



REVIEW ARTICLE

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Silvicultural intensification and agroforestry systems in secondary tropical forests: a review

Intensificação silvicultural e sistemas agroflorestais em florestas secundárias tropicais: uma revisão

ABSTRACT: Secondary forests are the woody vegetation that results from the successional processes of species colonization after the original primary forest clearance. Primary forest clearances occur due to disturbances caused by natural factors such as windstorms, hurricanes, landslides, or fire. Human activities as deforestation to implement crop fields, pastures, mines, and roads can also promote the increase of secondary forests. This paper discusses the problems faced to achieve economic profitability in tropical secondary forests, giving as example the northeast region of Pará state in the Brazilian Amazonia. One alternative to transform tropical secondary forests into more economically competitive land use is the intensification of silvicultural treatments aiming increased productivity of timber and non-timber tree species. This can be implemented through Organized Disturbances to promote: a) the improvement of natural regeneration; b) enrichment planting in gaps; c) tending over naturally established seedlings and saplings of commercial species; and d) Assisted Intensification of low density species. In addition to these silvicultural treatments, we propose a cyclic agroforestry system inside artificially created canopy gaps in small lands covered by secondary forests. This cyclic agroforestry system can provide crop production of grains and fruits with secondary forest conservation.

RESUMO: Florestas secundárias são as vegetações lenhosas que resultam dos processos sucessionais depois da perda da floresta primária original. As aberturas nas florestas primárias ocorrem devido a distúrbios causados por fatores naturais como tempestades, furacões, deslizamentos de terra ou fogo. Atividades humanas como o desmatamento para implementar lavouras, pastos, minas e estradas podem também promover o aumento de florestas secundárias. Este artigo discute os problemas em atingir rentabilidade econômica em florestas secundárias tropicais, dando como exemplo a região Nordeste do Pará na Amazônia brasileira. Uma alternativa para transformar florestas secundárias tropicais em um uso da terra economicamente mais competitivo é a intensificação de tratamentos silviculturais, a fim de aumentar a produtividade das espécies para fins madeireiros e não-madeireiros. A intensificação silvicultural pode ser implementada por meio de Distúrbios Organizados na floresta para promover: a) a melhoria da regeneração natural; b) plantio de enriquecimento em clareiras; c) condução de mudas de espécies comerciais naturalmente estabelecidas; e d) Intensificação Assistida de espécies com baixa densidade. Além desses tratamentos silviculturais, propõe-se um sistema agroflorestal cíclico dentro clareiras artificiais em pequenas propriedades rurais cobertas por florestas secundárias. Este sistema agroflorestal cíclico pode manter a produção de grãos e frutas com a conservação da floresta secundária.

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1 Introduction

Secondary forests are defined as the woody vegetation that results from the successional processes of species colonization after the original primary forest clearance. Primary forest clearances occur due to disturbances caused by natural factors or human activities such as agriculture, cattle ranching, mining, or the opening of roads.

In lands covered by primary forests, the formation of secondary forests only occurs after strong natural disturbances caused by windstorms, hurricanes, landslides, or fire. These disturbances destroy parts of the original old-growth forest forming small open-canopy patches. The natural formation of secondary forests usually occurs in a small scale, in areas hardly larger than one hectare. Because of the small scale of such phenomenon, the disturbed area is normally surrounded by primary forest, which helps to accelerate the succession process. Soil seed banks, seedlings banks, and propagules constantly generated by the surrounding primary forest provide the elements to start forest regeneration inside those open areas. Taking into account that the successional processes occur rapidly in these spots, a forest with the same species composition and structure observed in the surrounding primary forest is formed within a few decades.

The losses of primary or old-growth forests through deforestation to provide lands for agriculture and cattle ranching activities have been the most significant factor for the increase of secondary forests worldwide. Lands converted to agriculture and cattle ranching have their soils exhaustively used, without the application of soil conservation techniques, which results in losses of soil fertility. The loss in soil fertility is the most important reason for land abandonment by farmers. When abandoned, the agriculture fields or pastures immediately start to be covered by natural vegetation under an ecological mechanism defined as secondary succession (Guariguata & Osterlag, 2001). A deforested land under this successional process can be covered again by a secondary forest similar to the original primary forest lost. However, depending on the conditions of soil and biodiversity sources, a secondary forest can take decades to centuries to reach the same features of the previous primary forest.

