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Plant Reproductive Phenology and Dispersal Patterns After Natural Regeneration in a Limestone Mining Spoil Banks

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ABSTRACT

Studies were carried out on the phenological patterns and dispersion of a plant community developed naturally after limestone mining operations, in accumulated materials of wastes (spoil banks). The objectives were to focus the seasonality of plant reproductive in a degraded environment; to analyze the community according to dispersal syndrome and to know about plant resources for the animals Monthly observations of flowering and fruiting patterns of the community were done, comparing the herbaceous, shrubs and woody species. Proportion of anemochorous and autochorous was higher in the herbaceous and shrubby strata. The zoochorous ones, on the contrary, were more frequent in the woody stratum. This study showed that natural introduction of the animals at the unreclaimed area, increased the chances for long time, of preserving the plant species since they are pollinated and dispersed their seeds.

Key words: Phenology, mining, Brazil, plant dispersal, herbivores, community

INTRODUCTION

Today, one of the major land uses and causes of deforestation in the tropics is the exploration by mining, which results drastic changes in the landscape. After exploration of a limestone mining, sometimes, may appear limited number of plant species producing a new ecosystem with low diversity (Soave, 1996). This may also result restricted land-use potential and low wildlife conservation value (Bradshaw, 1983; Griffith 1980; Roberts et al., 1981; Bradshaw, 1983; Lima, 1986; Chapin et al.,1994). In these cases, seed dispersal plays a critical role in the regeneration of most community by stimulating and attracting herbivores (Dirzo et al., 1992; Fort and Richards, 1998). It represents the source of feeding (pollen, fruit and seed) for the animals.

It is possible to expect a relationship between plant reproductive strategies and pattern of available of feed resources by frugivores in these new ecosystems (Soave, 1996). The degree of insulation may affect pollinators, pollination and seed output levels in plants (Lovejoy et al., 1986). Phenological studies contribute for understanding the regeneration and reproduction of plants, temporal organization of communities resources, plant-animal interactions and evolution of life history of the animals that depend on plants for feeding, like herbivores, pollinators and dispersers (Lieth, 1974; Frankie et al., 1974; Morellato and Leitão Filho, 1990). Phenology contributes to understanding about dispersal patches and relation fruit-frugivorous (Gentry, 1983; Fleming, 1992).
Some studies are suggested that synchronized flowering of different species could facilitate pollination through increase of resource density

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and local pollinator attraction (Thompson, 1982) or fruit dispersal mode (Janzen, 1971; 1974; Yap and Chan, 1990). The survival of fresh seed, the long-term survival of dormant seeds and transition from seed to seedling are important life history processes that may be influenced by animal dispersers and seed predators, as well as, the space-temporal variation in the abiotic environment (Horvitz and Schemske, 1994). When plant-animal interactions are established in mining area, it is possible that these communities support and survive in the new environment.

The lack of knowledge about the long-term development of these new ecosystems evolved from mining area is reflected in a poor understanding of management of degraded environments (Griffith, 1980; Lima, 1986; Soave, 1996). The aim of this study was: 1) to focus the seasonality of plant reproductive in a degraded environment whose community was naturally developed; 2) to analyze the community according to dispersal syndrome into vegetation strata (herbs, shrubs and trees); 3) to know about plant resources for the animals.

MATERIALS AND METHODS

This study was carried out in spoil banks evolved from limestone mining quarries at Rio Claro, State of São Paulo, Brazil. The research area lies in the sedimentary bedrock belonging to Irati Formation, mainly composed of limestone. The coordinates of the site are 22^o 30'40''S and 47^{o}35'W. The climate is Awa. The mining area in 1992, presented plants and soil chronosequence on the stripping spoils banks, ranging 1 to 40 years old of accumulation. The selection of spoils to be studied was based on general accessibility and freedom from possible human disturbance.

The flowering and fruiting patterns of the spoil banks species were analyzed from data obtained in the floristic survey carried out from August 1992 to July 1994. The botanical material at reproductive stage was collected with the walking-and-gathering method. The collected material was deposited at Herbarium Rioclarensis of Biosciences Institute of UNESP - Campus of Rio Claro, São Paulo, Brazil. During this period, phenological observations were made along the spoils that extended 2.000 m^2 at the different strata of vegetation: trees, shrubs and herbs. At each 15 days, the species were observed and qualitative's related to flowering and fruiting periods: for example, a certain month, if at least one individual of a determined species was found producing fruits, the species was considered to be in its fruiting period.

