Fructification phenology as an important tool in the recovery of iron mining areas in Minas Gerais, Brazil

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(With 4 figures)

Abstract

"Canga" is a name given to the ferruginous rocky fields that can be found in the "Quadrilátero Ferrífero" of Minas Gerais, Brazil. The endemism and species richness make them areas of special biological importance, regarded as high-priority for conservation. Nevertheless, they are being threatened by intense mining activity. Aiming to understand more about this flora, this study was performed in order to determine the maturation or dispersal period of the fruits of four Canga species, *Alibertia vaccinioides* K.Schum. (Rubiaceae), *Coccoloba acrostichoides* Cham. (Polygonaceae), *Miconia sellowiana* Naudin (Melastomataceae), and one probable new species of *Calyptranthes* Sw. (Myrtaceae). Although fruit maturation or dispersal tended to occur at the end of the dry season, some asynchrony was observed in these species, with food sources being available during most of the year. This shows that these species have the potential to attract animals the whole year round, and planting them for the recovery of iron mining areas may increase the community's self-regeneration capacity, leading to a more successful restoration process.

Keywords: fleshy fruit, ironstone outcrop, rocky field, seasonality, zoochoric species.

Fenologia da frutificação como importante ferramenta na recuperação de áreas de mineração de ferro em Minas Gerais, Brasil

Resumo

Canga é um nome dado para os campos rupestres ferruginosos encontrados no Quadrilátero Ferrífero de Minas Gerais. O endemismo e riqueza de espécies os tornam uma área de importância biológica especial, considerada prioritária para conservação. Além disso, tem sido submetida à intensa atividade mineradora. Este estudo objetivou determinar as épocas de maturação/dispersão de frutos de quatro espécies de ocorrência na canga, *Alibertia vaccinioides* K. Schum. (Rubiaceae), *Coccoloba acrostichoides* Cham. (Polygonaceae), *Miconia sellowiana* Naudin (Melastomataceae) e de uma provável espécie nova de *Calyptranthes* Sw. (Myrtaceae). Apesar da maturação/dispersão dos frutos ter apresentado uma tendência de ocorrer no final da estação seca, foi constatada uma assincronia do evento entre essas espécies, com disponibilidade de alimento aos animais frugívoros ao longo de grande parte do ano. O plantio dessas espécies para recuperação de áreas ferruginosas similares degradadas pela mineração poderá atrair fauna durante todas as estações, aumentando o potencial de autorregeneração da comunidade e o consequente sucesso no processo de restauração.

Palavras-chave: afloramentos rochosos, campos rupestres, espécies zoocóricas, frutos carnosos, sazonalidade.

1. Introduction

The "Quadrilátero Ferrífero" (Ferriferous Quadrilateral) region is regarded as a conservation priority area with special biological importance that demands urgent scientific investigation, due to its plant and amphibian endemisms, richness of vertebrate species, and also because these ferruginous fields are a unique environment (Drummond et al., 2005). The edaphic conditions of these areas, with high iron ore content, provide a characteristic ironstone outcrop vegetation named "Canga". These plant communities are associated with

large mineral reserves. In Brazil, the two most important reserves are "Serra de Carajás" (Carajás Mountains), in the Amazon forest, and the Quadrilátero Ferrífero, in the southeast. Brazil is the world's second largest iron ore producer, and about 75% of this production is extracted from the Quadrilátero Ferrífero, where, currently, about 50 opencast mines are in activity (Jacobi et al., 2007). Therefore, this environment has been suffering expressive impact from the extraction of iron ore, and that is why special attention to its conservation and recuperation is required.

Mining is one of the main activities that cause drastic changes in landscape (Frenedozo, 2004) and impacts on wildlife. Rehabilitation programs for these areas are sometimes difficult to implement, for there are some gaps in the knowledge about the "canga" environment. The first approaches used non-native species, but efforts have been proposed towards inserting native species during this process (Parrotta and Knowles, 1999; Grant, 2006). However, the use of native species is only possible with previous knowledge about their biology, such as population dynamics, phenology, reproductive success, seed germination, seedling establishment, and growth rate. Therefore, studies that investigate the biology of native species are of great importance to their management and to the restoration of degraded areas. Phenological studies, which may be applied to the regeneration of forests (Parrado-Rosselli, 2006), help to understand plant-animal interactions, the communities' resource availability through time, and the evolution of the life history of animals that depend on plants for feeding (Frenedozo, 2004).