Land uses that take into account secondary tropical forests will only be competitive with the adoption of effective silvicultural systems for timber and non-timber production. Hence, secondary tropical forests will be ecologically and economically more profitable under silvicultural intensification through the Organized Disturbances. Organized Disturbances can be defined as artificial disturbances applied in natural forests in order to improve the regeneration of commercial species (Schwartz & Lopes, 2015). Organized Disturbances can be followed by: a) enrichment planting; b) tending of naturally established regeneration; c) Assisted Densification; and d) agroforestry systems.

Nevertheless, the success of applying such techniques depends on fast-growing and commercially valuable tree species for timber and non-timber forest products. Secondary tropical forests can be financially profitable also when integrated in a production system that includes agriculture and cattle raising. The objectives of this work are a) to present a review on the ecological aspects of secondary tropical forests, b) to

propose well established management alternatives to increase the economic profitability of secondary tropical forests, and c) to exemplify possible production systems applicable to the secondary forests of the Brazilian Amazonia.

2 Development

2.1 Secondary forests in tropical environments

The successional process, which forms secondary forests, is a component of the natural dynamics of primary forests. This process is also responsible for maintaining the diversity and functioning of primary forests (Denslow & Hartshorn, 1994). Successional processes normally occur when one or more parts of a given primary forest are lost due to strong natural disturbances such as windstorms, hurricanes, landslides or fire. At the end of a successional process, the tree species composition and frequency will depend mainly on stochastic events and on the availability of banks of seeds and seedlings in the soil, or from propagules from the surrounding forests (Guariguata & Osterlag, 2001; Chazdon, 2012).

In tropical forests, many tree species depend on animals for their dispersal (Rodrigues et al., 2012). Because of this feature, the formation of secondary forests through successional processes becomes more complex and unpredictable. Despite its complexity, the successional process can advance more rapidly when there are more old-growth forests in the surroundings. In addition to this faster formation, these resulting secondary forests can be more diverse, presenting more species than secondary forests formed in places with no surrounding primary forests (Finegan, 1992). The speed that a secondary forest reaches the same features of a primary forest, in terms of composition and structure, will depend on how far the first is from the latter - the nearer, the faster. Isolated secondary forests can take several centuries to attain features similar to those of primary forests. Furthermore, it can also take centuries for a secondary forest to achieve the same biomass of the previous old-growth forests (Guariguata & Osterlag, 2001). Based on stochastic factors, a secondary forest can also reach a successional point of equilibrium with other sets of species different from the set that initially formed the previous primary forest. Hence, secondary forests can attain many different species compositions compared with the species composition present in the previous primary forest (Chua et al., 2013).

In abandoned lands that were previously used for agriculture, the outcomes of the stochastic processes in the secondary succession depend mainly on two variables: a) the period that a given land had been used and b) how this land had been used. Both variables strongly influence the availability of propagules in the seed bank of the soil. The former land use will also determine the soil fertility and the availability of essential nutrients in the soil. This will, consequently, determine how many species will be able to establish themselves in the new environment during the successional process (Carim et al., 2007). Another important source of regeneration in secondary forests is tree resprouting. The high resprouting capacity of branches and roots is an evolutionary survival strategy found among tropical tree species. The resprouting capacity is often seen in pioneer species; therefore, this can highly accelerate the succession process. This survival strategy can explain why

secondary forests recover faster in lands previously used for slash-and-burn cultivation than in lands used for pastures or agriculture fields. The slash-and-burn cultivation system requires smaller areas than pasture or agriculture fields normally demand. Consequently, several trees located near the space occupied by the slash-and-burn cultivation can keep roots around and within its surrounding areas, which can easily resprout as soon as the area is abandoned.

Young secondary forests, not older than 20 years, present high rates of biomass accumulation; consequently, they provide an important environmental service as efficient sinks of atmospheric carbon. When the secondary forests are over 20 years old, then they can also provide the same ecosystem goods and services compared with those provided by primary forests. These services can include, for example, the conservation of water, soil, nutrients, biodiversity, and landscape (Chazdon, 2012; Chua et al., 2013).