Flowering was the period that included when flowers were open and apt to pollination. Fruiting included the initial, growth and mature fruit and presence to dispersers (Rathcke and Lacey, 1985). After the phenological studies, plants were grouped and classified according to their morphological criteria (dispersal patterns): anemochory, zoocory and autochory (Pijl, 1982). The flowering and fruiting periods were also related to climatic variations (temperature and precipitation) and propagules dispersion syndrome, comparing the herbaceous, shrubs and woody floras.

RESULTS

The climatic diagram (Fig. 1) was made according to Camargo (1983) which showed that the dry period of the year was between June and August, and the wet one between September and April during a period of ten years. Mean annual rainfall was 1506 mm.yr-1 and mean monthly temperature was 20,3^o C. Coldest months are June and July and the hottest were January to March. Natural vegetation probably has been tropical forest (semidecidual forest), according data from IBGE (1977). Near the mining land, there were disturbed gallery forests along rivers and fragments of mountain forest. The gallery forest probably has been a source of propagules mainly of tree seeds. The mine flora was composed mainly (about 74%) of weed species, many of which were characteristic of agricultural areas (Lorenzi, 2000). Lists of species that occurred in the limestone quarries during the period of 1992 to 1994 are presented in Tables 1, 2 and 3, respectively for herbaceous, shrubs and tree strata. Herbaceous and shrubby species were classified as ruderal ones, in accordance to Lorenzi (2000). During the floristic survey, they were sampled 95 plant species.

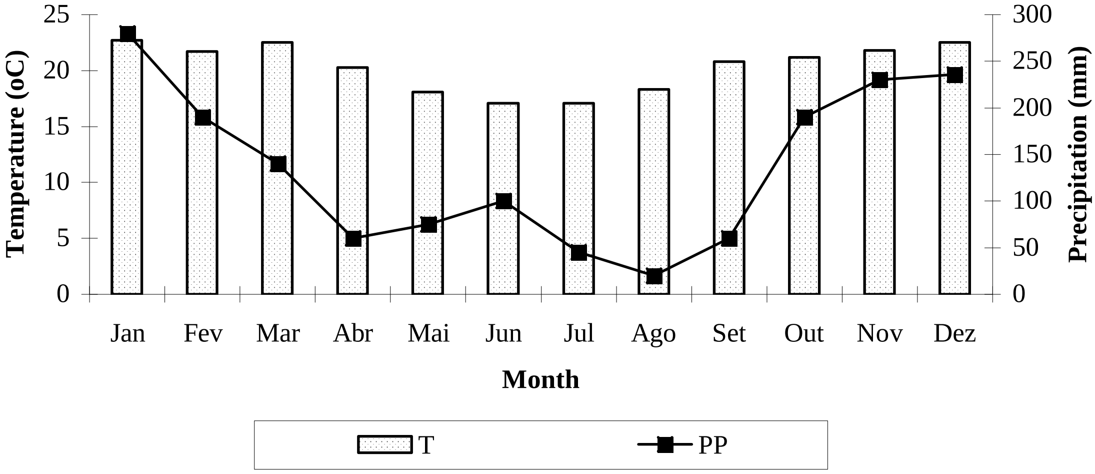

Figure 1 - Climate diagram during 1992 to 1994. T = temperature; PP = precipitation.

Table 1 - List of collected herbaceous species at limestone mining quarries, Rio Claro, SP. Disp. = dispersal syndrome; ANE = anemochorous, AUT = autochorous, ZOO = zoochorous; ND = non defined; fl. per. = spores production or flowering period; fr.per = fruiting period; 1 = january, 2 = February, ..., 11 = november and 12 = december. The hyphen (–) represents continuity between months.

