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SUCCESSIONAL CHANGES IN CERRADO AND CERRADO/FOREST ECOTONAL VEGETATION IN WESTERN SÃO PAULO STATE, BRAZIL, 1962–2000

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Surveys over a period of 38 years have shown a rapid successional change in the remaining areas of cerrado vegetation in western São Paulo State. Cerradão (the dense, tall, forest form of cerrado (*sensu lato*)) and cerrado/Atlantic forest ecotonal vegetation have replaced more open forms (such as campo cerrado) during this period. An aerial photographic survey in 1962 showed 75% cerrado (*sensu stricto*), 16% campo cerrado, and only 9% cerradão, while a survey combining Landsat imaging of 1992 with aerial photography of 1984 gave 69%, 0.6%, and 30.5% respectively for the same physiognomies. Visiting 10% of the sites of the latter survey in 2000 showed that cerradão had become the dominant vegetation of 68% of them. In a particular 180 ha site in Assis municipality, cerradão increased from 12.0 to 41.4% of the area in 22 years. Reduction of anthropic pressures, such as fire and cattle-grazing, is considered responsible for these rapid changes. Conservation issues and research priorities related to these changes are discussed and proposed.

Keywords. Atlantic forest, cerrado, dynamics, ecotonal vegetation, neotropical savanna.

INTRODUCTION

São Paulo State is located in a transition region between two very distinct biomes, the southern limits of the cerrado (Fig. 1) and the Atlantic forest, both of which are included among the 25 hotspots considered as global priorities for biodiversity conservation by Myers *et al.* (2000).

The original landscape in western São Paulo State at the end of the nineteenth century was probably a mosaic of forest and cerrado patches and this was correlated with soil properties (Gibbs *et al.*, 1983; Monbeig, 1984; Leitão Filho, 1992; Salis *et al.*, 1995; Torres *et al.*, 1997). Maps of the original vegetation of the region are rare and at small scale (Campos, 1912; Victor, 1975), and they show only large patches of contrasting vegetation types, while the methods used for their production are not clearly explained.

In the early decades of the twentieth century most of the forest vegetation in western São Paulo State was replaced by arable cultivation and plantations, especially in

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FIG. 1. Location of São Paulo State in the southern limits of the cerrado domain (adapted from Durigan *et al.*, 2004).

those areas with more fertile soils. At this time, the open cerrado vegetation was exploited only to provide fuelwood and for extensive cattle-raising and was burned almost every year to stimulate the production of herbaceous shoots for grazing. The use of these cerrado areas has since been converted to intensive agriculture, mostly during the last four decades when changes resulting from modern technology and genetic improvement made such exploitation of cerrado soils both possible and profitable. Of particular significance has been the rise in importance of soya and sugar cane as crops (the latter related to the policy for the development of alcohol fuel as a substitute for petroleum).

In recent years, legal protection afforded to the Atlantic forest in 1993 by *Decreto 750* (Diário Oficial da União, 1993) has further increased developmental pressure on land under cerrado vegetation. This federal law forbids any destruction of natural vegetation within the Atlantic forest limits as shown on an official map (IBGE, 1988). However, most areas of cerrado or ecotonal cerrado/forest vegetation are not included in this map. As a consequence, cerrado and transitional vegetation have been rapidly cleared for agriculture in São Paulo State since forest areas are no longer legally available.

Nowadays, the remaining cover of cerrado vegetation in São Paulo State is reduced to less than 7% of its original area (Kronka *et al.*, 1998): the same level of deforestation as recorded for the particularly vulnerable Atlantic seasonal semi-deciduous forest in the same region. The remaining natural vegetation in western São Paulo State is restricted to thousands of very small fragments, and only a small number of areas larger than 1000 ha exist (see Kronka *et al.*, 1993). Some of these remnants have been highlighted as priority areas for cerrado or Atlantic forest conservation based on their biological characteristics and the degree to which they are endangered (Joly *et al.*, 1997; Cavalcanti *et al.*, 1999; Pinto *et al.*, 2000).

During the field work of the recent project *Conservation feasibility of cerrado remnants in São Paulo State* (see Durigan *et al.*, 2003) all fragments of cerrado vegetation considered as priorities for conservation were surveyed. In comparing the results with observations made previously we realized that great changes in physiognomy and floristic composition had occurred in a relatively short time, and this communication is devoted to consideration of them.