Although secondary forests are usually associated with the loss of primary forests, they can have essential ecological and economic roles. Under an ecological perspective, secondary forests are relevant for: a) accumulation of biomass and nutrients; b) conservation of several biogeochemical cycles; c) maintenance of the genetic flux of wild species; and d) maintenance of water, soil, and landscape. On the economic side, secondary forests can produce a) wood, b) firewood, c) fruits, d) seeds, e) medicinal plants, and f) raw material for handicraft, carpentry, and other domestic uses. Therefore, secondary forests under long-term management can provide an economic, competitive land use in relation to agriculture and cattle ranching. Long-term management of secondary forests can significantly increase a) ecological productivity with higher growth rates of commercial tree species and b) economic returns from the increased production of commercial tree species.

2.2 Economic uses of secondary forests

Secondary forests, when managed for timber production, have been economically less profitable than primary forests. There is a large number of hardwood species from primary forests that reach the highest timber prices. Individuals of these high-value hardwood species present low growth rates under natural conditions (Schwartz, 2013). As a consequence of these low natural growth rates, most of the individuals that are currently being cut in primary forests took centuries to reach their sizes. The high availability of hardwood individuals with the minimum cutting diameter (DBH = 50 cm for the Brazilian Amazonia) in primary tropical forests occurs due to the advanced age of these forests. Moreover, the abundance of timber from highly valuable species in the Brazilian domestic market suggests that these species are being extensively harvested over primary forests in vast regions of the Brazilian Amazonia. Consequently, the logging of old individuals of these species over vast regions of the Brazilian Amazonia is not a long-term sustainable activity.

Commercial light-wood species commonly found in tropical secondary forests can assume a more relevant role in the timber market because of the decline of hardwood species from tropical primary forests. Despite the changes in primary forests or in the market for tropical hardwood, tropical secondary forests worldwide can be economically more productive through

the increase of light-wood production. This is an attainable alternative since there is an intensification of the silviculture applied in secondary forests under long-term forest management plans. When submitted to appropriate management techniques, secondary forests in tropical environments can be very productive both in ecological and economic terms. This production can be combined with perennial and annual crops in the production system of small-farms (Finegan, 1992), which can also include the use of agroforestry systems.

2.3 Organized disturbances and assisted densification

Forest disturbances caused by natural factors that result in canopy gaps are crucial for the maintenance of species diversity in tropical forests (Denslow & Hartshorn, 1994; Zhu et al., 2014). Like the natural disturbances, the artificial disturbances can also promote good conditions for the species diversity maintenance in tropical forests. Furthermore, these disturbances improve the recruitment and growth of tree species belonging to the ecological groups of long-lived pioneers and light-demanding species.

Artificial disturbances can be applied in secondary forests of the tropical environments through Organized Disturbances. The Organized Disturbances are defined as planned artificial disturbances applied in parts of the forest that needs to have its regeneration improved (Schwartz & Lopes, 2015). Thus, the Organized Disturbances have no other purpose than to improve the recruitment and growth of commercial tree species. The silvicultural technique of applying Organized Disturbances can be followed by further silvicultural techniques such as enrichment planting and the tending of naturally established regeneration, which will ensure the productivity increase of secondary forests (Schwartz et al., 2013). Hence, one of the solutions to attain higher ecological and economic incomes from secondary forests is the intensification of silvicultural techniques, which must include Organized Disturbances.

The canopy gaps opened through Organized Disturbances provide the required conditions for commercial species to thrive naturally (Tuomela et al., 1996). As a complementary silvicultural treatment applied on top of the Organized Disturbances, Assisted Densification arises as a crucial alternative. Assisted Densification consists in increasing the artificial density of less common tree species through enrichment planting or the tending of natural regeneration. Thus, Assisted Densification is recommended to increase populations of rare and highly valuable commercial tree species (Schwartz & Lopes, 2015).