Family	Species	Disp.	fl. per.	fr. per.
Acanthaceae	*Thumbergia alata* Bojer	AUT	3	6
Amaranthaceae	*Alternathera tenella* Moq.	AUT	12-4	2-5
	Gomprhrena celosioides Mart.	AUT	10-5	3-11
	Amaranthus sp	AUT	11-4	7-10
Asclepiadaceae	*Asclepias curassavica* L.	AUT	11-3	4-6
Asteraceae	*Ageratum conyzoides* L.	AUT	11-4	6-9
	Bidens pilosus L.	ZOO	11-5	11-6
	Chaptalia integerrima (Vell.) Burkart	ANE	3-4	3-4
	Emilia sonchifolia DC.	ANE	11-3	11-3
	Gochnatia pulchra Cabrera	ANE	2-8	6-11
	Mikania cordifolia Willd.	ANE	12-6	2-10
	Parthenium hysterophorus L.	ZOO	11-4	11-4
	Porophyllum ruderale Cass.	ANE	3	3
	Pterocaulon lanatum Kuntze	ANE	3-4	4-6
	Siegesbeckia orientales Willd.	ANE	11-3	11-3
	Tridax procumbens L.	ANE	11-3	11-4
Convolvulaceae	*Ipomoeae cairica* Sweet.	AUT	2-6	-
Cucurbitaceae	*Cicyos poliacanthus* Cogn.	ZOO	9-12	9-12
	Momordica charantia Linn.	ZOO	10-3	2-4
Cyperaceae	*Cyperus brevifolius* (Rottb.) Hassk.	AUT	11-4	1-5
	Cyperus flavus J. and C. Presl,	AUT	7-9	7-10
Euphorbiaceae	*Euphorbia heterophylla* L.	AUT	7-10	9-3
	Euphorbia hirta L.	AUT	11-3	12-4
	Euphorbia hyssopifolia L.	AUT	7-9	9-12
Lamiaceae	*Hyptis lophanta* L	AUT	4-7	10-11
	Leonotis sp	AUT		
Leguminosae	*Aeschynomene marginata* Benth.	ANE	10-6	1-12
	Crotalaria incana L.	AUT	1-3	2-4
	Crotalaria lanceolata E.Mey,	AUT	1-4	2-5

(Cont.)

(Cont. Table 1)

	Desmodium canum Schins and Thellung	ZOO	11-12	12-2
	Desmodium purpureum Fawcet and Rendle,	ZOO	11-1	12-3
	Phaseolus lathyroides L	AUT	1-12	12-2
	Vigna sinensis Endl.	AUT	1-4	1-4
Malvaceae	*Sida hyssopifolia* L.	AUT	2-3	2-3
	Sida spinosa L.	AUT	1-3	2-5
	Sida urens L.	AUT	3	3
Poaceae	*Digitaria insularis* (L.) Mez ex Ekman	ANE	12-2	–
	Eragrostis ciliaris (L.) R. Br.	ZOO	12-2	2-4
	Hyparhenia rufa (Ness) Stapf	ANE	6-9	7-11
	Mellinis minutiflora Beauv.	ANE	6-7	6-11
	Paspalum notatum Fluegge,	ANE	11-3	3-11
	Rhynchelitrum roseum Stapf and Hubbart.	ANE	5-2	5-2
	Setaria geniculata (Lam.)Beauv.	ZOO	–	5
	Sporobolus indicus (L.) R. Br.	ZOO	12-5	5
Polypodiaceae	*Polypodium* sp	ANE	1-12	–
	Pteridium aquilinum (L.) Kuhn.	ANE	–	–
Sapindaceae	*Cardiosperma halicacabum* L.	ANE	NO	NO
Solanaceae	*Solanum aculeatissimum* Jacq.	ZOO	9-2	1-2
Sterculiaceae	*Melochia pyramidata* L.	AUT	12-3	12-4
	Waltheria indica L.	AUT	1-8	9-10

Table 2 - List of collected shrubby species at limestone mining quarries, Rio Claro, SP, Brazil. Disp. = dispersal syndrome; ANE = anemochorous, AUT = autochorous, ZOO = zoochorous; fl. per. = spores production or flowering period; fr.per = fruiting period; 1 = january, 2 = february, ..., 11 = november and 12 = december. The hyphen (–) represents continuity between months while comma (,) means interruption.

Family	Species	disp	fl. per.	fr. per
Asteraceae	*Baccharis dracunculifolia* A.DC.	ANE	12-4	1-7
	Eupatorium laevigatum Lam.	ANE	5-9	1-9
	Eupatorium maximiliani Schrad.	ANE	4-7	1-12
	Merostachys sp	ANE	ND	ND
	Tagetes minuta L.	ANE	ND	ND
	Vernonia polyanthes (Spr.) Less.	ANE	10-11	10-7
Euphorbiaceae	*Ricinus communis* L.	ZOO	11-2	2-4
Leguminosae	*Cassia hirsuta* L.	AUT	2	–
	Crotalaria mucronata Desv.	AUT	1-3	2-4
	Indigofera truxillensis H.B. and K.	AUT	–	5-7
	Stylosanthes viscosa Sw.	AUT	10-7	11-8
Malvaceae	*Sida carpinifolia*	AUT	9	9-10
	Sida cordifolia	AUT	2-5	3-5
	Sida rhombifolia	AUT	1-3	3
	Sida viarum A . St. Hil.	AUT	2-4	4
	Sida viscosa L.	AUT	2-3	3-4
Myrtaceae	*Psidium guajava* L.	ZOO	9-10	11-3
Solanaceae	*Solanum lycocarpum* A . St. Hil.	ZOO	1-4	5-12
Tiliaceae	*Triumfetta bartramia* L.	ANE	10-12	ND
Verbenaceae	*Lantana camara* L.	ZOO	12-3	12-3
	Lantana lilacina Desf.	ZOO	12-3	12-3

