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Sustainable Forest Management of Native Vegetation Remnants in Brazil

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1. Introduction

A region's species diversity is an important factor, resulting as a component of social and economical development when used wisely. The correct commercialization of a region's natural resources guaranties the preservation of local culture and habitat maintenance by means of the obtained income. Hence, the idea of sustainability arises, a widespread theoretical theme which is beginning to gain force in Brazil's consumer market.

The principal conceptual shift was the erroneous notion that timber resources from forests are inexhaustible, since the processes of recomposition/restoration naturally occur after exploration. Indeed a system is capable of regeneration, but this is tied to a series of factors that are usually not respected in areas illegally explored. According to a conference realized in Melbourne by Raison et al. (2001), the concept of sustainability must encompass social and economic conditions such as: respect the forest growth rate; legislation based control; productive capacity; ecosystem's health and vitality; soil and water resource protection; carbon balance and preservation of biological diversity.

Under this scenario, Brazil presents great potential for the use of its natural resources. This is due to the country's vast territorial extension (8.5 million km^2) and high diversity of recurrent vegetation physiognomies. The country possesses about 5.2 million km^2 of forest land (60% of its territory), of this total, 98.7% consists of natural forest formation and 1.3% of planted forests. The forest types found in Brazil can be classified as Cerrado (Brazilian savanna), Amazônia (tropical rainforest), Mata Atlântica (Atlantic rainforest), Pantanal (wetlands) and Caatinga (semi-arid forest) as well of transition areas which promotes a mixture of habitats. In many cases, the deforestation of these environments is associated with illegal logging practices coupled with agriculture and cattle-raising. The damage caused by this include modifications of the carbon cycle and consequential rise of CO_2 emissions; forest fragmentation; alteration of the hydraulic cycle; species extinction; rural exodus and loss of local fauna and flora diversity.

Possibly the most logical use of these forests is the application of sustainable forest management for wood production destined for fire wood, charcoal and logs for industrial purposes. The motives for this strategy are evident, involving aspects attached to the reduction

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of environmental impacts during exploration; preservation of areas not economically productive; adequacy to local productive capacity by the quantification of present available stock; reduction of costs and rise of income; achievement of continued production; market expansion through forest certification; compliance of current laws; creation of employment opportunities and most importantly to legalize the activity. Forest management can be understood as the administration of a forest resource by a set of principals, techniques and norms. Its objective is to organize the actions necessary to determine production factors and to control its efficiency and productivity in order to reach pre determined objectives. According to Blaser et al. (2011) in International Tropical Timber Organization (ITTO) Brazil has presented great advance in the sustainable management of natural forests, expanding the areas subject to these practices as have other countries such as Peru, Malaysia, Gabon and Guiana.

A few explications that account for this expansion are: enhancement of technologies used for forest monitoring; improvement of administration systems; forest certification and stricter demands from consumer markets concerning timber origin.

Amaral and Neto (2005) comment that sustainable forest management has conquered increasing space as an alternative for Latin Americas' rural communities, driven by governments, donors, NGOs and community organizations. According to the authors, the main problems encountered in the implementation of forest management in the Amazon are: (a) establishment of mechanisms for land regularization; (b) strengthening of local social organization; (c) credit access; (d) forestry technical assistance and (e) the need for market access mechanisms. These problems can easily be extrapolated to the other physiognomies besides the Amazon in Brazil.

Law 11.284/2006 drafted by the Brazilian Government regulates forests management in public areas; creates the Brazilian Forest Service (SFB) as the regulator agency of public forest management and at the same time the promoter of forestry development; creates the National Forest Development Fund to promote technological development, technical assistance and incentives for the development of the forestry sector. The law also defines three types of management: (a) Conservation units for forestry production; (b) Community Use and (c) Paid forest concessions in Conservation Units of Sustainable Use and in public forests. Forest concession in Brazil is still a new experience.

A sustainable cutting plan is only feasible when it respects the time needed to close the exploration cycle, i.e. the time it takes the forest to grow biomass to equal before harvest levels. The amount of biomass required determines the duration of the cycle, since it depends on the forest growth rate. Thus, an increased growth rate through silvicultural treatments promotes shorter cutting cycles, and consequently a lower demand of forest area, reducing impacts on other forest areas. For example, the cutting cycle (polycyclic) in the Amazon can be 30 years long considering a selective exploration of marketable species, removing a maximum of 30 m^3/ha (IBAMA, 2007), which could represents up to 5 trees/ha (Putz et al., 2008). The determination of the cycle duration depends on the forest type and its growth rate (Braz, 2010), this information is presented in the Brazilian legislation.

2. Case studies

2.1 Savanna (Cerrado)

Cerrado is an important Brazilian biome present in the central area of Brazil (Figure 1), formed by a high number of endemic flora and fauna species, and considered a world biodiversity hotspot. According to IBAMA (2010), the biome presents more than 10,000

species of plants, 837 species of birds, 67 genera of mammals, 150 species of amphibians and 120 reptile species, of which 45 are endemic.

It is estimated that the Cerrado biome occupies an area of 203 million hectares, with about 66.4 million hectares remaining, with a population of 29 million inhabitants (SFB, 2010). The vast majority of the population lives in urban areas, the other fraction in rural areas, whose main activity is agriculture (soy, rice, wheat and livestock). Reforestations of *Eucalyptus* spp. can be found, intended for the production of coal, pulp, sawn wood among other uses.

The Brazilian Cerrado's colonization process was stimulated by the government, starting from the 60's, where the development of intensive agriculture, mineral production and extraction of native vegetation was encouraged. This process was made possible by the construction of new highways. During this period, the Cerrado became target of deforestations and fires, being gradually replaced for other uses, and in more extreme cases, areas were abandoned after intense degradation. For example from 2002 to 2008 the deforestation area was 85,074 km² (SFB, 2010).



Fig. 1. Spatial distribution of the Cerrado biome in Brazil (IBGE, 2004).

Despite the great interest in the use of these environments for farming, Cerrado's soil has high acidity (aluminum saturation) and low chemical fertility (phosphorus, potassium, calcium and magnesium), with average annual rainfall of 1500 mm (ranging from 750 mm to 2000 mm) and of concentrated nature. The average annual temperature fluctuates between 21ºC to 25 ºC. However, due to its flat topography, its lands became valuable since low

water deficits in dry periods and low fertility can be controlled through modern technology. The biome's zone of occupation presents an intense river network, which contributes to the formation of the main Brazilian rivers, such as the São Francisco, Amazon, Tocantins, Paraná and Paraguay rivers. The water produced is used for human consumption, industrial ends, agricultural and electric power generation.

The Cerrado interacts with other types of Brazilian biomes, such as the Amazon rainforest, Atlantic forest, the Pantanal and Caatinga, creating diverse ecotones. However, the Cerrado has unique and peculiar features. In general terms it can be considered a transition between forests and grasslands, presenting gradual reductions in biomass and arboreal/shrub density in the landscape, possessing plants with deep root systems as a survival strategy in times of drought. In addition, it features a grass cover that receives a high intensity of light, depending on the arboreal/shrub density of each location.