In old secondary or degraded forests of the tropics, where natural regeneration as well as the growth rates of commercial species are low, the silvicultural technique of the Organized Disturbance can be applied through the opening of canopy gaps. Firstly, the gap to be opened is designed below the forest canopy. The second step consists in cleaning the understory layer. Next, the larger trees within the defined area of the canopy gap are felled. The wood obtained from such operation can become an economic income when used for rural property demands or sold as firewood. The resulting canopy gap offers sufficient space and better conditions for improving the regeneration and growth rates of commercial tree species. However, if

the regeneration of commercial species is low, the gap also permits further silvicultural techniques, such as enrichment planting, Assisted Densification, and the establishment of small agroforestry systems (Schwartz et al., 2013). Among the commercial tree species to be planted in the artificial gaps, there are fast-growing timber species and fruit tree species.

The size of a canopy gap artificially built inside secondary forests in tropical environments and the height of the surrounding trees are essential for the establishment and growth of commercial species. These variables have a strong influence on the success of planted or naturally regenerated seedlings inside artificial gaps (Fredericksen & Putz, 2003; Lopes et al., 2008). Artificial gaps of approximately 400 m² are large enough for the establishment of shade-tolerant and shade-intolerant species, but the control of competing weeds and aggressive non-commercial light-wood or pioneer species is necessary to obtain satisfactory returns in the growth and survival of seedlings (Schwartz et al., 2013).

Therefore, Organized Disturbances are applicable to the management of secondary forests to promote a) the improvement of natural regeneration, b) enrichment planting in gaps, c) tending over naturally established seedlings and saplings of commercial species, and d) the Assisted Densification of low density species.

2.4 Agroforestry systems inside secondary forests

An agroforestry system consists in the integration of crops and forests in the same cultivated environment. This integration promotes species diversification where the ecosystem goods and services are maintained (Da Silva et al., 2008). The main economic aspect of an agroforestry system is the increase of farmers' economic incomes per unit of area in a diversified crop and forest production. This enables uniform and constant revenues, especially in small farms maintained by the family labor. The production of the agroforestry systems can supply part of the families' demands for food, and its surpluses can be sold in local markets (Peck & Bishop, 1992). Small farmers are less likely to have economic losses when they manage an agroforestry system than when they cultivate a single or few crops. The wide set of species in an agroforestry system offers various crops, fruit trees, and timber species to be harvested, which allows small farmers to deal with price variations of their diversified production. Agroforestry systems present some ecological advantages, they not only maintain all the ecosystem goods and services offered by forests, but also contribute to alleviate pressures on primary forests. The implementation of agroforestry systems in secondary forests can diminish the pressure for the opening of new agricultural frontiers over natural old-growth forests.

In tropical forests, the disturbances caused by tree falls in secondary forests are smaller and less frequent than those observed in primary forests (Denslow & Hartshorn, 1994). The canopy gaps opened by tree falls in secondary forests are much smaller than those normally opened in primary forests. This process is a consequence of the size of trees in secondary forests. These trees have narrower crowns and shorter heights than those present in primary forests. Because of this ecological feature of secondary forests, Organized Disturbances are recommended for these forests (Schwartz & Lopes, 2015) in

order to create canopy gaps. These artificially opened canopy gaps will offer the conditions required for the establishment of a specific agroforestry system with no negative interference on the tree diversity of the managed secondary forest.

Agroforestry systems demand initial investments such as soil fertilization and the acquisition of seeds and seedlings. The soil may require acidity correction and fertilizers, which imply in an initial financial cost to implement the agroforestry system. A less costly way to improve soil fertility is to promote green fertilization through the planting of leguminous species that fix nitrogen in the soil.

Seeds and seedlings to be used in agroforestry systems must have high quality; this is a crucial factor for the system success. The seeds must have high germination rates and be of known provenance, while the seedlings must be healthy to increase their chances of establishment and growth. Nurseries to produce high quality seedlings can be built in the communities under a cooperative system. Financial credits to invest in an adequate agroforestry system, including those inside secondary forests, could come through government policies and incentives aimed to increase economic incomes of small farmers, food security, or nature conservation (Smith et al., 2003).

2.5 The Brazilian Amazonia

Most of the secondary forests in the Brazilian Amazonia that originated from deforestation during the 20th Century do not count on individuals of hardwood species with harvestable size. This occurs because these forests are very young compared with the primary forests of the region. The most common timber species in secondary forests of the Brazilian Amazonia are the light-wood and fast-growing species, which are hardly commercialized under high prices, both in the domestic and international markets (SEMA, 2014). Another important problem that undermines the economic competitiveness of secondary forests in the Brazilian Amazon region is the widespread of illegal logging over its primary forests. Illegal timber represents more than 70% of all timber traded in the region (Lawson & Macfaul, 2010). Illegal logging has been supplied mainly by the domestic market through several high value timber species, which leave no space for light wood produced in the secondary forests of the region.

