Evaluation and economic modeling of forest restoration in the State of Pará, eastern Brazilian Amazon

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DATA SHEET

“Evaluation and economic modeling of forest restoration in the State of Pará, eastern Brazilian Amazon” is a report produced by Terra Nativa under contract to its collaborating authors Imazon (Amazon Institute of People and the Environment) and incorporates research from specialized literature, personal interviews and independent technical analysis, extensively reviewed by specialists in the economics of environmental restoration. To evaluate forest landscape restoration, we utilized the Restoration Opportunities Assessment Methodology (ROAM) (IUCN & WRI, 2014), which features “Restoration Economic Modelling and Valuation” as one of its key tools.

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ABOUT IMAZON

Imazon is a research institute whose mission is to promote sustainable development in the Amazon thorough studies, support for the establishment of public policies, broad dissemination of information, and professional training. The institute is a non-profit association licensed by the Brazilian Ministry of Justice as a Civil Society Public Interest Organization (Oscip in Portuguese).

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ABOUT TERRA NATIVA

Established in 2004 and currently located in the city of Guaxupé (MG), TERRA NATIVA AGRO-ENVIRONMENTAL MANAGEMENT is an agronomic consulting company focuses on economic evaluation and training to integrate agribusiness and environmental management, with social responsibility. The company operates throughout Brazil and has experience in the preparation of Business Models, production processes and products, economic and socio-environmental indicators for agribusiness.

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EXECUTIVE SUMMARY

As part of its contribution to the global effort to mitigate climate change, the Brazilian government has announced a goal of 12 million hectares for restoration and reforestation by 2030. The state of Pará could contribute up to 25% of this target if it restores its forest deficit, estimated at 3 Mha. Of these 3 Mha, we estimate a deficit between 760 thousand ha and 1 Mha in Areas of Permanent Preservation (APP) and approximately 2.3 Mha in areas of Legal Reserve (LR). The estimated cost of restoring riparian APP and LR in Pará is BRL 7.7 billion to BRL 9.4 billion (BRL 2.5 billion to 4.4 billion in APP and BRL 5.2 billion to 6.9 billion in LR), over 22 years, at current values for the year 2015. The opportunity cost of the land is estimated at between BRL 4.8 billion and BRL 5.3 billion, in addition to a reduction of more than 20% of the agriculture and livestock production area (between 5.3% and 7.5% in APP and 15.7% in LR). We did not consider the forest compensation for the deficits in the calculations (i.e. by acquiring a new area with forest surplus), since we do not have an estimate of the LR area that will be effectively compensated in the entire state.

The cost of forest restoration in Pará ranged from BRL 2,280 to BRL 11,243/ha (current values for 2015) depending on the method adopted (e.g., fencing the area, total planting (1,666 trees/ha), enrichment with seedlings). The uncertainties in the total restoration costs in this report are related to: i) lack of information about dimensions of the APP to be restored, which in turn depends on the advance and validation of the Rural Environmental Registry (CAR, in Portuguese), since the preservation area to be restored around rivers varies according to the size of the property; and ii) definition of the restoration method.

We estimated the potential gains from carbon credit at BRL 6.6 to BRL 7.4 billion (BRL 1.8 to 2.6 billion in APP and BRL 4.8 billion in LR), which would pay up to 92% of the implementation costs in the LR and up to 74% in APP. We calculated that up to 120 million tonnes of CO_2 equivalent can be taken up per year (between 40.9 and 57.6 $MtCO_2$ in APP and 62.8 $MtCO_2$ in LR) with an annual restoration of up to 232 thousand ha of forest (between 84 thousand and 119 thousand ha in APP and 113 thousand ha in LR). Brazilian environmental law at federal level has determined 20 years for restoration or compensation of forest deficits, but the state regulations demand that APP restoration be completed in nine years. However, mechanisms to capture financial resources and regulations that guarantee legal certainty for the investors and beneficiaries of carbon credit are both lacking.