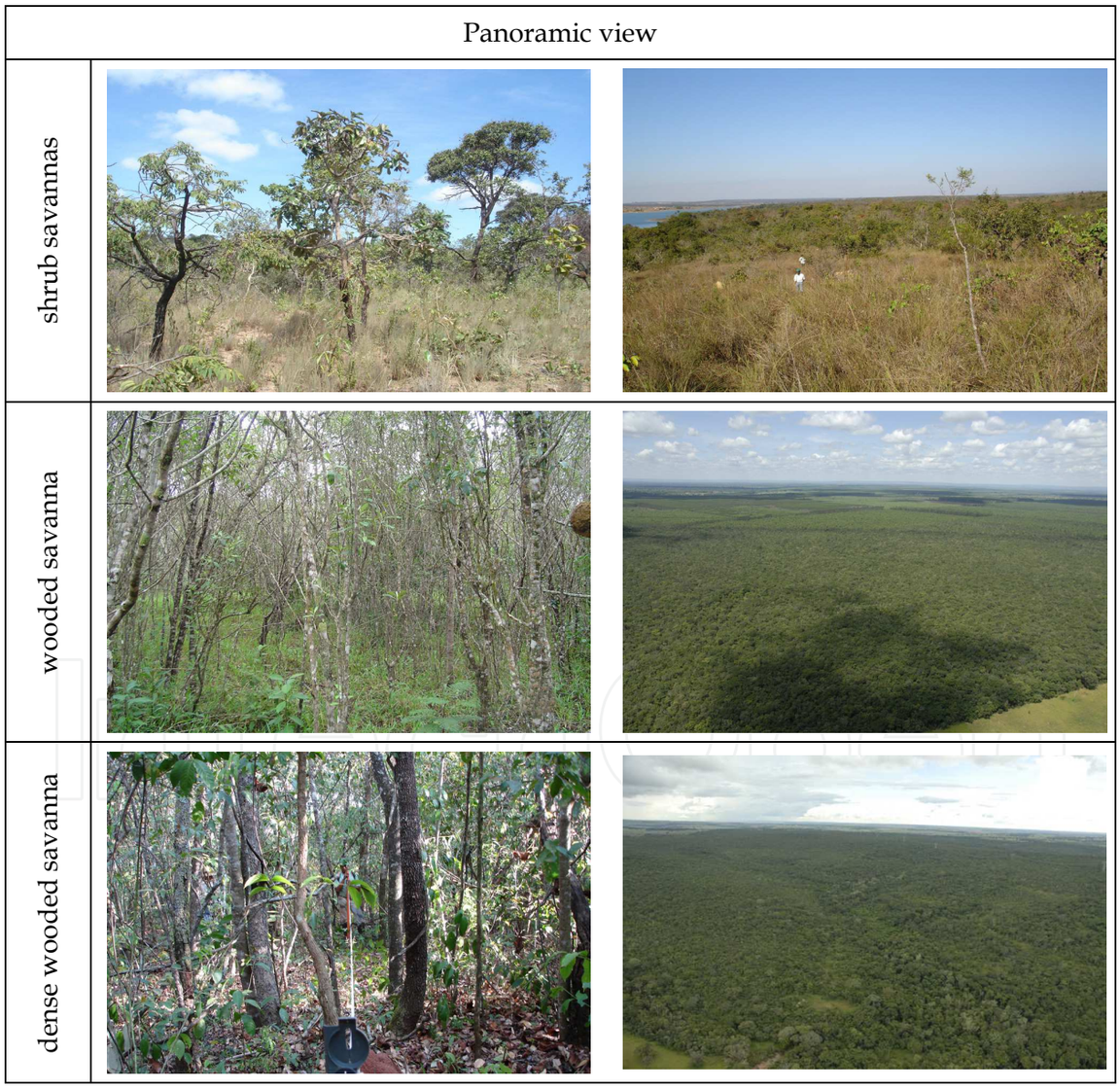


Fig. 2. Examples of the variation amongst physiognomic types existent in the Cerrado in relation to tree size and density.

The vegetation's structure and size are determined by variations in soil type, climate, altitude, hydrology, anthropic actions and natural impacts such as forest fires. As a result the vegetation presents physiognomies varying from forest formations to grasslands. The forest formations are represented by the Cerradão (dense wooded savanna), Mata seca (semi-arid savanna) and Mata ciliar (riparian forest). The intermediate formations are predominantly Cerrado *Sensu Stricto* (wooded savanna), Veredas, Palmeiral (Palm forests) and Parque Cerrado (parkland). The grassland formations are composed of campo sujo, campo limpo (shrub savannas) and campo rupestre (rupestrian fields). These vegetation types are listed in the same order of biomass reduction. An illustrative example of the existing variations can be seen in Figure 2 and Table 1 presents a quantitative overview of stand characteristics for different Cerrado types. According to Scolforo et al. (2008a), the following species can be classified as the most recurrent in the Minas Gerais cerrado biome: *Astronium fraxinifolium* Schott ex Spreng.; *Caryocar brasiliense* Cambess.; *Copaifera langsdorffii* Desf.; *Qualea grandiflora* Mart.; *Qualea multiflora* Mart. and *Roupala montana* Aubl.

Due to the structural characteristics of native Cerrado trees, timber production is basically converted into charcoal, whose purpose is to supply steel and construction companies in an indirect way. According to statistics of the forestry sector, approximately 50% of the charcoal used in the Brazilian market comes from native areas, where a fraction of the production is the result of illegal deforestation. In the 80's the amount of charcoal from native areas was 85% (AMS, 2007). According to the Brazilian Silviculture Society - SBS (2008), in 2007 the Brazilian charcoal consumption of native origin was 11.88 million tons. On the other hand, the multiple use of the Cerrado can be stimulated, in view of the possibility of production of resins, barks, seeds, flowers, fruits and handicrafts, contributing to the maintenance of the biome.

Stand characteristics	Cerrado types		
	shrub savannas	Wooded savanna	Dense wooded savanna
Number of areas inventoried	5.0	57.0	5.0
Quadratic mean diameter (cm)	11.2	10.2	12.0
Mean height (m)	4.3	5.1	7.4
Average tree number (N/ha)	370.4	1168.9	1626.8
Basal area (m^2/ha)	3.5	9.4	18.3
Aboveground wood volume (m^3/ha)	17.7	48.5	129.0
Aboveground carbon stock (t/ha)	5.0	14.3	35.1

Table 1. Stand characteristics for different cerrado types in Minas Gerais State, where the data is provided for trees with DBH greater or equal to 5cm (Scolforo et al., 2008a).

2.1.1 Sustainable forest management of the Cerrado

In recent decades Brazil has structured and regulated the forestry sector, with the primary purpose of supplying the country's domestic needs, and subsequently the foreign market. This period was marked by government tax incentives and stimulus to reforestation. Strategic planning allowed for market advancement and expansion, driving the development of technologies to replace native wood consumption.

