect to the budding of leaves, a strong positive correlation with rain precipitation was found in all of the three sub-areas ($r_s = 0.91$ for the intact *cerrado* sub-area; $r_s = 0.75$ for the reforested sub-area; and $r_s = 0.53$ for the burnt sub-area). The correlation was significant for the intact and reforested sub-areas ($p<0.05$), but not for the burnt sub-area ($0.1<p<0.05$). Leaf-budding also presented a strong positive correlation with average temperature ($r_s = 0.87$ for the intact sub-area; $r_s = 0.67$ for the reforested sub-area; and $r_s = 0.49$ for the burnt sub-area), however only significant for the intact sub-area ($p<0.05$).

Senescence and leaf-shedding presented a weak negative correlation with rain precipitation and average temperature for the intact cerrado sub-area ($r_s = -0.33$ for rain precipitation; $r_s = -0.45$ for average temperature) and reforested sub-area ($r_s = -0.26$ for rain precipitation; $r_s = -0.03$ for average temperature). However, there was a weak positive correlation in the burnt sub-area for rain precipitation ($r_s = 0.15$) and average temperature ($r_s = 0.20$). No correlations were significant at the $\alpha = 0.05$ level.

Phenological events for the populations of each species studied in the three sub-areas are shown in Table 1. In general, the species sampled in the intact cerrado sub-area presented fewer flowering and fruiting individuals and major shedding of leaves in the months of July and August. In the reforested sub-area the species phenology followed a pattern similar to that of the intact sub-area. The species in the burnt cerrado sub-area were observed to bud only after two weeks. The exotic grass species *Brachiaria decumbens* (Poaceae) was the first herbaceous species to spring, followed by *Andropogon leucostachyus* (Poaceae) and *Bulbostylis capillaris* (Cyperaceae). In mid-September several herbaceous species started to bud, and *A. leucostachyus* and *B. capillaris* began to flower. In November, *B. decumbens* also began to flower and had grown tall enough by then to obliterate the growth of most other herbaceous plants.

Table 1. Phenology of cerrado herbaceous species in Southeastern Brazil (21°58′-22°00′S and 47°51′-47°52′W). IC = intact cerrado, RC = reforested cerrado, SC = burnt cerrado; 1 = January, 2 = February... 11 = November, and 12 = December. The hyphen (-) represents continuity between months while the comma (,) means interruption.