Sustainable forest management (legal logging) in 50% of LR was evaluated as the second source of direct financial benefits from restoration, and this activity showed returns that are competitive with agriculture and livestock production. The annualized Net Present Value (ANPV) of the native species evaluated was: BRL -319/ha (negative) for cumaru (*Dipteryx alata*); BRL

2,110/ha for marupá (*Simarouba amara*); BRL 453/ha for sucupira (*Bowdichia virgilioides*); BRL -962/ha (negative) for cedar (*Cedrela fissilis*); BRL - 58/ha (negative) for copaiba (*Copaifera langsdorffii*); and BRL 1,316 for paricá (*Schizolobium amazonicum*). Two species showed competitiveness with agriculture and livestock activities with a financial risk below 1%: marupá and paricá – species with a more rapid exploitation cycle. Despite the financial return, it is not feasible to expect forestry management practices throughout the entire LR area to be restored, due to low liquidity and unfair competition from illegal logging. The barriers to large-scale restoration and logging in the LR are similar: little knowledge of adequate planting techniques for restoration and exploitation of these areas; high cost of native seedlings and production inputs; little effective demand for restoration; and shortages of skilled labor.

We emphasize that the LR deficit should not be solved only through restoration, since part of this forest deficit may be offset by forest areas outside the property, reducing the total cost of large-scale restoration. However, there are no regulations and incentives for the marketing of these surpluses (e.g. via the Environmental Reserve Quota (CRA) market).

The use of Agroforestry Systems (AFS) can make restoration feasible for smallholders, according to our review of the literature. AFS have an average return of BRL 2,000/ha. However, intensive use of labor hinders the large-scale adoption of these systems. Furthermore, we do not know to what extent AFS will be implemented, since they are a legal option that can be adopted for any rural property, even if they are more commonly used in small properties. Thus, to estimate AFS revenues in this report, we extrapolated net revenue (in present value) only for the environmental deficit areas of small properties, resulting in a potential return of BRL 446 million per year.

As an indicator of the effectiveness of restoration, we evaluated the habitat availability to fauna in three scenarios, with and without restoration. The western region presented the greatest habitat availability. The west also shows the greatest combination of threats to habitat loss: deforestation driven by the growth of soybean production; infrastructure investments such as the BR-163; the Tapajós hydropower complex; and the port for distributing agricultural products (e.g. soybean). As most of the municipalities show a similar habitat increase by restoration (<5%), we suggest prioritizing the restoration in those areas with an intermediate amount of habitat availability (between 20% and 50%), but with a higher habitat gain. In this case, the most prominent were the municipalities located in the central-south region, such as Altamira, Novo Progresso and São Félix do Xingu. APP restoration increases habitat availability at a high financial cost, estimated approximately as a 1% gain in habitat availability for each BRL 1 million spent on restoration.

Below, we present recommendations to facilitate large-scale restoration in the state of Pará, first, to the restoration supply chain: i) invest in Research and

Development (R & D) for the production of native species; ii) structure the value chain for commercialization and valorization of the products from restored areas; and iii) establish a state strategy for restoration, starting with the mapping of conservation priority areas and coordinating actions with the agricultural sector. In addition to these direct actions, it is also necessary to promote some public policies to support the restoration, such as: i) validation of the CAR and monitoring compliance with the Forest Code, so that the demand for restoration may be realized; ii) the establishment of a strategy for forest credit within the Low Carbon Agriculture plan (ABC - Agricultura de Baixo Carbono, in Portuguese) and other financial support mechanisms; and iii) implementation of restoration incentive mechanisms for landowners and settlers because, despite the forest deficits, landowners have not sought restoration.