Table 3 - List of collected woody species at limestone mining quarries, Rio Claro, SP (coordinates). Disp. = dispersal syndrome; ANE = anemochorous, AUT = autochorous, ZOO = zoochorous; fl. per. = spores production or flowering period; fr.per = fruiting period; 1 = january, 2 = february, ..., 11 = november and 12 = december. The hyphen (−) represents continuity between months while comma (,) means interruption.

Family	Species	Disp	fl. per.	fr. per
Bignoniaceae	*Stenolobium stans* Seem.	ANE	08-12	10-2
Boraginaceae	*Cordia ecalyculata* Vell.	ZOO	10	3
Dilleniaceae	*Curatella americana* L.	ND	ND	ND
Flacourtiaceae	*Casearia* sylvestris Sw.	ZOO	7-10	–
Lauraceae	*Nectandra megapotamica* (Spreng.) Mez	ZOO	–	–
Lecytidaceae	*Cariniana estrellensis* L.	ANE	7-10	10-11
Leguminosae	*Acacia plumosa* Lowe	ANE	12-2	–
	Bauhinia foficata Link	ZOO	10-12	12-3
	Lonchocarpus sp	ANE	ND	ND
	Machaerium aculeatum Part.	ANE	–	–
	Teramnus sp	ND	ND	ND
Meliaceae	*Cedrela fissilis* Vell.	ANE	9-12	4-8
	Melia azedarach L.	ZOO	8-10	10-3
	Trichilia elegans A . Juss.	ZOO	9-10	10-11
Myrtaceae	*Eucalyptus citriodora* Hook.	AUT	ND	ND
	Eucalyptus saligna Sm.	AUT	ND	ND
Piperaceae	*Piper* sp1	ND	ND	ND
	Piper sp2	ND	ND	ND
Rhamnaceae	*Rhamnidium eleocarpum* Reiss	AUT	ND	ND
Sterculiaceae	*Guazuma ulmifolia* Lam.	AUT?	11	7-11
Tiliaceae	*Luehea divaricata* Mart.	ANE	12	–
Ulmaceae	*Celtis iguanae* (Jacq.) Sargent.	ZOO	9	5
	Trema micrantha Blume	ZOO	3-5, 8-10	2,5,9
Urticaceae	*Morus alba* L.	ND	ND	ND

Herbaceous stratum was the most important and abundant in number of species in the quarries. Trees and shrubs were sparse and located in the spoils where profiles were more evolved and presented with meliorated physical and chemical properties, as could be seen in older quarries (Soave 1996). The proportion of flowering in herbaceous species was lower in August, increased from November to March, remaining high until March (Fig. 2). In herbaceous stratum, the flower production was more intense at the end of the rainy season, as can be seen for shrubs too. For the wood stratum, the major percentage of flowering species was during September to December, which represented the wet hot season, while the minimal number of species in flowering was in June-August, in dry cold season.

The fruit production (Fig. 3) presented similar pattern with the flower production. The peak of fruit production was in January (in the rainy season) and other peak in May (dry season). This factor was very important because it represented a source of food for animals during the seasons along the year. The plant species observed in the spoils were classified according to their dispersal pattern (Pijl,1982).

Fig. 4 shows the distribution of dispersal syndrome at different vegetation strata. Of the total plant species presented in the community, 38% were anemochorous, 27% were zoochorous, 24% autochorous and 11% weren’t defined or observed. Of the total herbaceous (50) species, 46% were anemochorous, 28% autochorous, 20% zoochorous and 6% were not defined or observed in the field observations. For herbs, anemochorics syndrome dominated. In the shrubby ones, the dispersal was dominated by zoochory (about 35%), followed by 30% for anemochorics, 13% autochorics and 22 % of species whose mode of dispersal was not defined. Tree species presented 33% zoochorics, 24% autochorics, 14% anemochorics and 29%, dispersal pattern was not observed. Batalha and Mantovani (1996) found similar patterns in a reserve of cerrado at Santa Rita do Passa Quatro, State of São Paulo, Brazil.

Number of fruiting herbaceous species along the year is shown in Fig. 5. Presented data were average of two years from phenological observations. Fruiting period, for herbs, occurred all year long, but the most of species fruited during November to March, which corresponded to the warmer and weather climate. For the herbs, it was observed that anemochorics species produced fruits maximum in March, which corresponded to the beginning of the dry season of the region.