Structural variation in cerrado vegetation and its terminology

The Brazilian cerrado (savanna) biome covered an area of c.2 million km^2 before the recent exploitation of the region for intensive agriculture during the last 35 years. It stretched from São Paulo and Paraná States in the south (the region we are considering in this paper) as far as the southern Amazon drainage in the north, and even included some disjunct areas north of the River Amazon itself (Fig. 1).

The dominant vegetation of the biome is the xeromorphic, pyrophytic, savanna vegetation known as cerrado, but it also includes large areas of riverine forests, deciduous and semideciduous forests on more fertile soils, swampy areas, etc. Cerrado encompasses a series of vegetation forms from open grasslands to dense woodlands, and more or less recognizable points in this continuum are given vernacular names. Dry grassland without shrubs or trees is called *campo limpo* (= clean field); grassland with a scattering of shrubs and small trees is known as *campo sujo* (= dirty field); where there are numerous trees and shrubs but there is still a vigorous ground layer the vegetation is termed *campo cerrado* (= closed field); the next stage when the vegetation is obviously dominated by trees and shrubs but there is still a fair amount of ground cover between them is known as *cerrado* (= closed, i.e. the vegetation has closed); the last stage is an almost closed woodland made up of trees, often of 8–12 m or even taller, casting a considerable shade so that ground vegetation is much reduced – this form is called *cerradão* (the augmentative of cerrado). Clearly the dividing line between the last three forms is somewhat arbitrary, but workers in the field usually agree surprisingly well on the classification of the vegetation. It is confusing that in common usage the term cerrado can refer to Brazilian savanna vegetation in its generic sense and to one particular subvariant of it. To avoid this, cerrado (*sensu lato*) is usually used for the former and cerrado

(*sensu stricto*) for the latter. In Brazilian literature the structural forms of cerrado (*sensu lato*) are usually called *fisionomias* (= physiognomies). Criticisms have been made by a number of authors of this modified vernacular terminology and elaborate schemes proposed to replace it. However, none of these have had widespread adoption and it seems best to continue with the present pragmatic usage.

The cerrado/forest transition

The transition between savanna and various types of forest vegetation has been described in several regions of Brazil and observations made on its dynamics (see Ratter, 1992, for a summary of much of the information on the subject). The boundaries between the deciduous and semideciduous forests and the cerrados of Central-West, East, and Northeast Brazil are related to soil conditions, with forest occurring on more fertile soils and cerrado on dystrophic soils, and a transition vegetation, termed *mesotrophic facies cerradão*, occurring on the intermediate mesotrophic soils (Ratter *et al.*, 1973, 1977, 1978a; Furley & Ratter, 1988). The studies of Goodland & Pollard (1973) and Lopes & Cox (1977) which correlated increased production of woody vegetation with an increasing soil fertility gradient clearly relate to this type of transition. Dubs (1992, 1994) reached similar conclusions from an elegant, meticulous, study on the differentiation of semideciduous forest, mesotrophic facies cerradão and wet savanna along a soil moisture gradient in the Pantanal do Rio Negro, Mato Grosso do Sul State.

Studies have also been made in transitions between vegetation types on dystrophic soils where there seems to be no relationship with nutrient or moisture conditions. Ratter *et al.* (1973, 1978b) found no obvious soil differences along the transition from Amazonian forest to cerrado through a band of characteristic dystrophic facies cerradão in eastern Mato Grosso. In this area there was much evidence that the forest was expanding into the cerrado vegetation. Similarly, considerable expansion of forest into cerrado through an intermediate dystrophic cerradão was observed in an area of the Federal District protected from fires for 14 years (Ratter, 1992).

Soil moisture can also be responsible for differences in vegetation in the cerrado landscape (Furley & Ratter, 1988), as observed in hydrologic savanna in Roraima (Furley & Ratter, 1990), where the upper limit of seasonal flooding controls the boundaries.

The cerrado/Atlantic forest transition has rarely received specific attention. In Uberlândia, Minas Gerais State, Moreno & Schiavini (2001) concluded that soil factors exerted an important influence on the floristic composition and structure of the vegetation along the gradient from forest to cerrado.