1. INTRODUCTION

Recently, at the United Nations (UN) climate conference in Paris (COP-21), the Brazilian government announced the goal of restoration and reforestation of 12 million hectares in the Amazon and Atlantic Forest by 2030, as part of its contribution to the global agreement to reduce the effects of climate change (Brazil, 2015). However, forest restoration involves investments, costs and benefits that are not well-defined, mainly in the Amazon, where the concern with forest restoration is only recent and access to information on the subject is still incipient.

In Brazil, protection of forests in private areas is provided by the Native Vegetation Protection Law (Law 12,651/2012, also known as the Forest Code) and non-compliance implies sanctions such as pecuniary fines or embargoes on productive areas. According to the law, rural properties must conserve native vegetation in Legal Reserve (LR) and Areas of Permanent Preservation (APP), located around rivers (riparian vegetation), slopes and hilltops. The protection of riparian forests established in Brazilian environmental legislation varies with a 30m to 500m buffer zone around rivers, lakes, dams or springs, depending on the width of the watercourse; and the APP to be restored varies from 5m to 100m around the watercourse, depending on the size of the property and width of the watercourse. In the case of LR in the Amazon biome, forest protection can reach 80% of the property, depending on its location (e.g. area with Ecological-Economic Zoning that reduces LR), size of the property, and period of deforestation. The recovery of forest deficits in LR areas also depends on the same factors. In other Brazilian biomes, the LR can reach up to 35% of the size of the property.

LR deficit can be remedied through restoration or compensation mechanisms (e.g., Environmental Reserve Quota – CRA in Portuguese) and direct lease of other property with no deficit. However, the APP deficit should only be repaired through restoration. In this study, we estimate the cost of restoring Pará’s forest deficits without considering compensation mechanisms, since we do not know the size of the area that will be effectively compensated by landowners.

According to article 3 of the Forest Code, one of the functions of the APP is to preserve biodiversity, facilitating the genetic flux of fauna; hence the importance of considering indicators related to biodiversity conservation in the restoration. To estimate the effectiveness of restoration in ecological terms, this report evaluated the increase in the availability of fauna habitat in scenarios with and without restoration. The individual number of any species supported in a landscape is closely linked to the amount of habitat available in that landscape (Hubbell, 2001; Fahrig, 2003).

We also analyzed the cost-benefit of the LR and riparian APP to be restored in the state of Pará in various scenarios provided by the National Plan for Recovery of Native Vegetation (PLANAVEG, Brazil, 2014). To estimate the total cost of restoration in the designated areas, we considered: i) the costs associated with implementing the restoration using various methods, such as planting and isolation of the areas; and ii) the loss of agriculture and livestock production in the areas destined for restoration, or the opportunity cost of land. To estimate the benefits of restoration, we considered: the revenue potential with carbon sequestration in APP and LR and gains for harvesting timber in LR. These financial benefits are an underestimate of the total restoration gains, which include ecosystem services such as soil protection, water sources, biodiversity, among others, but these are difficult to measure due to the lack of specific data.

The analyses were made using land use and land cover data from the TerraClass 2012 project (Inpe, 2014), Prodes (Inpe, n.d.) and the CAR in Pará (Sema, n.d.); from Imazon's LR and APP estimates (Nunes et al, in press, Nunes et al, 2016); and information on agriculture and livestock production from the Brazilian Institute of Geography and Statistics (IBGE). The APP were mapped for the entire state, but the area to be restored presented a range in its estimate (between 760 thousand ha and 1 Mha) due to the uncertainty of the size of rural properties in areas that are not covered by the CAR. The LR estimates considered only those properties registered in the CAR for Pará, covering about 60% of the state's registered area.

1.1. What is ROAM?

The Restoration Opportunities Assessment Methodology (ROAM) is an approach developed by the International Union for Conservation of Nature (IUCN), in partnership with the World Resources Institute (WRI), to identify opportunities, analyze data and promote Forest Landscape Restoration (FLR). The methodology focuses on the identification of ecosystem services arising from restoration, considering political factors and the economic cost-benefit of landscape restoration.