Family	**Species**	**Area**	**Flowering**	**Fruiting**	**Leaf-budding**	**Leaf-shedding**
Asteraceae	*Chaptalia integerrima* (Vell.) Burkart	IC	1-6, 9-11	1-6, 10-12	1-6, 9-12	1-10, 12
	Chaptalia integerrima (Vell.) Burkart	SC	1, 10, 12	1-2, 10-12	1-5, 9-10	1, 4-6
	Chaptalia nutans (L.) Pol.	SC	1, 10-12	1, 10, 12	1-4, 9-12	1-5, 12
	Emilia sonchifolia (L.) DC.	RC	1-3, 9-12	1-5, 11-12	1-4, 9-12	1-8, 12
Cyperaceae	*Bulbostylis capillaris* (L.) C.B. Clarke	IC	1-5, 9-12	1-4, 6, 9-12	1-4, 9-12	2-12
	Bulbostylis capillaris (L.) C.B. Clarke	SC	1-4, 6, 11-12	1-7, 12	1-12	1-6
	Cyperus brevifolius (Rottb.) Endl. ex Hassk.	RC	1-2, 9-12	1-6, 12	1-4, 9-12	1-8
	Cyperus polystachyos Rottb.	IC	1-4, 11-12	2-5	1-4, 10-12	2-6, 11
	Fimbristylis autumnalis (L.) Roem. & Shult.	RC	9-12	1-6, 10-12	1-4, 9-12	1-9
Fabaceae	*Chamaecrista rotundifolia* (Pers.) Greene	RC	1-5, 11-12	1-6, 12	1-5, 9-12	2-8
	Chamaecrista rotundifolia (Pers.) Greene	SC	2-5, 11-12	2-5, 10-12	1-12	1, 5-7, 12
	Desmodium adscendens (Sw.) DC.	IC	2-3, 9-12	1-4, 9-12	1-3, 9-12	3-6, 9-12
	Desmodium incanum DC.	IC	1-4, 9-12	1-5, 9-12	1-4, 6, 9-12	3-9, 11-12
	Desmodium incanum DC.	SC	1, 10-12	1, 11-12	1-3, 5, 9-12	1-6, 8, 10-12
	Mimosa capillipes Benth.	IC	1-4, 10-12	1-6, 8, 11-12	1-4, 9-12	3-12
	Mimosa capillipes Benth.	SC	2-3, 10-12	1-4, 12	1, 4, 9-12	2-8
	Stylosanthes guianensis (Aubl.) Sw.	IC	1-3, 9-12	2-5, 9-12	1-4, 9-12	3-8, 10-12
	Stylosanthes guianensis (Aubl.) Sw.	RC	1-5, 9-12	2-56, 9-12	1-5, 9-12	3-8
Lamiaceae	*Hyptis atrorubens* Poit.	IC	4-8, 10-12	1, 7-8, 12	1-7, 10-12	7-8, 10-11
	Hyptis eriophylla Pohl ex Benth.	IC	1-6, 8-12	1-6, 8-12	1-3, 5-12	1-12
Malvaceae	*Sida glaziovii* K. Shum.	RC	3-4, 9-10	1-6, 9-12	1-5, 9-12	1-8, 10-12
	Waltheria douradinha A.St.-Hil.	RC	1-12	1-12	1-6, 9-12	1-12
Poaceae	*Andropogon leucostachyus* Kunth	SC	9-10	11-12	1-2, 9-12	1-5, 11-12
	Brachiaria decumbens Stapf	RC	2-5, 10-12	1-8, 11-12	1-12	1-8
	Brachiaria decumbens Stapf	SC	1-4, 6, 11-12	1-6, 12	1-12	1-8
	Chloris polydactyla (L.) Sw.	RC	1-2, 9-12	1-5, 9-12	1-2, 9-12	1-8
	Digitaria insularis (L.) Fedde	SC	3-4, 10	1-4, 11-12	2-4, 9-12	1-5, 11-12
	Melinis minutiflora P. Beauv.	RC	5-6, 10-12	1, 6-8, 10-12	1-12	1-8, 10-12
Verbenaceae	*Stachytarpheta cayennensis* (Rich.) Vahl	IC	1-4, 9-12	1-5, 10-12	1-5, 8-12	3-12
	Stachytarpheta cayennensis (Rich.) Vahl	SC	1-2, 10-12	1-2, 12	1-3, 9-11	1, 5-6, 8, 12

DISCUSSION

Meteorological variables (i.e., rain precipitation and average temperature) appear to directly influence the phenology of the species under study. Flowering presented a strong positive correlation between the number of species, rain precipitation and average temperature in the stricto sensu cerrado sub-area as well as in the sub-area damaged by fire, however weak for the reforested sub-area. During the rainy months, especially in November, December and January, almost every species displayed maximum flowering and fruiting peaks. Fruiting also correlated positively, though weakly, with rain precipitation and average temperature.

Flowering and fruiting of the whole of the species present in the stricto sensu cerrado area under investigation followed patterns similar to those described in studies carried out in cerrado regions in the State of São Paulo (Mantovani and Martins 1988; Batalha *et al.* 1997; Batalha and Mantovani 2000). In these studies the herbaceous community flowered throughout the entire year, but with an observable drop in June and July, the dry season peak. Flowering and fruiting decrease in the dry season probably due to lack of soil moisture, which suggests that lack of rain may be a limiting factor to the development of most species in this environment (Munhoz and Felfili 2005). In semi-arid regions in Northeast Brazil – i.e., *cerrados* and *caatingas* – most species flower and fruit during the rainy season (Pereira *et al.* 1989; Costa *et al.* 2004). Life cycles of herbaceous/sub-shrub species are generally assumed to be limited by water availability in superficial underground systems (Rachid 1947; Monastiero and Sarmiento 1976; Sarmiento 1983; Mantovani and Martins 1988).