In São Paulo State, the transition also coincides to a large extent with changes in soil properties: cerrado vegetation is restricted to dystrophic soils derived from sandstone and forests occur on eutrophic soils derived from volcanic rocks or more nutrient-rich sandstones. Cerrado and Atlantic seasonal semideciduous forests in this region occur under the same climatic conditions, where annual rainfall ranges

from 1200 to 1500 mm and the dry season in the winter lasts for one to three months. The gradual transition in soil fertility and water-holding capacity results in a floristic gradient from cerrado to seasonal semideciduous forest, with ecotonal sites containing variable proportions of cerrado and forest species, so that it is impossible to classify them as either cerrado or Atlantic forest (Durigan *et al.*, 2003). These sites are the only remaining fragments of a once widespread ecotonal vegetation and represent the last areas available to study the transition in western São Paulo State.

History of changes of area and physiognomy of cerrado (*sensu lato*) in São Paulo State

While Atlantic forest and cerradão were replaced after 1880, at first by coffee and cotton and later by pastures (Brannstrom & Oliveira, 2000), open cerrado areas in western São Paulo State were used for a long time only for extensive cattle-raising based on native grasses, since their soil could not support traditional arable agriculture. Fire was frequently applied as a management technique to renovate the pasture, reducing tree- and increasing grass-cover (Coutinho, 1982). Cerrado trees were also cut for uses such as fuelwood and fence-posts. Under these continuous pressures, areas originally covered by cerradão were converted to cerrado (*sensu stricto*) or campo cerrado. This was useful to farmers, since cerradão, with little or no herbaceous ground layer, is unsuitable for cattle-grazing.

This was probably the situation when an aerial photographic survey was made in 1962. Based on the survey photographs, Chiarini & Coelho (1969) mapped the vegetation of cerrado (*sensu lato*) of São Paulo State, quantifying the area covered by each physiognomy. At that time, cerrado (*sensu stricto*) at 75% was the most extensive vegetation type, followed by 16% of campo cerrado and only 9% of cerradão, and the total area covered by cerrado vegetation was 33,929 km^2 (13.7% of the State).

Following the 1962 survey the total area of cerrado vegetation was drastically reduced and replaced by arable cultivation, plantations, and high productivity pastures of African grasses, since extensive cattle-raising on native vegetation became unprofitable as land prices increased. At the same time changes in environmental laws in São Paulo State prohibited the use of fire as a management tool in native cerrado pastures, causing changes in the vegetation of the remaining areas.

The most recent complete mapping of natural vegetation in São Paulo State was in 1992, using Landsat satellite images (Kronka *et al.*, 1993). These showed a total area of 2379 km^2 covered by cerrado (*sensu lato*), a reduction of 93% since 1962 (Chiarini & Coelho, 1969). Since the satellite images were not precise enough to identify the cerrado physiognomies clearly, aerial photographs of the same areas taken in 1984 were used by the authors to differentiate them. The mapping therefore shows the areas present in 1992 but carrying the vegetation which occupied them in 1984. The figures for this are 68.9% cerrado (*sensu stricto*), 30.5% cerradão, and

TABLE 1. Changes in the proportion of cerrado physiognomies in São Paulo State (1962–1992)

Year	Campo cerrado (%)	Cerrado (*sensu stricto*) (%)	Cerradão (%)	Reference
1962	16	75	9	Chiarini & Coelho (1969)
1992*	0.6	67.9	30.5	Kronka *et al.* (1993)

*Classification based on aerial photographs from 1984 (see text).

0.6% campo cerrado. Since we have no reason to believe that cerradão suffered relatively less clearing than other forms of cerrado, this indicates that a remarkable increase of cerradão and decline of campo cerrado occurred during the period from 1962 (Table 1).

Durigan *et al.* (2003) surveyed 10% of the remaining area of cerrado vegetation in the State eight years after the Landsat survey reported in Kronka *et al.* (1993). They revisited the sites mapped by these authors and recorded cerradão as the most common physiognomy, observed in 69.8% of the sites. The degree of change was such that at the start of the field work programme (in 2000) the survey team thought that there was an error in the legend of the 1992 maps (showing the physiognomies present in 1984). At most sites the vegetation had changed: campo cerrado had grown into cerrado (*sensu stricto*) (sometimes cerradão); cerrado (*sensu stricto*) had become cerradão, and many areas classified as cerradão now contained ecotonal vegetation of cerrado/seasonal semideciduous forest. Only a few sites, many of which were affected by fire, showed the presence of the same physiognomies as indicated on the maps.