A handbook to ROAM (IUCN & WRI, 2014) was developed to assist decision-makers, specialists, practitioners, and project implementers who support the development of restoration strategies and programs at the sub-national and national levels. Accordingly, ROAM has supported countries and states that assume commitments to forest landscape restoration, such as the Bonn Challenge, which is a global effort to restore 150 million hectares of the world’s deforested and degraded land by 2020.

To propose a set of policies and actions for restoring forest landscapes in an area/region, ROAM requires a step-by-step approach based on dialogue with local stakeholders. The entire process has been developed to answer the following questions:

- Where is restoration socially, economically and ecologically feasible?

- What is the total extent of restoration opportunities in the country/region?
- Which types of restoration are feasible in different parts of the country?
- What are the costs and benefits, including carbon storage, associated with different restoration strategies?
- What policy, financial and social incentives exist or are needed to support restoration?
- Who are the stakeholders with whom we need to engage?

ROAM uses a powerful combination of stakeholder engagement ("best knowledge") with the analysis of available data ("best science") to identify and investigate FLR opportunities. The intention is to increase the resilience of landscapes and establish future options that allow the adjustment and optimization of goods and services, according to the needs of society (IUCN & WRI, 2014).

This report aims to contribute to the economic analyses required by the ROAM methodology. There is, however, no precise definition of what analyses or economic data ROAM requires, but there is a general framework proposal that includes the cost-benefit and cost-effectiveness analyses of the restoration, for the various restoration methods identified in each region that ROAM is applied. There are some recurring variables for other experiences such as Uganda, Rwanda, and Mexico, for example, where the ROAM implementing team considered carbon sequestration a benefit. In this report, we propose the use of robust tools already established in the economic literature, in a manner in line with the ROAM proposals, as described in the section "Methodological considerations". Additionally, the economic approach to restoration in Pará presented in this document is the same as that used in other ROAM sub–national initiatives in Brazil, such as in Espirito Santo, Distrito Federal, Pernambuco, and Santa Catarina.

2. METHODOLOGICAL CONSIDERATIONS

2.1. Study Area

The study was conducted in Pará, Brazil's second largest state, with a geographical area of 1.25 million km², and larger than countries such as South Africa and Colombia. We focused on Pará because it is the most advanced Amazon state with regard to registration of private areas in the CAR; >60% of its eligible area was registered in the state government database by 2015; currently, it has one of the highest rates of deforestation in the Amazon: an average of 2,000 km² per year between 2011 and 2015 compared to 5,500 km² per year for the entire Brazilian Amazon region. State and municipal governments, together with civil society, have been active in their efforts to reduce deforestation, making the state an example for other parts of the Amazon through the Green Municipalities Program, for example.

Pará is in the eastern part of the Brazilian Amazon and its economy consists mainly of mining and extraction (e.g. iron ore and bauxite, wood, coal), agriculture (e.g. palm oil and manioc) and livestock (Pará has the fifth largest herd in Brazil – 20 million heads in 2015, according to IBGE (2015)). As shown in Figure 1, approximately 55% Pará's territory, or 685,575 km², is composed of some form of public protected area or indigenous reserve (MMA/Funai, 2013). Twenty-one percent of the state had been deforested by 2014 (Inpe, n.d.) and it continues to have one of the highest rates of deforestation in the Amazon.