Munhoz and Felfili (2005) showed that the phenological rhythms of an herbaceous/sub-shrub community in a "campo sujo" nearby Brasília (Central Brazil) were seasonal, with some synchronicity between species flowering and rainy seasons, and between fruit ripening and seed dispersing and dry seasons. Rain seasonality is thus assumed to be a preponderant factor in this context (Munhoz and Felfili 2005). On the other hand, Gouveia and Felfili (1998) compared the community phenological patterns between areas of soils with different draining conditions and pointed to the absence of phenological seasonality in areas with greater water availability.

In a cerrado area in Goiás (Central Brazil), Batalha and Martins (2004) identified a flowering peak of its herbaceous component in the end of the rainy season, positively correlating flowering with rain precipitation. Batalha and Mantovani (2000) showed that the number of flowering and fruiting species increased until February and diminished until August. This pattern was equally verified in the intact cerrado sub-area under study. Tannus *et al.* (2006) – reinforcing the suggestion that this may be a general pattern for all herbaceous cerrado species – reported that the herbaceous/sub-shrub cerrado species reached flowering and fruiting peaks in rainy seasons, there existing a positive correlation between flowering and temperature as well as between fruiting and rain precipitation.

Reproductive and vegetative activity were observed to take place throughout the entire year in cerrado areas of Central Brazil, leaf-budding and -shedding, flowering and fruiting not being limited to any season. However, the intensity of these phenological events was found to be different throughout the year (Gouveia and Felfili 1998; Oliveira and Gibbs 2000; Munhoz and Felfili 2005).

This is the first study to establish flowering strategies of populations of herbaceous species in the Brazilian cerrado. The reproductive phenology at the specific level has indicated the existence of three flowering strategies: (a) continual flowering throughout the year exhibited by *Bulbostylis capillaris*, *Chamaecrista rotundifolia*, *Desmodium incanum*, *Emilia sonchifolia*, *Hyptis eriophylla*, *Stachytarpheta cayennensis*, *Stylosanthes guianensis* and *Waltheria douradinha*; (b) episodic flowering – *Brachiaria decumbens*, *Chaptalia integerrima*, *Cyperus polystachyos*, *Desmodium adscendens*, *Digitaria insularis*, *Hyptis atrorubens*, *Melinis minutiflora* and *Sida glasiovii*; and (c) seasonal flowering – *Andropogon leucostachyus*, *Chaptalia nutans*, *Chloris polydactyla*, *Cyperus brevifolius*, *Fimbristylis autumnalis* and *Mimosa capillipes.* Continual flowering of herbaceous species at the community level is important in that it makes them available to animal life dependent on flower resources throughout the entire year.

As regards fruiting, it was also possible to define three strategies employed by herbaceous plants of the *cerrado*: (a) continual fruiting, observed for *Chamaecrista rotundifolia*, *Sida glasiovii* and *Waltheria douradinha*; (b) lengthy fruiting, for *Brachiaria decumbens*, *Bulbostylis capillaris*, *Chaptalia integerrima*, *Chloris polydactyla*, *Cyperus brevifolius*, *Desmodium adscendens*, *Desmodium incanum*, *Digitaria insularis*, *Emilia sonchifolia*, *Fimbristylis autumnalis*, *Hyptis eriophylla*, *Melinis minutiflora*, *Mimosa capillipes*, *Stachytarpheta cayennensis* and *Stylosanthes guianensis*; and (c) seasonal fruiting, for *Andropogon leucostachyus*, *Chaptalia nutans*, *Cyperus polystachyos* and *Hyptis atrorubens.* Continual and lengthy fruiting strategies are important to herbaceous cerrado species as they enable the colonization of open areas as soon as they are formed all year around.