The fitness of individuals within isolated plant populations, such as those of mountaintop "Cangas", depends on successful dispersal among populations, as do the creation and maintenance of metapopulations and the necessary species migrations in response to environmental changes (Martine et al., 2004). Hence, the phenology of fruiting has an important bearing on community diversity, as frugivorous species depend on a constant food supply (Fenner, 1998) and some plant species depend on animals for their dispersal. The competition for dispersers can result in a pattern of responses for the purpose of reducing phenological overlapping among species, resulting in asynchronous ripening periods (Van Schaik et al., 1993).

Synchrony and the phenophase period interfere in the quantity and quality of resources available; they also bear influence on the structure, activity and regeneration of communities (Williams et al., 1999). Therefore, phenological studies can provide helpful information for the selection of the species used to restore degraded areas (Oliveira and Paula, 2001), such as the mining areas of the Quadrilátero Ferrífero in Minas Gerais. No studies about the seasonal patterns of "Canga" species exist. For this reason, the present study aimed to investigate the phenological behaviour of four "Canga" species, identifying their relative contribution to fruit availability to local fauna.

2. Materials and Methods

This study was conducted in an area covered by an ironstone outcrop vegetation called "Canga couraçada" (armor-clad "Canga") (Rizzini, 1979), which has a heterogeneous flora (Oliveira and Stehmann, 2007). It is situated near the county of Barão de Cocais (19° 53' 08" S and 43° 26' 11" W), in the Quadrilátero Ferrífero of Minas Gerais, southeastern Brazil (Figure 1), at an altitude of 1,120 m. The wet season occurs from November to March, and the dry season from April to August, when rainfall is less than 20 mm/month. The "Canga's" heating during the day, and its fast cooling at night result in a broad range of daily temperatures (Vincent et al., 2002), an important characteristic of this area.

A floristic study identified 117 species, with predominance of shrubs and herbaceous species (Oliveira and Stehmann, 2007). Four of these species were studied in this work, namely: *Alibertia vaccinioides* K.Schum. (Rubiaceae), *Coccoloba acrostichoides* Cham. (Polygonaceae), both restricted to the state of Minas Gerais (Melo, 2000); a probable new species of *Calyptranthes* Sw. (Myrtaceae) (Sobral, pers. comm.), and *Miconia sellowiana* Naudin (Melastomataceae). According to characteristics described by Van der Pijl (1982), these species present zoochoric dispersal syndrome, and they were chosen because they were the prevailing zoochoric species found in the area during initial visits. Except for *M. sellowiana*, which is a tree, these are shrub species. The botanical material collected was included in the herbarium collection of the Department of Botany at the Federal University of Minas Gerais (BHCB). Visits were performed monthly during a period of 15 months. During each visit, the maturation or dispersal of fruits of ten previously marked individuals of each species was observed in the field. Fruit maturation was characterised by changes in fruit colour and dispersal was defined as the falling of fruits. The species' behaviour was described using the index of activity based on phenophase presence or absence, as per Bencke and Morellato (2002).

Circular data analysis, using the ORIANA software (Kovach, 2002), was performed in order to verify the level of synchrony among individuals disposed around an average angle, which means the average date on which the phenophase occurs with the highest frequency. Based on the dates of field visits, the test generates an average vector (μ), its significance (Rayleigh test p), and an average vector length (r). The average vector (μ), represented in degrees, allows one to calculate the average date on which there is a high probability of finding individuals of each species in a certain phenophase. The average vector's significance (Rayleigh test p) points out the probability of the data being randomly distributed around the circle of 360°. Average vector length (r) is an index that