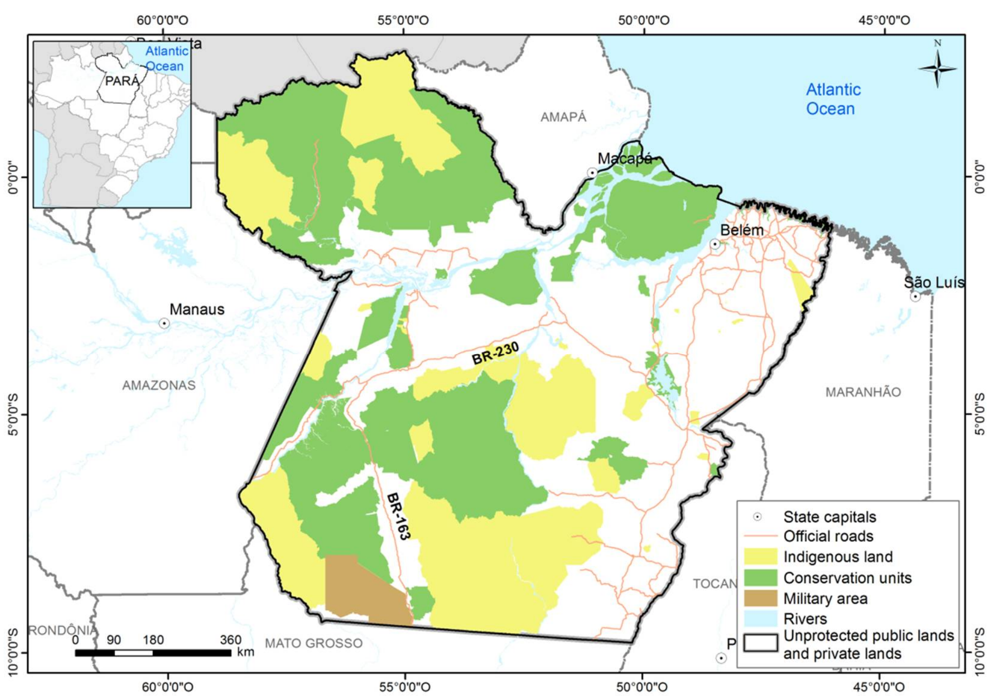


Figure 1. State of Pará (study area), with roads, rivers and Protected Areas (Indigenous Land, Conservation Unit and Military Area)

2.2. Estimated area for restoration

Based on the Inpe's land use and land cover mapping (2014, n.d) and the CAR database (Sema, n.d) in Pará, Nunes et al. (2016) estimated a forest deficit of ~2.3 million hectares in LR. The estimate of riparian APP to be restored varied due to the uncertainty of the size of those properties not registered in the CAR: a minimum of 760 thousand ha and a maximum of 1 million ha (Nunes et al, in press). To identify the APP, we used available hydrography data for the state (Nunes et al, in press). The deficit calculations were derived from Pará's CAR database for December 2014, covering 60% of the registered area in the state. For the settlements, we relied on the Conduct Adjustment Agreement (Termo de Ajuste de Conduta – TAC in its Portuguese acronym) from the National Institute of Colonization and Agrarian Reform (INCRA) (MPF, 2012), in order to consider the total area as a single rural property, treated as a small one, which should maintain a collective LR, even if the lots of settlements are exempted individually.

The LR and APP estimates consider different geographic scales. The LR was estimated for the area registered in the Pará CAR until 2014 (Nunes et al, 2016), excluding the non-registrable area, and for the APP, the hydrography of the entire state was utilized (Nunes et al, in press). Moreover, it is not possible to consider the simple sum of the two areas as a total of the deficits, since: i) we do not know the exact allocation of the LR on the property, which may or not be overlapped on APP already accounted for in another study; ii) our LR estimates do not remove the APP to be recovered. For this reason, we will present separately the cost-benefit results for APP and LR.

Finally, we point out that since we do not know how much of the deficit will be offset by other properties with surplus LR, we considered the total area of forest restoration deficit of rural properties in the calculations.

2.3. Estimated cost of transport

We determined the transport distance from three nursery poles, in the regions of Paragominas, Medicilândia and the metropolitan vicinity, evidenced by the Institute for Applied Economic Research (Ipea, in Portuguese) survey on the production of native forest seeds and seedlings in Brazil (Ipea, 2015). The value of the transportation cost (in BRL/ton and BRL/km) was defined based on the average of the Aprosoja (2016) data for interstate freight on 26 routes and the Federal University of Rio de Janeiro (UFRJ) (Coppead/UFRJ, 2006) survey. The UFRJ values were updated to 2015 by the General Market Price Index (IGP-M). Then, with the definition of costs by distance (same range as Coppead/UFRJ (2006), see Table 1), we used the unofficial roads map from

Brandão & Souza (2006) to spatialize the transport cost through the networking analyst tools of the ArcGIS software.