The reforested sub-area presented both native and exotic species and at least two species were found flowering and fruiting during the period of investigation. Additionally, contrary to the other cerrado sub-areas, the correlations between the number of flowering species and precipitation/temperature were weak. No studies were found about the probable causes of meteorological factors not influencing more strongly herbaceous species in this type of environment. A tentative explanation is that both the employment of arboreal species and the management of the soil during the many succeeding reforestation stages have a significant impact on phenological patterns of herbaceous communities. However, it is not yet possible to come to this conclusion due to lack of field data.

After the fire invasive species occupied the area, disrupting the growth of native species. Soares and Lima (2000) also observed in a cerrado area in São Carlos that fire had promoted the development of exotic species and a greater population of *Melinis minutiflora*. In present study, exotic grass species, especially *Brachiaria decumbens*, thrived in the area that suffered scorching. Pivello *et al.* (1999)

analyzed a cerrado area in the State of São Paulo and concluded that *B. decumbens* and *M. minutiflora* are the chief invasive species, especially occurring in open and sunlit areas. In the cerrado core region (Central Brazil), these above referred exotic grasses were also the most important invasive species (França *et al.* 2007). In all probability these species are competitively displacing herbaceous cerrado species in these areas.

What is more, the occurrence of invasive grasses in cerrado areas, in particular *M. minutiflora*, strongly affects the fire dissemination pattern (Mistry and Berardi 2005). *Melinis minutiflora* is a grass species of African origin that invades degraded areas of the cerrado region to the detriment of native species. Therefore, in reforested and burnt areas such as the ones under consideration adequate management must be carried out in order to curb the growth of exotic populations (see Martins *et al.* 2004).

It has been observed that the reproductive pattern of some grasses changes after a fire: some species are highly dependent on fires and few flower if the savanna is not scorched (Sarmiento 1992; Canales *et al.* 1994). Studies in "campo sujo" areas subject to periodical fires show that fire acts on the species biology, promoting flowering and fruiting (Munhoz and Felfili 2005). After extensive observations in burnt cerrado fields, Coutinho's (1982) reported that fire promoted fruiting and seed dispersion of some herbaceous and sub-shrub species and that increases in temperature favoured germination of some cerrado species. However, Hoffmann and Moreira (2002) suggested that flowering of some herb and sub-shrub species could be prevented by fire.

In this study flowering patterns were shown to be similar among all of the species under study in both the intact cerrado sub-area and burnt sub-area, whereas fruiting took place mainly within six months after the fire. The differences between the phenological patterns observed in investigations in other cerrado areas that underwent scorching and those found in this study may be explained by the anthropic origin of the fire in the latter case. It seems that the pattern observed for naturally burnt cerrado areas was not observed in this study because the pattern found for the case in question represents the phenology of early colonizing herbaceous species and not of herbaceous plants that respond to fire in an adaptive way.

As regards the vegetative phenology, it was observed in this study that leaf-budding is influenced by meteorological variables (rain precipitation and average temperature), with a greater number of species budding in the rainy season. Damascos *et al*. (2005) previously verified – in the same study area – that leaf-budding of arboreal species started in the beginning of the rainy season and went on for about six months.

Mantovani and Martins (1988) observed that leaf-budding also occurred in the rainy season for a cerrado community in São Paulo State, especially during the months of September and October and leaf-abscission in the beginning of the dry season, peaking in July and August. Herbaceous/sub-shrub species in the Federal District (Brasília, Central Brazil) presented an inverse and significant correlation with leaf-senescence whereas leaf-budding occurred in the beginning or end of the dry season (Munhoz and Felfili 2005). Fire altered leaf-budding and -shedding patterns in the area under study as compared to non burnt areas, with meteorological variables not influencing leaf-shedding in the burnt area. Leaf-deciduousness is regarded as an adaptation to water loss on the part of cerrado plants, consequently, as their way to endure unfavourable periods such as dry seasons (Mantovani and Martins 1988).

Recent studies pointed out the major importance of herbaceous component in cerrado community studies, as well as the lack of substantial data in this strata that could lead to generalization (Batalha and Martins 2007; Munhoz and Felfili 2007). The present study, carried out with a sample of herbaceous species, underlies the importance of carrying out more comparative studies on vegetative and reproductive phenology of cerrado herbs growing in disturbed and undisturbed habitats.

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