The era of large *Pinus* spp. and *Eucalyptus* spp. reforestation allowed for the gradual substitution of native wood use, contributing to the protection and preservation of remaining natural areas. Even with the decreased wood use from native forests, the Cerrado vegetation is still being exploited, due to low costs of wood produced. According the Brazilian Forest Service - SFB (2010) the total wood volume in the Cerrado is 870 million m^3, with an above-ground biomass of 496 million tonnes. Starting from this available stock it is necessary to draw plans and rules for its exploration, define the optimum cutting cycle without causing negative impacts to local biodiversity, and at the same time promote the increase of biomass.

In the past, and still nowadays in some regions, there were not any technical or scientific procedures to apply the efficient management of this vegetation, where the land owner established the traditional process that combined fire and deforestation for conversion into agricultural areas across the landscape (land use change).

The knowledge of the optimum cutting cycle is a predominant factor for the administration of these forests. Through its determination a detailed and exact management plan can be prepared, informing the ideal level of wood removal to ensure sustainability over time. Allied to this information, the knowledge of floristic composition correlated with environmental and spatial factors enables a holistic understanding of the system, contributing to the development of new silvicultural techniques and exploration criteria.

Forest management seems to be a good alternative in combating rampant deforestation, contributing to the reduction of native vegetation conversion in to grasslands, agriculture and degraded areas. The activities to be considered in a sustainable management should include: available forest resource inventory with a characterization of its structure and forest site; identification, analysis and minimization of environmental impacts; study of technical, economical and social viability of the project; adoption of forestry exploration procedures that minimize ecosystem damage; checking if the remaining stock is sufficient to ensure sustained production; and the adoption of an appropriate post exploration silvicultural system.

The sustainable forest management of the Cerrado case study is part of a set of experiments and research developed by the Federal University of Lavras and its Forest Science Department, dating back from the 80's until the present. The studies were conducted in the Minas Gerais State with reference to the works of Lima (1997), Mello (1999), Mendonça (2000), Oliveira (2002), Oliveira (2006a), Oliveira (2006b), and Scolforo et al. (2008a).

The main issue in vegetation management is the degree of exploration or cutting intensity to be applied, because the lack of this information leads to losses to the environment. Thus, a study was conducted in a Cerrado *Sensu Stricto* in the State of Minas Gerais (municipality of Coração de Jesus). Six intensities of basal area removal (0%, 50%, 70%, 80%, 90% and 100%) were tested and subsequent evaluation in 1986 (year of implementation of the experiment), 1996, 1998 and 2004. The experiment was installed in an area of 30 ha being applied 6 treatments/removal criteria and 5 repetitions per treatment, with sample plots of $600m^2$. The individuals were identified botanically, and the criteria for measurement was a circumference at breast height (CBH) ≥ 15.7 cm. The purpose of the study was to verify the influence of the cutting intensity in recovery time of number of individuals, volume and basal area, as well as the behavior of the tree species diversity. Due to initial variation between treatments (1986), a correction factor was applied permitting comparison of the results in different periods. The results can be seen in Table 2. A gradual increase in the number of individuals occurred in all treatments after exploration. This fact was expected since Cerrado plants feature a great sprouting capacity, as noted in the works of Ferri (1960), Rizzini (1971), Thibau (1982), Toledo Filho (1988), among others.

Removals in basal area of 70% and 100% presented higher plant density in relation to the control treatment 12 years after intervention, for the other treatments this occurred after 18 years. The response in tree numbers suggests the mentioned cutting cycles ages. In contrast, basal area growth assumes a different behavior from the previous variable because it depends on the development capacity of each species. Thus, up to 1998 there was an accentuated basal area increase of all removal intensities, with variation ranging from 43.05% (80%) up to 90.62% (100%), surpassing the values presented before intervention. The control treatment presented the largest increase, followed by the clear cutting. However 18 years after installation of the experiment (in 2004), clear cutting (14.75 m^2/ha) surpassed the control treatment (12.91 m^2/ha). This demonstrates the great recovery capacity of the Cerrado after its structure has suffered intervention. Volume behaved in a manner similar to basal area. As far as a constant wood volume production is concerned, the results show that for 100% removal of basal area a silvicultural cutting cycle of 12-16 years allows the Cerrado to return to pre-intervention basal area and volume values in the studied area. In the Cerrado, stump and root sprouts are responsible for the larger part of the natural regeneration, when compared to seed rain dispersal (Durigan, 2005). This way, after exploration it is expected that the plants sprout followed by diameter growth, and then migrate to higher diameter classes.

Variable	Year	Treatments (basal area removal %)					
		0	**50**	**70**	**80**	**90**	**100**
Number of trees/ha	1986	1716	1716	1716	1716	1716	1716
	1996	1933 b B	1520 a A	1769 a A	1707 a A	1655 a A	2155 c A
	%	12.65	-11.43	3.09	-0.53	-3.58	25.56
	1998	1993 a B	1803 a B	2007 a B	1976 a B	1915 a B	2477 b B
	%	16.14	5.07	16.98	15.15	11.61	44.35
	2004	1820 a A	1832 a B	2044 b B	2011 b B	1853 a A	2550 c B
	%	6.06	6.76	19.11	17.17	7.97	48.62
Basal area (m^2/ha)	1986	6.72	6.72	6.72	6.72	6.72	6.72
	1996	12.94 c A	9.85 b A	9.66 b A	8.07 a A	8.15 a A	10.72 b A
	%	92.56	46.63	43.8	20.1	21.33	59.49
	1998	13.43 b A	11.01 a A	10.32 a A	9.61 a B	9.71 a B	12.81 b B
	%	99.85	63.9	53.6	43.05	44.48	90.62
	2004	12.91 b A	12.03 b B	11.26 a B	10.7 a C	10.94 a C	14.75 c C
	%	92.09	78.97	67.56	59.22	62.85	119.51
Volume (m^3/ha)	1986	21.61	21.61	21.61	21.61	21.61	21.61
	1996	44.64 c A	33.52 b A	32.81 b A	26.79 a A	27.1 a A	36.71 b A
	%	106.05	55.1	51.81	23.95	25.41	69.86
	1998	46.32 c A	37.79 b B	35.25 a A	32.62 a B	32.98 a B	44.18 b B
	%	114.34	74.87	63.13	50.94	52.6	104.44
	2004	44.53 b A	41.43 a B	38.68 a B	36.64 a B	37.54 a C	50.75 b C
	%	106.03	91.71	79	69.56	73.68	134.82

Table 2. Number of trees, basal area and volume per hectare in the different measurement dates (1986, 1996, 1998 e 2004). Equal letters in the same column (capital) or line (lower case) indicate that the values are equal, according to the Scott-Knott means grouping test at a 95% confidence level.