After visiting 86 areas we concluded that the differences between the physiognomies shown in the maps (Kronka *et al.*, 1993) and in the field in 2000 reflected natural changes which had occurred since 1984. This represented a continuation of the thickening of the arboreal vegetation since the original survey of 1962, with the aerial photographic study of 1984 showing an intermediate stage. A survey in Assis, São Paulo State (SP) (Durigan *et al.*, 1987) demonstrated the same process, with cerradão increasing in 22 years from 12.0 to 41.4% of an area of 180 ha. The changes in this area from 1962 to 2003 are shown in Fig. 2. Other workers have also noticed similar rapid changes, e.g. Ratter, within 14 years in the Federal District (Ratter, 1992), and probably within 19–35 years at Angatuba, SP (Ratter *et al.*, 1988), and over 30 years at Emas, SP (Goodland & Ferri, 1979). Such changes are also confirmed by anecdotal evidence of local long-term cerrado residents.

We believe that the main causative factor for these recent changes in the physiognomy of the remaining cerrado fragments in western São Paulo State is reduced disturbance and particularly the suppression of fires. We found evidence of frequent fires in less than 9% of the 86 areas visited in 2000 and no evidence of fires at all in 79%.

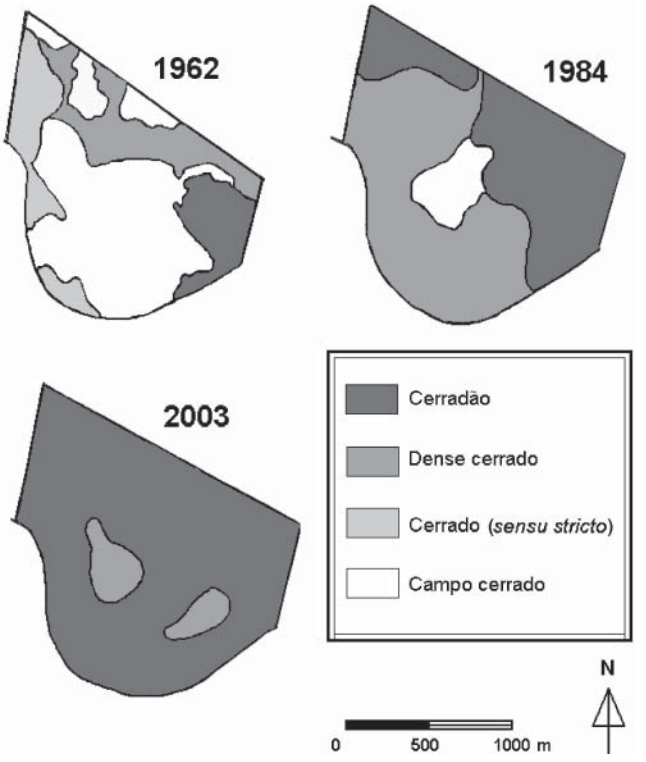

FIG. 2. Changes in the cerrado physiognomy in a 180 ha area of cerrado vegetation protected from fire at Assis State Forest, São Paulo State, Brazil (adapted from Durigan, 2006).

CHANGES IN FLORISTIC COMPOSITION OF CERRADO FRAGMENTS

The changes in physiognomy are accompanied by a succession in floristic composition. Unfortunately, no long-term studies on the dynamics of floristic changes in cerrado vegetation are available for comparison. However, results from studies in ecotonal communities, field notes and observations show that populations of heliophyte non-arboreal species (e.g. *Anacardium humile* A.St.-Hil., *Andira humilis* Mart. ex Benth., *Anemopaegma arvense* (Vell.) Stellfeld ex de Souza, *Campomanesia adamantium* (Cambess.) O.Berg., *Erythroxylum campestre* A.St.-Hil., *Peritassa campestris* (Cambess.) A.C.Sm.) have decreased or disappeared in some areas. Such species can regenerate only in large gaps or on the borders of cerradão or ecotonal vegetation. On the other hand, species that are shade tolerant during establishment (e.g. *Copaifera langsdorffii* Desf., *Mabea fistulifera* Mart., *Myrcia multiflora* (Lam.) DC., *Ocotea corymbosa* (Meisn.) Mez, *Pera obovata* Baill., *Protium heptaphyllum* (Aubl.) Marchand) tend to increase and become dominant in ecotonal areas.

Forest species seem to appear or become abundant only in sites where edaphic conditions are favourable. Under cerradão protected against fire for a long time,

nutrients from litterfall can considerably improve soil fertility in the upper layers and some understorey forest trees can then establish without exposing their roots to the high aluminium toxicity in the deepest soil layers (Durigan & Leitão Filho, 1995).