According to the current Brazilian environmental regulations, rural establishments need to maintain their legal reserve. A legal reserve is the area of the rural property that must be covered by the natural vegetation present in the region. In the Brazilian Amazon region, forest environments must cover 80% of the rural properties. Furthermore, the legal reserve can be managed for economic purposes, including timber production. Under the perspective of the Brazilian environmental regulations, tropical secondary forests must assume a more important role in the country. Considering the legal requirement where these forests must cover 80%, or more, of the land occupied by a rural establishment in the Brazilian Amazonia, the secondary forests present a strong demand to become economically more productive. To reach higher levels of financial income per unit of area per year, the research and development of more efficient ways of managing tropical secondary forests become vital. This will transform lands covered by tropical forests in more profitable land use alternatives. Hence, tropical secondary

forests under correct and constant management for generating timber and non-timber products can provide a more competitive land use, bringing higher financial incomes to their owners.

In terms of biological conservation and economic use, secondary forests have assumed a more substantial importance in the tropical world over the past decades. In the Brazilian Amazonia, the replacement of primary forests by secondary forests due to deforestation is still not as drastic as it has been observed in most of the tropical forests worldwide. A great proportion of the nearly 20% of primary forest lost in the Brazilian Amazon region is currently covered by secondary forests (Neeff et al., 2006). Most of the secondary forests in the Brazilian Amazonia are concentrated in specific areas as the arc of deforestation.

The arc of deforestation is a nearly 100 km-wide strip of land that stretches from the southeast of Pará state to the east of Acre state, passing through the states of Mato Grosso, Amazonas, and Rondônia. This area represents the newest rural frontier expansion in Brazil, where the highest levels of deforestation and land degradation in the Brazilian Amazon region have been observed (INPE, 2014; Schwartz & Lopes, 2015).

In the Brazilian Amazonia, monoculture plantations and cattle ranching are non-forest intensive land uses that have been more economically profitable than any economic activity held in secondary forests. Hence, landowners, including small farmers, are facing a dilemma between conserving the low-income secondary forests or shifting the land use of their farms from a forested land to monoculture plantations or cattle ranching.

2.6 Applications in the Brazilian Amazon region: The northeast of Pará state

Although there is a wide predominance of primary forests in the Brazilian Amazonia, the secondary forests are an important ecological element of the landscape in some specific parts of the region, as in the arc of deforestation and in the northeast of Pará state.

Like the lands under the arc of deforestation, the northeast region of Pará state was also an important agriculture frontier in the Brazilian Amazon region during the 19th and 20th centuries. Currently, with the expansion of agribusiness, this region once again appears as a rural frontier. When compared with the other regions of Pará state, the northeast region presents the highest proportion of lands covered by secondary forests. As a result of a long period of colonization through slash-and-burn agriculture, the secondary forests have dominated the region's landscape. Today, these forests represent nearly 90% of all forest cover of northeastern Pará state (Schwartz, 2007; Inpe, 2014). The original dominant vegetation formed by primary forests was the equatorial rain forest (Rizzini, 1963), which is still represented by small fragments in the southern portion of the region. Most of the landscape of the northeast region of Pará state is currently dominated by mosaics of different successional stages of secondary forests.

The land use changes in the northeast region of Pará state date back to 100 to 200 years ago, placing the region as the oldest rural expansion frontier in the Brazilian Amazonia. Furthermore, northeastern Pará state is currently one of the most populated regions in the Brazilian Amazonia, with

1.66 million people in an area of 80,074 km². Significant areas of this region have been used for agriculture and livestock. Other areas are covered by secondary forests or pastures that have been degraded due to many years of inadequate soil management. This mismanagement resulted in low soil fertility and, consequently, low crop productivity in the region.