Fig. 6 presents the number of fruiting shrub species along the year. Shrub species fruited all year long, exception for zoochoric ones. With the anemochorics fruited during July to October, that corresponded to dry season with strong winds and decreased in august and increased again in September, persisting until December. During the season, the number of species that was found in fruiting was small, as *P. lanatum* and *T. procumbens*. Similar results were observed for the zoochorics and autochorics.

Shrubs showed peaks of fruiting mainly during December to March for all syndromes. During dry season (from March to August), zoochorics fruits were absent. This factor represented reduction in research for herbivores.

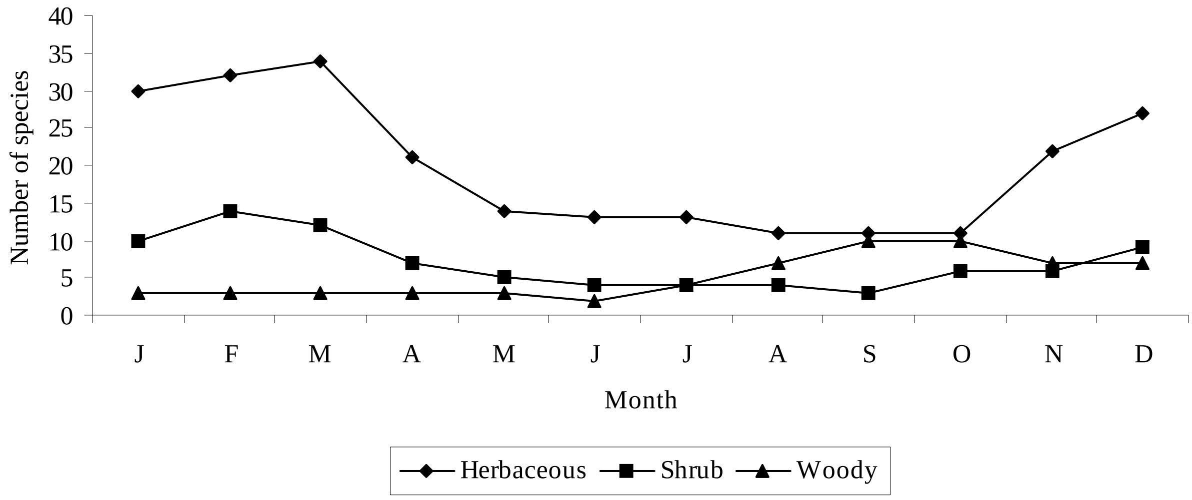

Figure 2 - Number of flowering species through the year.

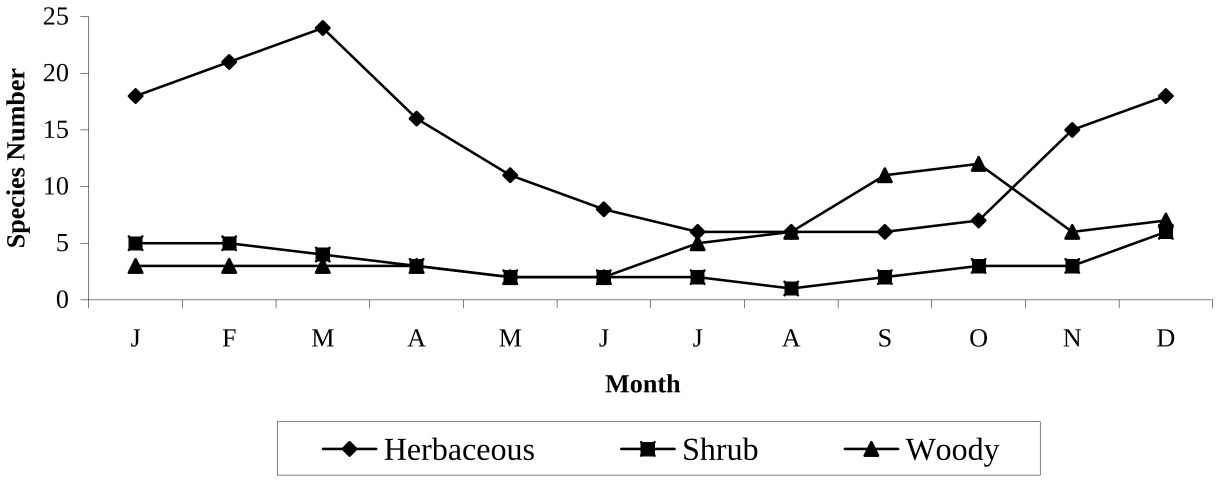

Figure 3 - Number of fruiting species through the year.