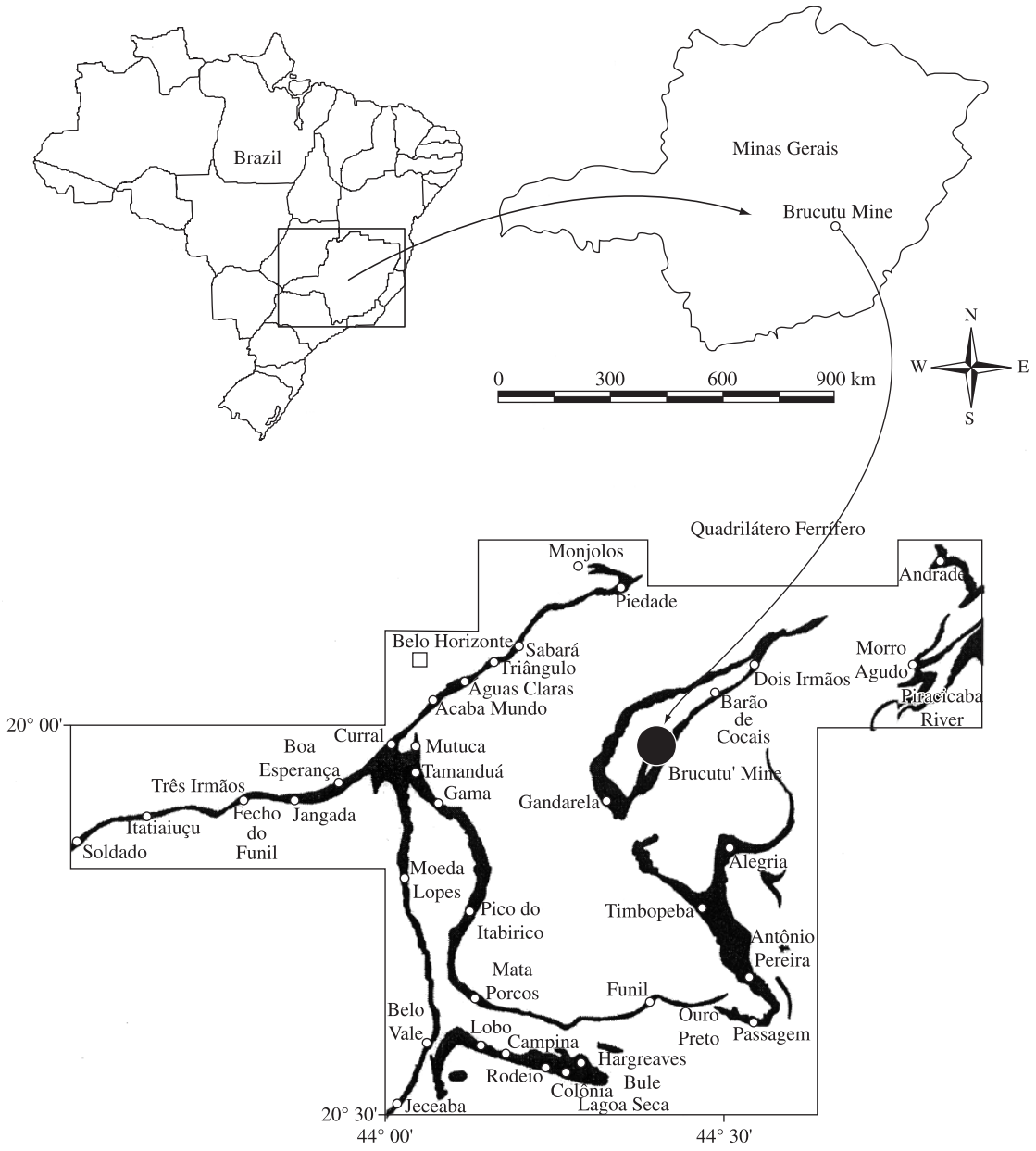

Figure 1. Study area, "Brucutu's Mine" in Minas Gerais State, southeast Brazil. Below, map of the Quadrilátero Ferrífero, modified from Pires (1995).

ranges from 0, or complete asynchrony of the event, to 1, which represents the highest possible synchrony (Zar, 1996).