An economical analysis was carried out to verify the viability of the removal intensities in relation to cutting cycles studied. The method used was the Net Present Value (NPV) considering an infinite planning horizon. Thus, a greater NPV indicates a more lucrative project. Wood production costs were based on the year 2005 (USD 1.00 = R$2.165), being calculated by hectare of forest, and included depreciation costs (structures, machines, equipments and tools), administration, taxes, social charges, labor costs, alimentation, personal transport, among others. An annual discount rate of 6% was used. The future cycles' productivity was estimated through a Markov chain type prognosis system (OLIVEIRA, 2006a). Table 3 presents NPV results considering cutting cycles of 10, 12 and 18 years.

Basal area reduction	Cutting cycle		
	10	12	18
50%	-19.62	-26.72	-55.45
70%	20.04	2.15	-38.12
80%	10.23	9.22	-32.02
90%	29.16	27.12	-19.85
100%	107.88	99.53	26.39

Table 3. Net present value (US$/ha) per treatment for cutting cycles of 10, 12 and 18 years.

The smallest economic viability was obtained by removing 50% basal area and the largest in 100% removal, where longer cutting cycles (12, 16 and 18 years) made the lower intensities of basal area removal become unviable. Despite the inviability of certain treatments, charcoal prices suffer great fluctuation in short periods of time, which may make them economically viable. This variation must be closely analyzed, since a price increase in the end product can elevate the number of projects that are economically viable.

A high floristic diversity exists in the study area, with Shannon index values ranging from 3.13 to 3.23. The diversity between treatments was very similar, and the small differences found are perfectly normal in a biological system. These high values indicate that the sprouting levels are sustainable for the maintenance of local tree species diversity of the trees stratum. In summary, the family Fabaceae presented the largest number of species in the six treatments. The family Vochysiaceae presented the largest number of individuals in all treatments. The species *Qualea grandiflora*, *Qualea parviflora*, *Eugenia dysinterica*, *Qualea multiflora*, *Eriotheca pubescens*, *Magonia pubescens*, *Platymenia reticulata*, *Hymenaea stigonocarpa*, *Dimorphandra mollis*, *Caryocar brasiliense*, *Annona crassifolia*, *Buchevania tomentosa*, *Tabebuia ochracea*, *Aspidosperma macrocarpum*, *Sclerolobium aureum*, *Astronium fraxinifolium*, *Bowdichia virgilioides*, *Annona crassifolia*, *Acosmium subelegans*, *Hyptidendron cana* and *Maclinea clausseniana* are those which easily regenerate naturally, possess high basal area and are present in the lower, middle and upper stratum of the Cerrado. These characteristics indicate that these species present potential to be managed.

Figure 3 shows the cluster analysis considering a floristic matrix that included all basal area removal treatments. According to the dendrogram there is a high connection between most of treatments by 25% cut level, which basically formed 3 floristic groups. The major cluster grouped 0% and 100% basal area removal for all survey periods (1996, 1998 and 2004), which suggest a lower risk of tree species loss up to 2004. Similar tendencies were obtained

by Souza et al. (2011) who related the impact of forest management in a Cerrado. The authors demonstrated that the floristic diversity increased over the years in all areas subject to vegetation removal, and did not differ statistically. They also concluded that eleven years after intervention, tree diversity change occurred in all treatments, inclusively in the unmanaged control treatment.

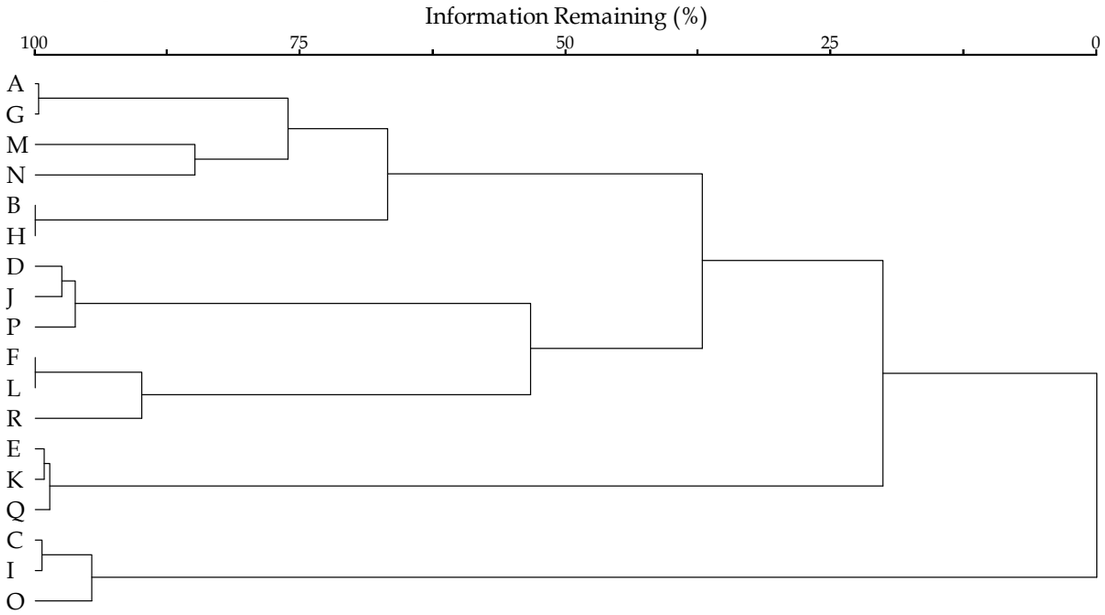


Fig. 3. Floristic dendrogram considering all treatments of percentage basal area removal and measurement dates, where: A - 0% (1996); B - 50% (1996); C - 70% (1996); D - 80% (1996); E - 90% (1996); F - 100% (1996); G - 0% (1998); H - 50% (1998); I - 70% (1998); J - 80% (1998); K - 90% (1998); L - 100% (1998); M - 0% (2004); N - 50% (2004); O - 70% (2004); P - 80% (2004); Q - 90% (2004) and R - 100% (2004).

The detreded correspondence analysis (DCA) was applied to support the discussions and interpretation of floristic recovery after intervention in 1986. The DCA was developed by Hill & Gauch (1980) being a multivariate method that contributes to analyze the connection among environment, species and other variables. Following the graphic result (Figure 4) the treatments 0% and 100% basal area removal are still close (dotted line circle), which suggest no significant loss of tree species after 1986. The rapid regeneration (sprouting) after cutting was observed and desirable for establishing the recovery of the physiognomy.

Considering only the tree stratum, it was noted in all treatments that 12 years after intervention the remaining vegetation presented diversity indexes similar to those found in Cerrado vegetation in other regions of Brazil not subject to intervention. According to Scolforo et al. (2008a) Minas Gerais state possesses potential for the sustainable timber management of the Cerrado, mainly in the North/North-West as shown in Figure 5.

Currently, the recommended option for sustainable management of the Cerrado is the clear cutting in strips, which consists in removing 100% of individuals (excepting tree species prohibited by legislation), realized in a maximum of 50% of the area destined for exploration (Figure 6). The explored and unexplored strips must be alternated, where the unexplored strips must have greater or equal dimensions in relation to the explored strips. The objective is to allocate a greater protection of the environment by preventing its degradation, as well

as the possibility of seed dispersal in the explored area, therefore helping to promote natural regeneration, which as stated earlier is achieved primarily by sprouting.