Dynamics of the transition

Natural and anthropogenically induced changes in climate, nutrient availability, fire regime and herbivory can change the borders between tropical savannas and other types of vegetation, as pointed out by Solbrig *et al.* (1996) based on the transition between Brazilian cerrado and tropical forest. The changes in physiognomies and floristic composition reported here in the transitional cerrado/forest vegetation in western São Paulo State are by no means necessarily permanent. Under renewed disturbances, these processes can be reversed. When exposed to fire or clear-cutting, cerrado vegetation reverts to more open forms and shade-tolerant cerradão or forest species decrease in importance or can even be eliminated from the community.

The question of further cerradão and forest expansion

Vegetation changes bringing about expansion of forest into cerrado areas and vice-versa linked to the occurrence of interglacial and glacial periods in temperate regions have occurred many times during the Quaternary. Climatic evidence and field observations indicate that at present we should be in a period of rapid forest expansion if it were not for anthropogenic factors such as fire, cattle-grazing, etc. A number of workers have speculated that before the advent of frequent man-made fires the denser forest forms of cerrado (i.e. cerradão) were more common and occupied a much larger area than they do today (Warming, 1892; Eiten, 1972; Rizzini, 1979; Furley & Ratter, 1988). The evidence from studies of changes in the remaining cerrado of São Paulo State clearly indicates that, with continued protection of natural vegetation, the succession will move towards a climax where more open forms of cerrado will be restricted to a few areas and forest species dominate in sites occupied by cerrado today – a process that has already occurred in the majority of the areas. Whether the climax will be the same as that which existed before humans started using fire as a tool in South America, or will differ as a result of global climatic changes or other processes, is impossible to predict. However, in some places with a high degree of protection against fire open forms of cerrado vegetation still appear to be the climax vegetation, as observed in some areas at Angatuba (São Paulo State) and other cerrado sites in the Federal District (Ratter *et al.*, 1988; Ratter, 1992).

Further thoughts

Attention has focused on the occurrence of rapid successional changes in the small areas of surviving cerrado vegetation as a result of the studies of the recent project

Conservation feasibility of cerrado remnants in São Paulo State. Such changes are of profound importance when considering how to conserve a highly endangered biome, and understanding the dynamic processes involved is essential. It is not simply sufficient to fence off and protect representative areas from all human influence: if we do so the environmental balance will be disturbed and the ecosystem will certainly change. The following items and priorities are suggested as important for consideration and implementation.

Some items for consideration

- Since cerrado vegetation has been subject to fires for such a long time that its native species are not only tolerant of, but sometimes dependent on them (Coutinho, 1990), is the total suppression of fires recommended?
- Since more open cerrado physiognomies are a specific habitat for a number of endemic plant and animal species, rapid changes induced by suppression of fires can lead to local extinction. Should use of fire therefore be recommended as a management tool for biodiversity conservation?
- At present emphasis is being placed on establishing conservation priorities for specific biomes. This is excellent, but urgency must also be given to protect ecotonal areas as they are an important genetic resource.
- The dynamics of forest and cerrado vegetation in São Paulo State has been strongly affected by fragmentation: a large continuous gene-pool has been isolated into little disjunct puddles! The maintenance of corridors in newly deforested areas and the re-establishment of them between already isolated areas could be an important way of reducing this problem.

Suggested research priorities

- Palaeoecological and palynological studies in transitional regions, to determine if and when current forest areas were covered by cerrado vegetation and vice-versa.
- Long-term community studies, using permanent plots, to characterize the dynamics of the cerrado/forest transition.
- Exchange plantings (cerrado species in forest soils and vice-versa) in relevant sites in the transition zone, to determine whether occurrence of species is limited by environmental factors, such as soil, or is more flexible and an issue of anthropic pressure and/or natural succession.
- Establishment of mixed plantings of cerrado and forest species in soil conditions characteristic of the two habitats and their transition, to determine the type of competition occurring.
- Establishment of trial corridors between isolated cerrado fragments (this would also be very useful in discovering suitable species to use in restoration plantings).
- Experimental burning and clear-cutting of ecotonal vegetation in permanent plots to determine degree of fire-resistance, power of coppice-regeneration, and the reversibility of forest expansion.

- Studies to determine the correct burning frequencies required to conserve areas of the various cerrado physiognomies (e.g. campo cerrado, cerrado (*sensu stricto*), etc.). If possible, the information derived might be used to maintain a range of physiognomies in the same conservation area and thus conserve maximum levels of biodiversity.

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