The circular analysis was applied to the fruit dispersal or maturation of each species separately, in order to verify interspecific variations. The test was also applied to all individuals, without distinction of species, during the first year of study (September/2002 – August/2003), in order to verify the phenological synchrony of this event at the community level.

3. Results

The species showed different maturation or dispersal behaviours (Figures 2 and 3). The fruits of *Alibertia vaccinioides* matured and/or were dispersed over many months, with only a few individuals providing food resources to frugivorous animals each month. *Calyptranthes* sp. was the only species that offered fruits in October/2002 and August/2003. This species was the main food provider, with a high number of individuals

bearing ripe fruits. The species that presented the shortest resource availability period (two months) was *Miconia sellowiana*. Conversely, *Coccoloba acrostichoides* displayed the largest continuous period of ripe fruit availability (seven months), and was the only species that offered resources in May/2003. The highest limitation of resources to frugivorous animals by part of the studied species occurred in November/2002 and 2003 and in March/2002.

The ripening or dispersal of *Calyptranthes* sp. fruits was synchronous among the individuals studied, and happened during the period with the lowest precipitation rates, from July to October (Figure 3). During this period, this species was the main provider of zoochoric fruits. It was observed that, upon the start of the wet season, many ripe *Calyptranthes* sp. fruits fell, making them available to the ground foraging fauna. *C. acrostichoides* dispersed from the middle of the wet season through the middle of the dry season, while *M. sellowiana* showed a shorter dispersal period, with great synchrony among individuals, in the wet season. Synchronical behaviour in the fruit production of a species can facilitate seed propagation, as it attracts more dispersing animals (Rathcke and Lacey, 1985). The period of maturation or dispersal of *A. vaccinioides* fruits showed no apparent relation