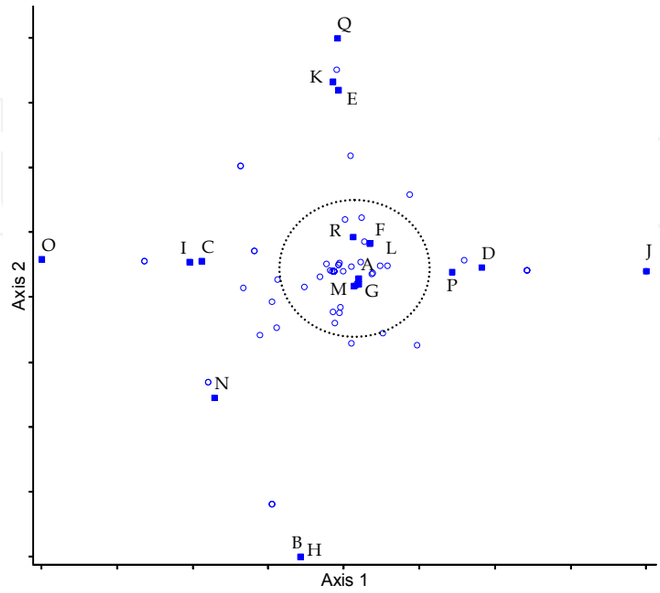


Fig. 4. The DCA analysis considering all treatments of percentage basal area removal and measurement dates, where: A - 0% (1996); B - 50% (1996); C - 70% (1996); D - 80% (1996); E - 90% (1996); F - 100% (1996); G - 0% (1998); H - 50% (1998); I - 70% (1998); J - 80% (1998); K - 90% (1998); L - 100% (1998); M - 0% (2004); N - 50% (2004); O - 70% (2004); P - 80% (2004); Q - 90% (2004) and R - 100% (2004). The blue squares represent the treatments and the open blue circles are the species.

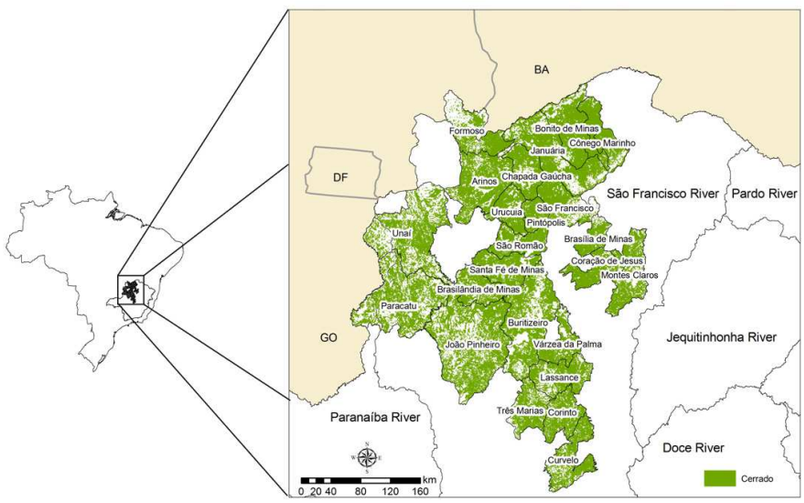


Fig. 5. Minas Gerais State's regions with potential for the application of sustainable forest management of the Cerrado.

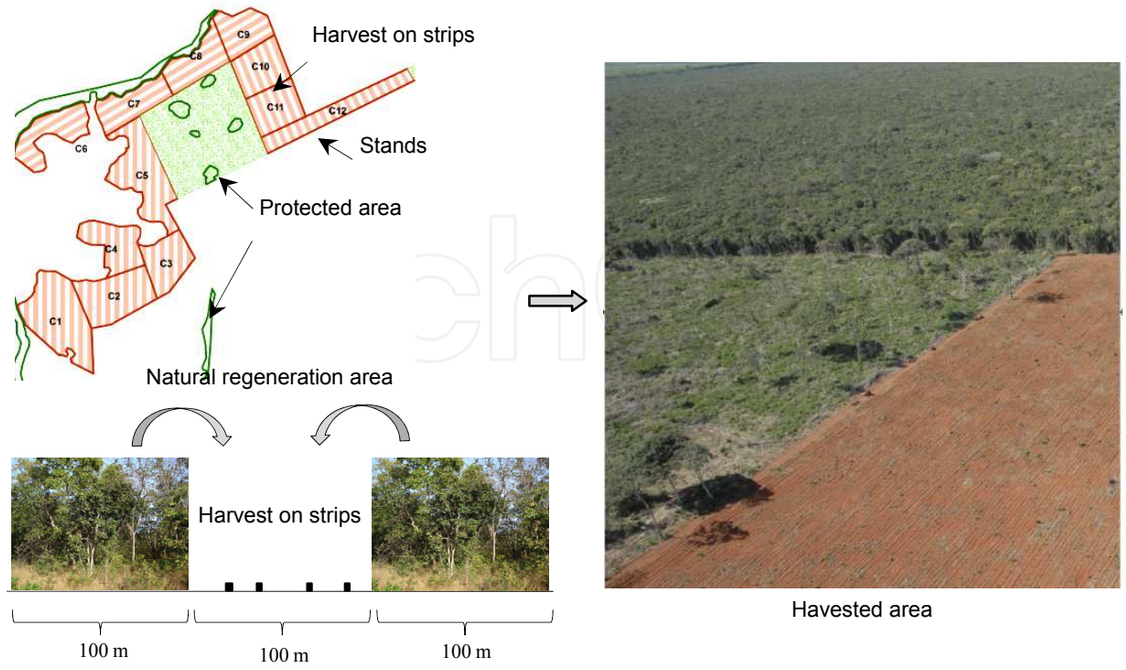


Fig. 6. Clear cutting in alternate strips scheme applied in the Brazilian Cerrado (Scolforo et al., 2008a).

The joint analysis of these studies show that the exploration of the Cerrado can be economically viable, being mainly dependent on the level of intervention, cutting cycle, productivity, land costs and market variables. The studies related here were focused in the tree stratum of the forests and as such consist of preliminary studies of the sustainability of cerrado management. Further studies on how forest management affects the fauna and other aspects of the flora (e.g. trees with DBH smaller than 5cm and herbaceous stratum) are required to provide more information on the impacts of forest management on the Cerrado. Multiple use of the Cerrado is an option, such as the already marketed species of *Dimorphandra mollis* (favela), used in the pharmaceutical industry, and the food products derived from pequi (*Caryocar brasiliensis*) and baru (*Dipteryx alata*).