A large proportion of these secondary forests (locally called *capoeiras*) are a component of the land used in slash-and-burn systems. This practice requires two main components: a) land under crop cultivation and b) land under the fallow period, where the secondary forests emerge. This agricultural system is widely applied in the region, being used as subsistence farming. However, many of the secondary forests present in the landscape of the northeast region of Pará state are a consequence of land abandonment after exhaustive soil use for agriculture and livestock (Schwartz, 2007).

In the northeast region of Pará state, most of the secondary forests present in small farms come as a consequence of the fallow period required to recover soil fertility in the slash and burn agricultural system. During the fallow period, however, these secondary forests have been used by farmers for economic purposes. In this region, products originated from secondary forests over abandoned lands and lands under the fallow period contribute to approximately 10% of the farmers' income. The most economically important products gathered from secondary forests in northeastern Pará state are firewood, charcoal, and fruits. A large proportion of the firewood gathered from secondary forests is used to feed ovens for preparing cassava flour. The cassava flour is frequently the most traded and most financially profitable product from small farms in the region (Smith et al., 2003).

In this way, there is a great potential for economic production of timber and non-timber products in the secondary forests of the northeast region of Pará state (Alvino et al., 2005). According to Smith et al. (2003), more than 20% of the area of small-scale farms in the northeastern Pará state is covered by secondary forests. This percentage of forest covering occurs because of the long fallow period adopted by farmers in the region. The same study shows that products from secondary regional forests contribute to nearly 10% to 20% of the farmers' income. In addition to this income, they also provide firewood, which plays a key role in small-farms. The key role of firewood lies on its extensive use to process cassava flour (locally called *farinha*). The cassava flour is the most important processed product from small farms in the northeast region of Pará state; it contributes with two-thirds of all cash income of the rural properties.

3 Final remarks and suggestions for further research

In the context of the northeast region of Pará state, the establishment of agroforestry systems in its secondary forests can be an important land use to conserve these natural forests in an economically and ecologically sustainable way (Francez & Rosa, 2011; Pompeu et al., 2009). The traditional and widespread cultivation of cassava in small farms can be integrated to agroforestry systems in secondary forests that include fruit trees and timber species. The incorporation of

cassava crops in an agroforestry system within a secondary forest therefore becomes one more viable economic use of lands covered by secondary forests. This is especially important for rural properties in northeastern Pará state, where at least 80% of their areas must be covered by forests.

Many secondary forests in the northeastern Pará state have been accumulating biomass at very low rates due to losses in their soil nutrients. These forests probably have reached a successional equilibrium, where tree species turnover is no longer observed. Thus, these forests will only be ecologically and economically productive under the intensification of silvicultural treatments. In addition, it is probably necessary to correct acidity and fertilize the soil to implement enrichment planting, agroforestry systems, or other silvicultural treatments.

In the northeast region of Pará state, there are many secondary forests with regeneration of valuable commercial tree species (Table 1). This regeneration can be improved with the application of proper silvicultural techniques under long-term forest management plans. According to Schwartz (2007), many tree species that are frequent in secondary forests of this region can be used as firewood or for timber production. Species such as *Tapirira guianensis*, *Lecythis lurida*, *Simarouba amara*, *Goupia glabra*, *Croton matourensis*, *Bagassa guianensis*, *Schefflera morototoni*, and *Jacaranda copaia* can reach high production levels if managed by proper silvicultural techniques (Table 1). As a valuable non-timber species, *Platonia insignis* produces merchantable fruits (locally called “bacuri”) that take part in many small farms’ incomes. A rich regeneration of this species is often found in secondary forests in the region. The management of the *P. insignis* regeneration can substantially increase its fruit production and the small farms’ revenues (Ferreira & Melo, 2007).

Despite the changes in land use caused by the advance of agribusiness, the rural properties of the Brazilian Amazon region, including the northeast region of Pará state, must have at least 80% of their land covered by forests. This legal requirement will create a demand for more economically profitable forests in rural properties in the Brazilian Amazonia. However, the secondary forests of northeastern Pará state will only become economically profitable under scientific and technical research

with the development and application of more efficient ways of long-term forest management. The small-farmers and their families will only remain in their rural properties if they have quality of living. Policies for small-farmers including incentives to increase forest production will help to improve their quality of life and will also increase the chances of conserving the secondary forests of northeastern Pará state. In this sense, the use of external inputs to recover the high levels of soil degradation over the past decades, or even centuries, needs to be considered in management plans for secondary forests in the region.