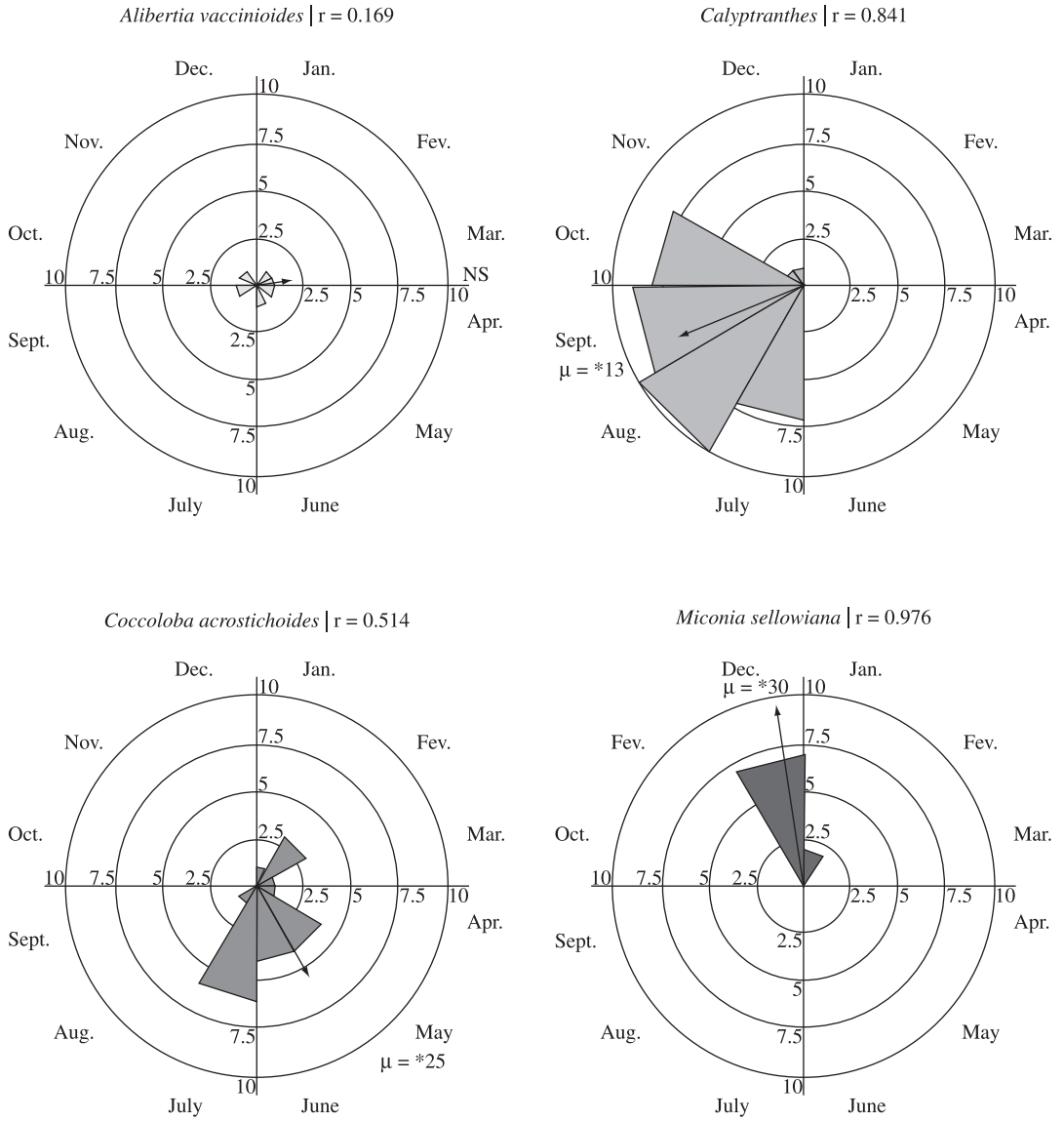

Figure 2. Circular representation of the number of individuals with fruits in the ripening or dispersal period, for four zoochoric species of the Canga. The arrows represent the average vector length (r) of each species and point to the average dates. In bold, * for significant average dates ($p < 0.001$, Rayleigh Test), NS for non-significant dates.

to rainfall variation, this phenophase being distributed among the individuals throughout the year.

Considering all of the studied species, the circular analysis pointed out a significant tendency (Rayleigh test $p < 0.001$) for dispersal to occur in September (Figure 4). This result is a consequence of the higher number of *Calyptranthes* sp. individuals, which presented mature or dispersed fruits at the end of the dry season and the beginning of the wet season. Nonetheless, due to the conditions of the other species throughout the year, the average vector length (r) calculated in this analysis was 0.302, a low value in a scale where 0 represents asynchrony and 1 represents maximum synchrony.

4. Discussion

With the exception of *Miconia sellowiana*, the fruit dispersal pattern observed for the studied species during the dry season is unusual. According to what is described in the literature concerning tropical plants, the majority of zoochoric species have a tendency to undergo this phenophase in the wet season (Gottsberger and Silberbauer-Gottsberger, 1983; Batalha and Mantovani, 2000; Oliveira and Paula, 2001), though some studies have been performed in the transition period between the wet and dry seasons (Ferraz et al., 1999; Dalponte and Lima, 1999).

The low seasonality of the fructification event, considering all studied species (r = 0.302), suggests the availability of fruits throughout the year, which is necessary to maintain the mutualism between plant and disperser (Fenner, 1998). The analysis of the average vector length (r) of each species resulted in high values, indicating synchrony of fructification among the individuals of each species, with the exception of *Alibertia vaccinioides*. The average date (μ) of this event for each species proves the dispersal of diaspores in different months, confirming the event's low seasonality when all species were considered as a group. Similar results were observed by Morellato et al. (1990) for species with fruits dispersed by animals in a montane forest. These results seem to indicate that these species respond differently to climatic variations (Fournier, 1974) or to evolutionary pressure applied by animals (Van Schaik et al., 1993).