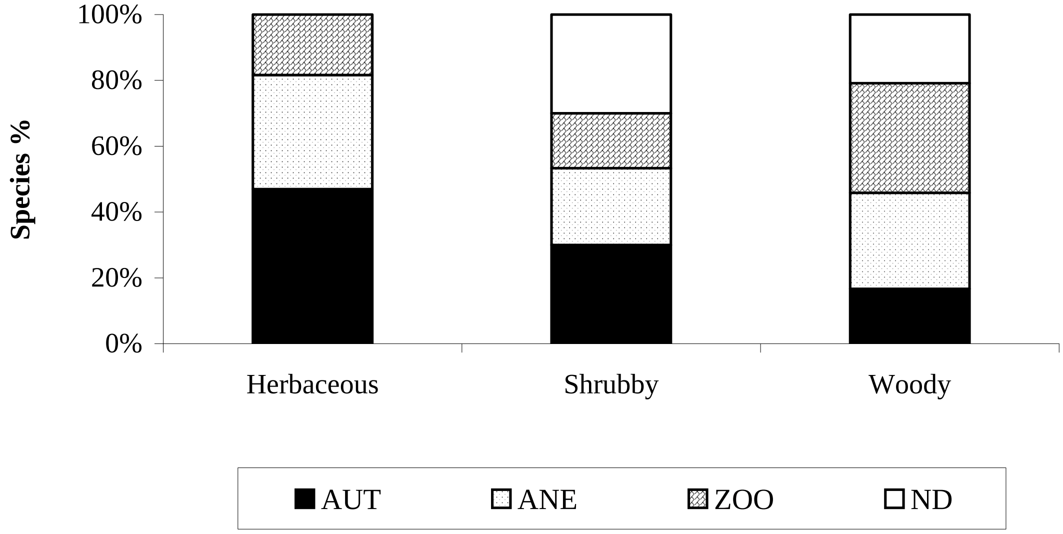

Figure 4 - Percentage distribution of dispersal syndrome in herbaceous, shrub and wood species.

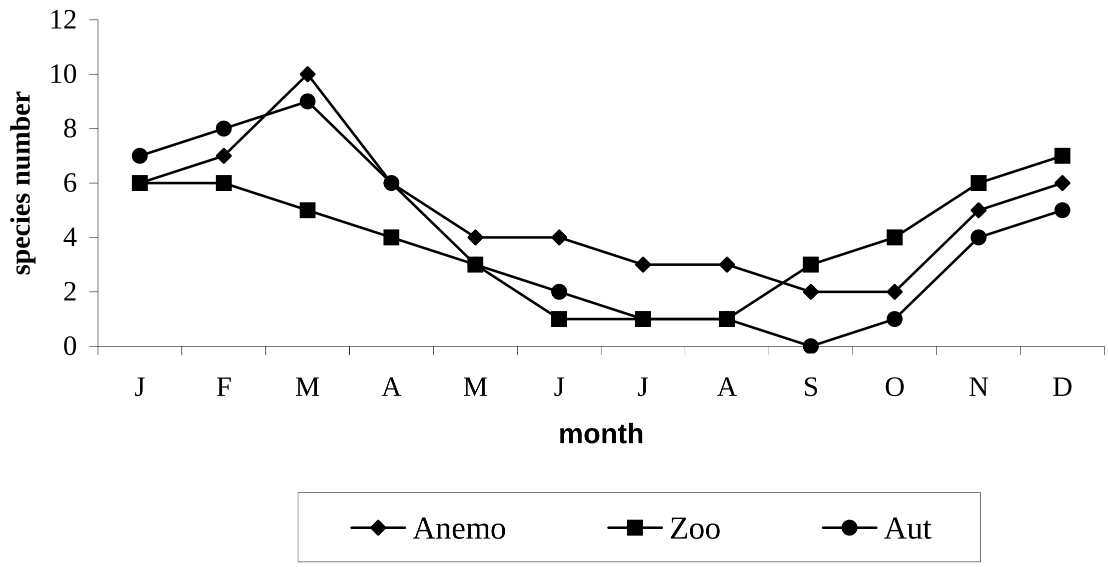

Figure 5 - Number of herbaceous species in fruiting and classified according dispersal syndrome.