The introduction, in a cyclic manner, of small agroforestry systems in canopy gaps of secondary forests will help these forests to remain standing. Moreover, these agroforestry systems will also help to maintain all the environmental goods and services provided by the secondary forests in the northeast region of Pará state. This silvicultural procedure can work properly in any other secondary forest worldwide.

A model of an agroforestry system implemented in artificial canopy gaps created in secondary forests in the region, or in other tropical secondary forests worldwide is given as an example in this article. In this system, each cycle lasts 25 years. One unit of the cyclic system can be arranged in a forest fragment of 7.6 ha with an average tree height of 10 m or more. At the time of the full implementation of the agroforestry system, the open canopy gaps will cover a total area of 1.3 ha (16.2% of the forest area). According to the scheme, only one gap of 25 m in diameter (491 m²) is opened per year for 25 years. When the 25th gap is opened, the cycle restarts in the first gap.

When the canopy gaps are opened, the wood obtained from these gaps can be utilized to supply the small farm necessities, such as to build fences or feed ovens for preparing cassava flour. Firewood can also be sold to bakeries for feeding ovens, which means financial returns for the land owner. The first step after the gap opening is the planting of crops and tree species for timber production. The crops or tree species to compose the agroforestry system inside the gaps should be at the farmer’s choice. The recommended crops to be planted in the gaps can also include the green fertilizers. The leguminous species of pigeon pea, wonder bean, or tithonia will fix the nitrogen needed for all other species of the system. The timber species can be planted following a spacing of 5 × 5 m. This means that each gap can contain 21 individuals of timber species such as *Schizolobium parahyba* var. *amazonicum*, *Bagassa guianensis*, *S. macrophylla*, *Cedrella odorata*, *Dipteryx odorata*, or *Tachigali myrmecophila*. It is also possible to plant more than one timber species in each gap, since this increases the system diversification.

Crops are harvested and fruit trees are planted in the second year after the agroforestry system establishment. At this time, the timber individuals should be 1.5 to 3.0 m in height, which is the ideal environment to plant fruit trees such as cocoa, cupuassu, and banana. Black pepper can also be planted using the previously planted timber species as tutors. Depending on the fruit tree, it will start producing in two or three years, so this is the time when the fruit harvesting starts. Still in the second year, a new gap is opened proceeding in the same way as in the first year. Similarly to the first and second years, the

Table 1. Timber species with high performance in survival and growth in secondary forests in the northeast region of Pará state, Brazil.

Tabela 1. Espécies madeireiras com alta performance em sobrevivência e crescimento em florestas secundárias no Nordeste do Pará, Brasil.

Species	Common name	Botanical family
<i>Bagassa guianensis</i>	Tatajuba	Moraceae
<i>Croton matourensis</i>	Maravuvuia	Euphorbiaceae
<i>Goupia glabra</i>	Cupiúba	Goupiaceae
<i>Jacaranda copaia</i>	Parapará	Fabaceae
<i>Schefflera morototoni</i>	Morototo	Araliaceae
<i>Schizolobium parahyba</i> var. <i>amazonicum</i>	Paricá	Fabaceae
<i>Simarouba amara</i>	Marupá	Simaroubaceae
<i>Tapirira guianensis</i>	Tatapiririca	Anacardiaceae

According to Alvino et al. (2005) and Schwartz (2007).

following years will demand the same previously mentioned procedures.

Based on the proposed cyclic agroforestry system inside gaps, the harvesting of the timber species planted in the first gap will occur in the 26th year, when a new cycle will start. The new cycle can start using the gap left by the harvesting of the timber species planted 25 years before in the first artificial gap.

Some of the leguminous species that can be successfully used as green fertilizers in the secondary forests of the northeast region of Pará state are “feijão-guandu” (pigeon pea – *Cajanus cajan*), “feijão-de-porco” (wonder bean – *Canavalia ensiformis*), “titônia” (tithonia – *Tithonia diversifolia*), and several species of the genus *Inga*. These leguminous plants can be later pruned to generate organic matter that will later be incorporated into the soil to increase its fertility even more (Rayol & Alvino-Rayol, 2012; Veiga et al., 2012).

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