The fruits of the studied plants are small (<10 mm diameter) and follow the pattern of little investment, proposed by McKey (1975), where fruits of low nutritive quality are produced in large quantities. The probable dispersers for *Calyptranthes* sp., *Miconia* sp. (Oliveira and Paula, 2001; Magalhães, 2003) and *Alibertia* sp. (Magalhães, 2003) are birds, which were frequently seen foraging in the area. Non-flying mammals disperse the fruits of *Alibertia* sp., (Oliveira and Paula, 2001; Dalponte and Lima, 1999), *Miconia* sp., and *Coccoloba* sp. (Dalponte and Lima, 1999); and ants were detected cutting down stems and carrying fruits of *Miconia* sp. (Pereira and Mantovani, 2001). Feces of the tapeti rabbit, *Sivilagus brasiliensis* (Lagomorpha, Mammalia), were found on some zoochoric shrubs, indicating that these animals visit the area where the fruits fall, despite their classification as browsers, and not frugivores (Emmons, 1990). Pakeman et al. (2002) observed that these animals select fruits for their diet, contributing to an increase in germination and seed dispersal. Therefore, knowledge of the displacements and fate of seeds that are carried by

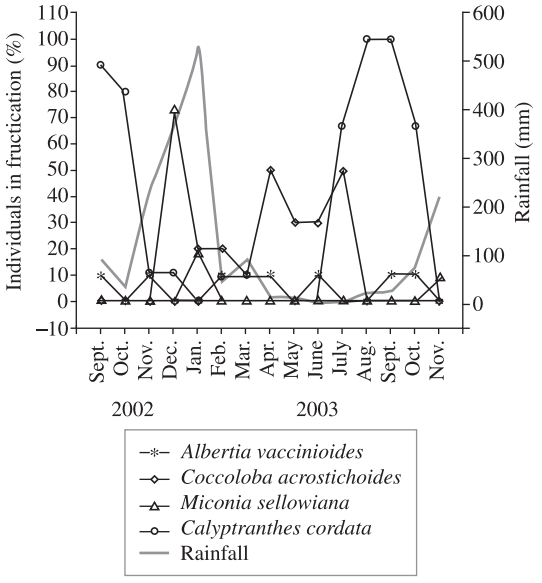

Figure 3. Rainfall indexes (mm^3) and frequency of individuals in fructification for four zoochoric species, during a fifteen month period, in a Canga area. Rainfall data for the years 2002-2003.

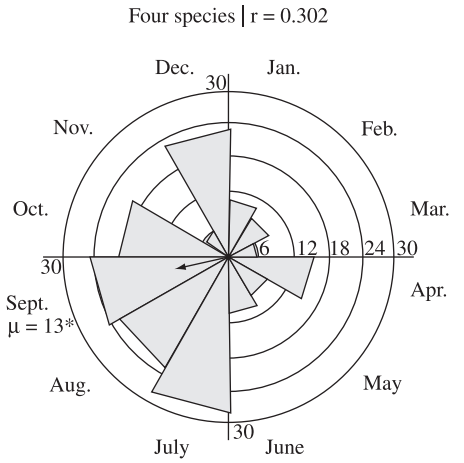

Figure 4. Complete circular representation of the number of individuals with fruits in the ripening or dispersal period, for four zoochoric species. The arrow shows the average vector length (r = 0.302) and points to the average date (September 13) * in bold, with a 95% confidence interval.

animals is essential for the understanding of patterns of species establishment, community structure, and, consequently, for the restoration of disturbed ecosystems (Chambers, 2000). The restoration of some ecological processes, such as dispersal, may improve forest diversity through external sources of fruits (Souza and Batista, 2004), which are carried through the guts of vertebrate frugivores that are attracted to recovered areas.

Miconia sellowiana was identified by Nappo et al. (2004) as the species with the best performance in colonization and structuring of natural regeneration in a mined area of Minas Gerais. This secondary species dominates the classes of largest height and largest diameter. It is the main species of the superior stratum in this initial phase of natural succession. Ecological knowledge is essential during restoration processes where it is necessary to manipulate an ecological system successfully to reach the desired goals (Davis and Slobodkin, 2004). When plant-animal interactions are established in a mining area, it is possible for these communities to support themselves and survive in the new environment (Frenedozo, 2004). Therefore, phenological behaviour is an important tool in degraded area recuperation programs, because it allows the selection of species that disperse in different periods. Hence, in conclusion, the studied species showed a potential to attract animals throughout the year, and planting them for the recuperation of iron mine lands of the Quadrilátero Ferrífero may increase the communities' self-regeneration potential. By this means, self-sufficiency can be attained through their natural dispersers, eliminating the future need to manage fruit dispersal.

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