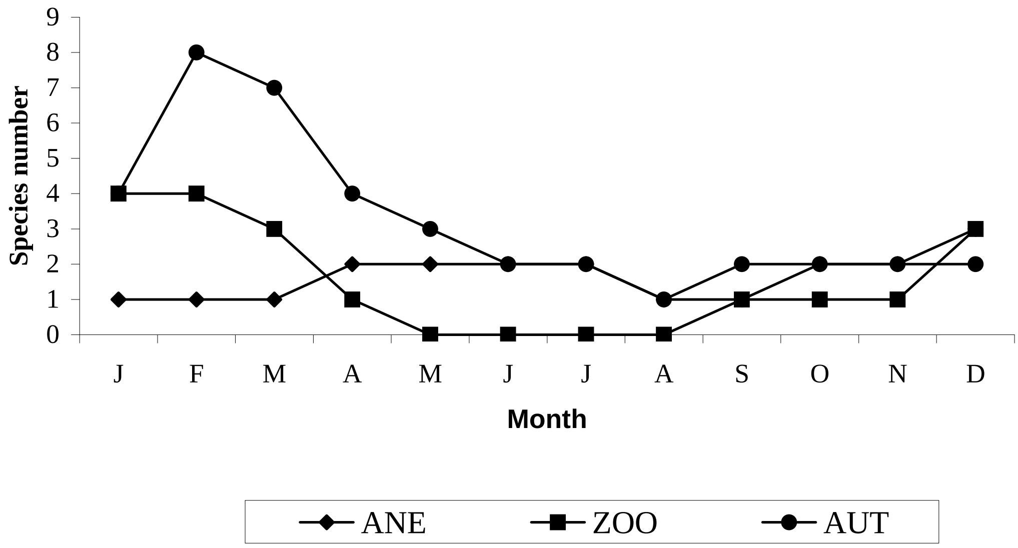

Figure 6 - Number of shrub species in fruiting and classified according dispersal syndrome.

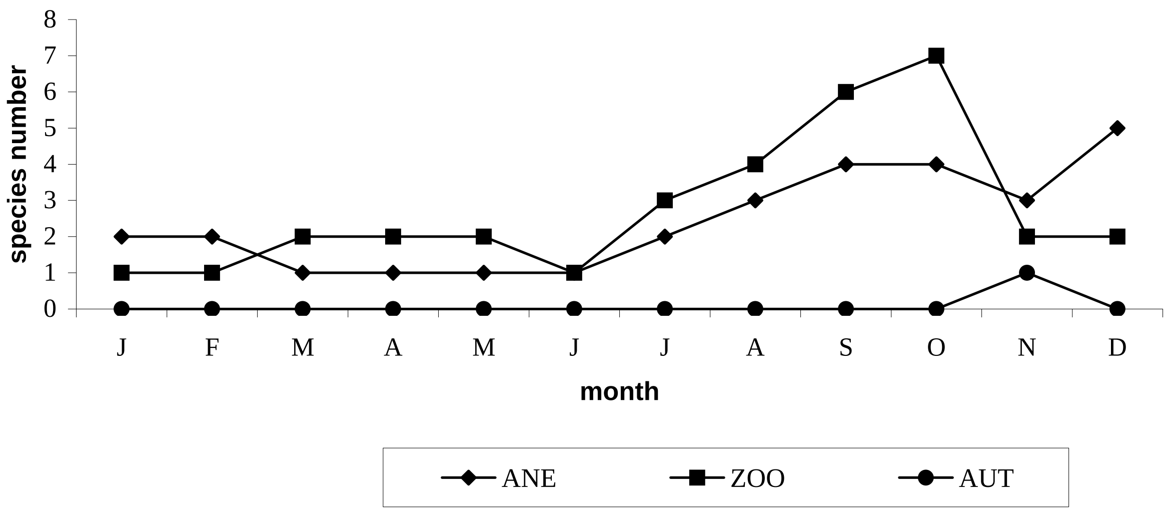

Figure 7 - Number of wood species in fruiting and classified according dispersal syndrome.

Tree species (Fig. 7) showed peaks of fruiting during August to October and a peak in December for anemochorics. During the study, some trees (4 species, about 15%) did not flower, probably due to age of the individuals and/or new conditions of the habitat. Spearman test showed that environmental factors have significant correlations with temperature and phenology (rs = 0.75, $p<0.05$ for flowering and rs = 0.877, $p<0.05$ for fruiting). For precipitation, the Spearman test showed similar results (rs = 0.74, $p<0.05$, for flowering and rs = 0.76, $p<0.05$ for fruiting).