2.2 Candeia tree

Formation processes of an environment over thousands of years gradually promote species selection, encouraging the development of strategic mechanisms to overcome the difficulties imposed by each habitat. The spatial distribution of species in a landscape presents a selective character, which added to between species competition, directs the occurrence and dynamics of a forest. As such, candeia (*Eremanthus* spp) predominantly occupies high altitude field areas, being quite recurrent in the State of Minas Gerais (Brazil), as shown in Figure 7.

Candeia is of the Asteraceae family, an ecotone species typical of transitional areas between wooded and grasslands. Even thought it presents several characteristics of pioneer species such as: production of large quantities of seeds, seeds dispersed by wind, high-density natural regeneration in open gaps, it must not be framed as such since its lifespan can exceed 50 years. There are several species of candeia, however *Eremanthus erythropappus*

(DC.) Macleish and *Eremanthus incanus* (Less.) Less are of greater economic importance and of higher occurrence in Minas Gerais. Candeia density ranges between 875 to 1536 trees per hectare (Scolforo et al., 2008b and Scolforo et al., 2008c), although values up to 50,000 trees per hectare (Andrade, 2009) have been reported for young candeia areas undergoing natural regeneration after exploration.

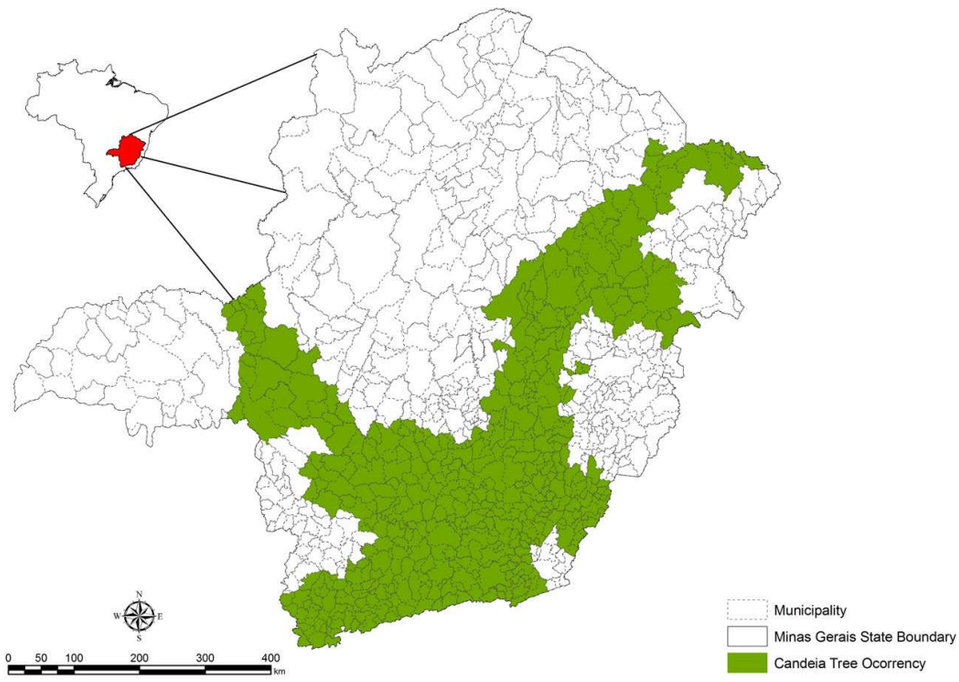


Fig. 7. Distribution map of candeia species in the State of Minas Gerais.

Eremanthus erythropappus develops predominantly in high altitude fields. Candeia is a monodominant species, such that is not uncommon to find small patches of forests formed exclusively by the species. An interesting feature of this species is its development in sites with shallow soils of low fertility. Its occurrence is heavily influenced by altitude, occurring 800 meters above sea level, where the highest abundances are found between 1,000 and 1,500 meters. Candeia develops in places where it would be difficult to employ agricultural crops or even other forest species.

Candeia possesses multiple uses, usually its wood is either used as fence posts due to its natural durability, or as a raw material from which essential oil is extracted. The essential oil's active ingredient is Alpha-bisabolol, employed in the manufacture of medicines and cosmetics such as creams, tanning lotions, sunscreens, vehicle for medicines, besides being used for prophylactic purposes and skin care of babies and adults, among others.

Native areas of candeia display decreasing diameter distribution, with trees typically reaching up to 32.5 cm. A candeia forest usually presents a average diameter of around 15 cm. However, individuals have been found that reached up to 62.5 cm. Average heights are between 6 and 7 meters. The height of the largest trees is around 9.5 to 10 meters, although an individual has been found with 16.5 meters, inside a semideciduous seasonal forest.

Candeia's trunk has thick bark presenting many fissures, newer branches have smoother bark. The characteristics of the leaves and inflorescence facilitate the identification of the

species even at a distance (Figure 8). The coloration of the wood is white or grayish with a darker cross grain. Its basic density averages 675 kilograms per cubic meter of wood.



Fig. 8. Example of a representative candeia individual and its floral structures (Andrade, 2008).

The candeia *Eremanthus incanus* (Less.) Less. is an arboreal species that when adult presents average height between 5 and 7 meters, average the diameters between 10 and 12 cm, where some individuals can reach up to 20 or 25 cm. Its stem is grayish-brown, with thick bark and few branches. It occurs between 550 and 1100 m altitude, in the Cerrado, in secondary forest or in the Caatinga. Its use is basically for the production of fence posts, since it has low productivity of Alpha-bisabolol oil.

2.2.1 Sustainable forest management

Exploration of candeia populations, in the form of sustainable forest management, is only authorized by the State's environmental agency for fragments with occurrence of at least 70% of individuals of the species *Eremanthus erythropappus* or *Eremanthus incanus*. This restriction is derived from the need for restoration of the area through natural regeneration, where areas with greater dominance of the species are more likely to recover and return to the initial stage. Beyond this point, the guarantee of the sustainability of these populations is correlated with the quality of the harvest project and compliance with the State's environmental laws.

Barreira (2005) studying the genetic diversity of candeia populations (*Eremanthus erythropappus*), in which she sought to quantify and compare the intra-population genetic variation and reproductive systems of candeia before and after exploration, noted that the species is suitable for management without loss in genetic diversity, as long as 100 individuals/ha are preserved as remnants. The study also showed a strong spatial genetic structure in the population, where trees in a 200 meters radius presenting some degree of kinship, with a 95% probability.

In addition to these efforts, the owner of the area under management must present a map of his farm containing the areas to be managed as well as the areas of Legal Reserve (20% of the total farmable land) and Permanent Preservation Areas (areas adjacent to waterways, with declivity greater than 45 º, hill tops and areas 1800 meters above sea level).

2.2.2 Evaluation of the legal viability of forest use

A forest inventory is the starting point to gain knowledge about a particular forest, in which a set of sample plots are distributed to quantify the variable of interest. In the case of legal viability studies of explored forests, a systematic sampling procedure is preferred with a minimal area of 600 square meters and maximum of 1000 square meters. Instead of a forest

inventory, another option is the conduction of a census, in which all the individuals above 5 cm diameter are counted, distributed in diameter classes with amplitude of 5 cm. The operation is performed with the use of a diameter fork, which speeds up the field operation obtaining the number of individuals/ha of candeia. Sustainable exploration is legality permitted only when more than 70% of individuals present in the forest fragment are composed of candeia. In more environmentally fragile areas only the census is allowed. Local volumetric quantification can be obtained by scaling and fitting regression models, or through specific equations already adjusted to various parts of the State.