DISCUSSION

The presence of weeds shrubs and other pioneer species is very important to facilitate the establishment and the growth of the woody species, because they provide micro-environmental conditions (Uhl et al.. 1991; Vieira et al., 1994;

Silva et al.. 1996; Vieira and Silva, 1997). The colonizer species that appeared at limestone mining quarries had high establishment ability to invade disturbed environments and exhibited biological characteristics such as high dispersal capacity (for example, *B. pilosa*, *B. dracunculifolia* and *E. sonchifolia*). These weedy species are well adapted for the occupation of disturbed habitats and often have several life-history characteristics: rapid colonization of disturbed successional habitats, high reproductive rates, early and continuous reproduction and rapid somatic growth (Vieira and Silva, 1997). Some species had success in anthropogenic habitat by combining characteristics such as high survival potential in inhospitable sites, aggregated spatial dispersion, synchronic fruiting and effective dispersal of seeds (generally anemochorics). These species predominated mainly in Asteraceae and Poaceae.

Limestone mining area may be considered as a primary succession stage, where environmental conditions are limiting and some stress-tolerant species became established (Fort and Richards, 1998). A persistent deficiency of vegetation cover, as observed in some parts of the mining, may result from a lack of microsites suitable for seed entrapment, germination and growth. If seed was not limiting, as observed, the physical and chemical properties of the wastes played an important role, where pH was higher than 7.0 (Soave, 1996). Predominance of wind-dispersed on mining quarries was comparable to other sites of primary succession, as observed onto a volcanic debris avalanche, onto volcanic pyroclastic flows and in a desert playa (Fort and Richards, 1998). These small seeds, probably, would be expected to disperse during high winds. Although the climate data showed a little seasonality, the phenological results presented significant correlations between them, where environmental factors influenced the reproductive phenology of species. According to Borchert (1980), reproductive patterns and growth of tropical species were primarily determined by endogenous periodic processes and, in secondary plan, by adaptation to environmental changes. Aide et al. (1995) had considered in environment with a little pronounced seasonal climate, the plant phenology determinants included biotic selective forces as herbivores, predator, competitors, pollinators and dispersers.

Flowering occurrence was, mainly, during November and December months, corresponding to rainy season, as was found in other tropical forests (Sarmiento and Montasterio, 1983; Batalha and Mantovani, 2000). This behavior was found in other Brazilian forests (Morita et al.. 1982; Costa et al.. 1992), although during dry season flowering in many herbaceous and shrub species was observed (Janzen, 1967; Araujo,1970). Pollination have a fundamental role in regulating the time of flowering species. Seasonal movements of varying spatial magnitudes are common in frugivores and nectarivores. According to Fleming (1992), in the tropics, habitat shifts generally involved movements among habitats along succession gradients. Other factors, including microclimatic constraints and nest requirements can also influence these movements.

Fruiting was seasonal with 2 peaks of higher availability: first one in the beginning of dry and the second in wet season. Many authors found similar results (Dalponte and Lima, 1999, Sakai et al.,1999). These species may guarantee food resources to the herbivores. Continuous production of dispersed fruits, as appearance of the fauna, is associated with a strategy to maintain of resources for dispersers of seeds (Snow, 1965; Hilty, 1980; Talora and Morellato, 2000). By their activity, herbivores create and modify much of the spatial heterogeneity that is so important in the dynamics of all species in a community (Crawley, 1983; Hunter, 1992).

After development of the first shrub species, they constituted a resting-place, especially for little birds that eat fruits and little seeds or nesting. These birds, by ingesting seeds and/or fruits, can eliminate them through faeces to other sites. These seeds were benefited by shading from grasses and other shrubs species (example, *B. dracunculifolia*). Natural introduction of the animals at the unreclaimed area, increase the chances, at longtime, the perseverance of plant species since they are pollinated and dispersed their seeds.

RESUMO

Estudaram-se os padrões fenológicos e dispersão em uma comunidade sucessional desenvolvida a partir de rejeitos de mineração de calcário. A comunidade vegetal era composta principalmente de indivíduos herbáceos e arbustivos, com algumas árvores esparsas. O estudo deu-se durante 2 anos (fevereiro de 1992 a julho de 1994), onde mensalmente os indivíduos foram observados e registrados a sua fenologia e os seus padrões de

dispersão, a fim de observar os recursos disponíveis para a fauna local. O número de espécies nos diferentes estratos foi: 50 espécies herbáceas, 21 espécies arbustivas e 24 espécies arbóreas. A proporção de espécies anemocóricas e zoocórias foi maior nos estratos herbáceo e arbustivo. O padrão zoocórico foi mais freqüente no estrato arbóreo. O estudo mostrou que a introdução natural da fauna ocorre mesmo em áreas mineradas não recuperadas e, as chances desta comunidade se manter existem desde que as plantas sejam polinizadas e dispersas.

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