2.2.3 Silvicultural systems

A balanced silvicultural system guides the harvest and post harvest operations, in order to ensure the restocking of the location in the shortest time possible. The concern with the correct manner to intervene in a forest must be predominant and must be considered and planned before the operation. The sustainability of the project depends on the efficiency of the remaining individuals' response, as well as the quality of the natural regeneration. Among the various silvicultural systems available for tropical forest management, only those that can be applied to the management of candeia are presented. They were defined based on scientific studies, including a) Clear cutting in strips system: applied in homogeneous candeia fragments with alternating strips each 20 m wide, following the isoline curves of the land; b) Seed tree with natural regeneration system: seed trees are retained in a maximum distance of 10 meters, where the retained trees must be phenotypically superior and with the greatest crown diameter possible; c) Group selection system: gaps are opened with a maximum diameter of 15 m, within these gaps a selective exploration of individuals is conducted, preserving all the border trees (IEF, 2007). Figure 9 presents a scheme containing the spatial distribution of exploration in a candeia fragment.

In the past, farmers used selective cutting as a form of exploration. This strategy is not in favor of pure candeia fragments, since natural regeneration depends on great luminous intensity. Therefore, the strategy undertaken was to increase the canopy gap between the remaining trees in the forest according to better results for the following silvicultural systems: clear cutting in strips system, seed tree with natural regeneration system and group selection system (Scolforo et al., 2008b). To guarantee a high intensity of natural regeneration the seeds must be in contact with the ground, receiving direct sunlight and rainwater. Dispersion occurs in the months of August through October and the seeds have no dormancy problems.

After the harvest, the remaining trees must have diameter at breast height equal to or superior than 5 cm. In the Group selection and Clear cutting in strips systems a maximum of 60% of the number of candeia trees are allowed to be explored, distributed in the different diametric classes. For the Seed tree with natural regeneration system the maximum is of 70%.

A peculiar point of the exploration process is the withdrawal of epiphytes (compulsory and optional) which may exist in the area. They must be quantified and transplanted to nearby areas as similar as possible to the area under management, with the purpose of preservation. After the removal of the woody material and immediately before seed dispersal of the remaining candeias that serve as seed trees (between the months of August and October), the area explored must receive silvicultural treatments with the purpose of promoting the germination of a large contingent of candeia seeds to ensure the sustainability of production and management (IEF, 2007).

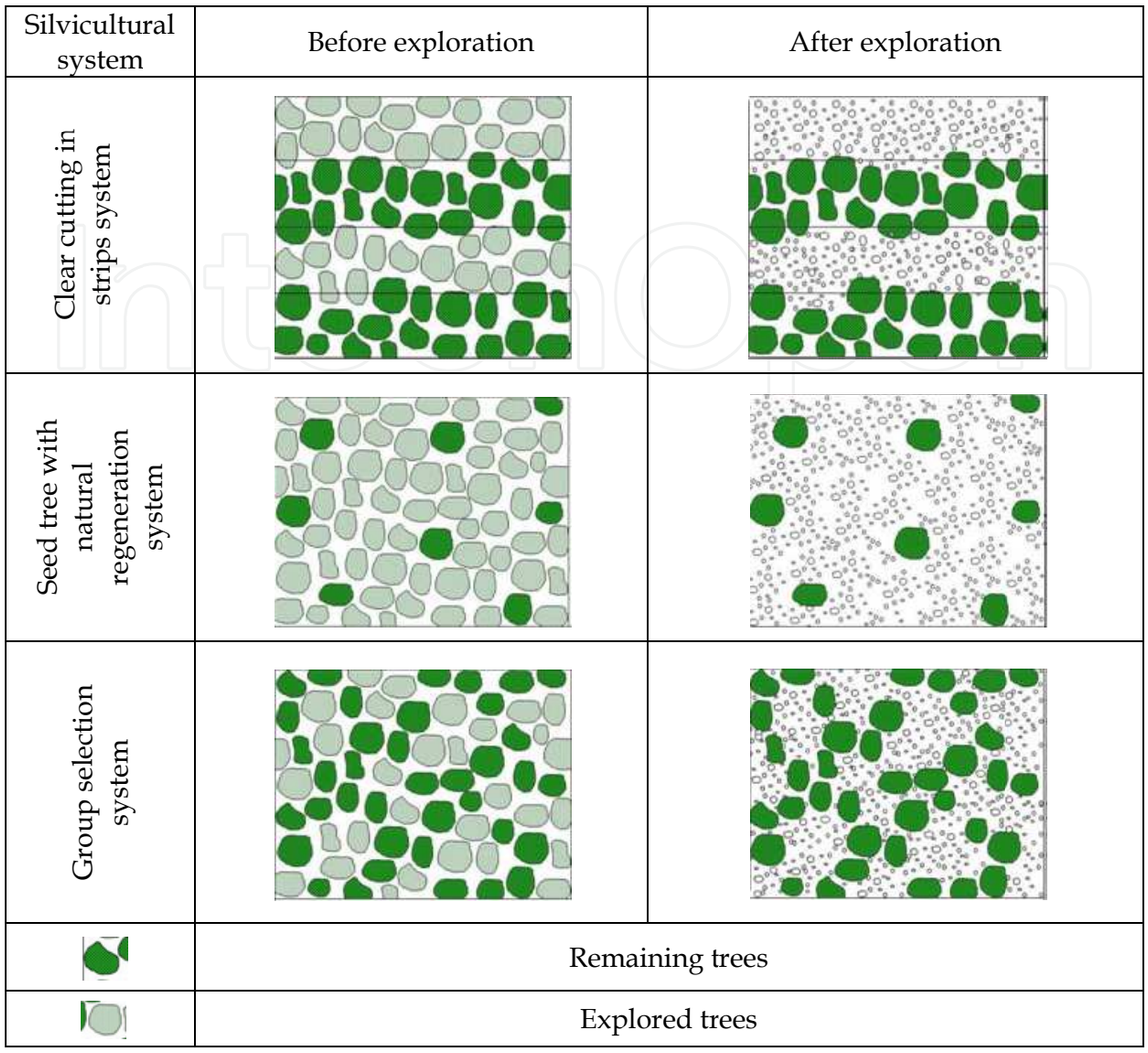


Fig. 9. Schematic representation of the silvicultural systems employed in the management of candeia fragments.

2.2.4 Exploration and natural regeneration

In most cases, the locations of candeia fragments are in montane regions of difficult access, usually with improper inclination for mechanization. The alternative adopted, and existent for centuries, is the withdrawal of the wood by mules to a nearby road (Figure 10). The opening of roads in the interior of the forest fragment is not recommended since it can cause erosion.

In the case of candeia (*Eremanthus erythropappus* or *Eremanthus incanus*), which colonizes areas through seed rains, a post exploration strategy is to conduct its natural regeneration, as shown in Figure 11. To this end it is necessary to evaluate its presence in the area that is being managed. If high intensity regeneration is present throughout the entire area, selective thinnings should be applied for competition reduction. However, if no natural regeneration in part of the area is detected or if its intensity is not satisfactory to promote the occupation of the site, other reforestation strategies must be adopted. This way, if the number of plants

is adequate or not is not only associated to the abundance of regeneration, but also to its distribution in the area. It is important to stress that any area subject to management must be protected from domestic animals and fire, this way not compromising the natural regeneration and consequently the sustained vegetation production over time.



Fig. 10. Wood removed from the forest fragment transported by mules.

(a) soon after exploration	(b) 6 months after exploration
	
(c) 24 months after exploration	(d) aerial view 24 months after exploration
	

Fig. 11. Implementation of the group selection system (a); candeia natural regeneration after 6 months (b) and 24 months after exploration (c); aerial view of the group selection system 24 months after exploration (d).

2.2.5 Post exploration conduction

A set of treatments are carried out to stimulate candeia's natural regeneration, guarantying environmental harmony and local restoration. The operations consist of withdraw only of candeia wood, i.e. not to interfere in non candeia woody vegetation that exists in the forest fragment. The practice is linked to revolving the ground in 5 to 10 cm depths. This procedure must be done in 60 cm diameter circles or in squares with 60 x 60

cm, distant about 2.5 meters of one another, without suppressing any other shrub or tree species. Therefore, their disposition may be irregular to meet this specificity of management (Figure 12).
Practices must be adopted in the conduction of natural regeneration to increase volumetric increment, involving the elimination of invasive species such as vines that may restrict the establishment of candeia, as well as thinning when competition is above the site's capacity. Typically this thinning should be performed when the larger plants present height of around 1 m.
So that there is no risk to the genetic diversity of candeia under management, for any of the systems implemented there should be a minimum number of seeds trees equivalent to at least 100 plants per hectare. In addition, it is mandatory that the managed areas be protected against the action of domestic animals and fire.



Fig. 12. Example of post exploration practices, soil scarification using a hoe.

For the evaluation of the regeneration of managed areas, Brazilian environmental agencies require Annual Technical Reports until the 3rd year after exploration, the transplanting of epiphytes and other components that characterize sustainable management.

2.2.6 Commercialized products and oil extraction

Diametric structure of a natural forest follows a negative exponential function, with a larger abundance of individuals in the smaller diameter classes. Regarding the average production of oil/stem diameter class the production is increased in larger classes, 4.042 kg for the trees between 30 and 35 cm in diameter, contrasting to 1.585 kg for trees between 5 and 10 cm in diameter. Nonetheless, the viability of exploration in smaller classes is achieved due to the large number of individuals (Pérez, 2001). The presence of oil in plants can be found in various parts (leaves, flowers, wood, branches, twigs, fruits, rhizomes), being composed of several chemical substances such as: alcohols, aldehydes, esters, phenols, terpenes and hydrocarbons. Due to the high presence of Alpha-bisabolol (on average 66.1% of its constitution) candeia's oil odor is very characteristic and unattractive to human smell. Table 4 presents the production generated by a candeia fragment to be explored, following the principles of sustainable forest management.
The process of extracting essential oil may be done by various methods, such as hydrodistillation, maceration, solvent extraction, effleurage, supercritical gases and microwave. In Brazil there are approximately 7 companies that extract candeia oil. The oil is commercialized for the production of: astringent; liquid lipstick; sunscreen; toothpaste; baby

diaper rash cream; sore cream for bedridden patients; peeling cream for cleansing and circulation stimulation; postoperative cream; toning cream; body emulsion; makeup removal wet wipes; anti-acne lotion; protective hair lotion and other goods.

Diameter class	Number of trees	Total Vob (m^3)	kg of oil per m^3 cc	Nº of fence posts
5 ├ 10	530.89	9.816	85.96	1114.87
10 ├ 15	250.00	12.290	119.20	900.00
15 ├ 20	71.97	6.656	74.92	374.27
20 ├ 25	17.52	4.572	65.48	176.91
25 ├ 30	4.14	1.504	13.29	52.99
30 ├ 35	0.96	0.488	4.86	18.44
TOTAL	875.47	35.327	363.70	2637.48

Where: Vob - total volume over bark and m^3 cc – cubic meter of wood with bark.

Table 4. Estimated production of a candeia fragment after the conduction of a census.

3. Conclusion

The joint analysis of these case studies permits one to conclude that the exploration of the Cerrado and candeia in a sustainable manner can be economically viable, being primarily dependent on the level of intervention, cutting cycle, productivity, cost of land and market variables.

Due to Brazil's territorial extension and high biological diversity, Brazilian native forest sector presents great importance on a global level, contributing to the world market supply of various products; ensuring the maintenance of biodiversity and water resources; as well as climate regulation in areas of influence. However, comparing the native and planted forest sectors in the country, the latter is more developed from a technology perspective.

The multiple use of the Cerrado is an appealing option to be pursued. In the case of candeia, advances may be focused on new product development, having as base the waste generated after oil extraction. This measure will add value to the production system, and elevate opportunities for revenue generation.

After harvesting, the cutting cycle must be respected, along with the promotion of mechanisms to maximize forest growth, accomplished through silvicultural systems. Without these cares the forest will enter into stages of degradation and fragmentation, causing permanent damage to the ecosystem. The studies related here were focused in the tree stratum of the forests and as such consist of preliminary studies of the sustainability of Cerrado and candeia management. Further studies on how forest management affects the fauna and other aspects of the flora (e.g. trees with DBH smaller than 5cm and herbaceous stratum) are required to provide more information on the impacts of forest management on the Cerrado and candeia trees' fragment.

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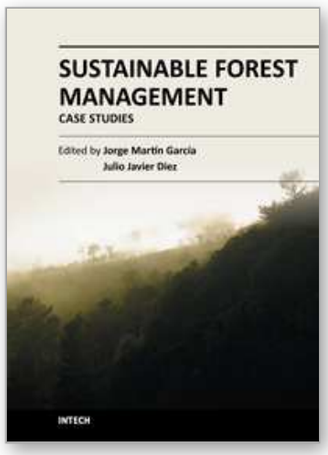
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The concept of forest sustainability dates from centuries ago, although the understanding of sustainable forest management (SFM) as an instrument that harmonizes ecological and socio-economic concerns is relatively new. The change in perspective occurred at the beginning of the 1990s in response to an increased awareness of the deterioration of the environment, in particular of the alarming loss of forest resources. The book collects original case studies from 12 different countries in four continents (Africa, America, Asia and Europe). These studies represent a wide variation of experiences from developing and developed countries, and should clarify the current status of SFM worldwide and the problems associated with its implementation.

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