For the economic modeling of the total cost of the restoration in Pará, we opted for a high value of BRL 200/ha for seedling freight (Appendix I), which is commonly applied by producers in southeastern Pará.

Table 1. Freight costs per distance range

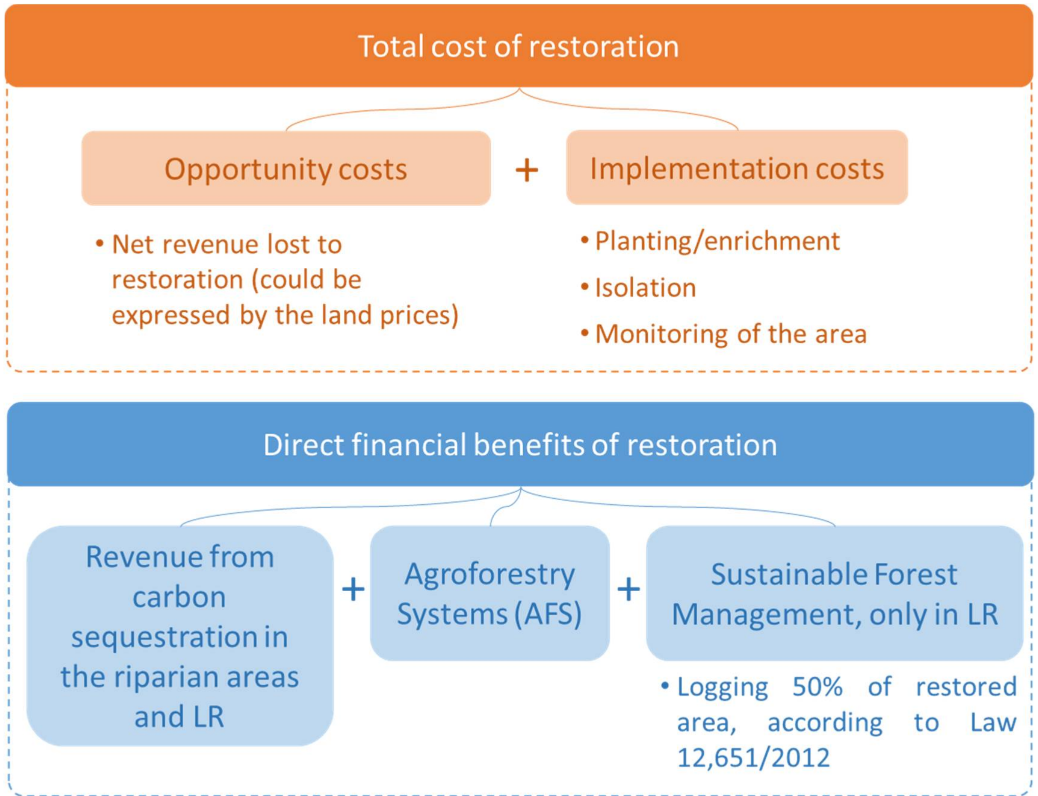
Freight cost (BRL/ton/km)	Distance (km)								
	50	**100**	**200**	**400**	**600**	**800**	**1000**	**1500**	**2000**
Coppead/UFRJ	0.43	0.3	0.21	0.16	0.15	0.14	0.14	0.12	0.12
Aprosoja			0.24	0.15	0.15	0.12	0.12	0.12	0.1
Average	**0.43**	**0.3**	**0.23**	**0.15**	**0.15**	**0.13**	**0.13**	**0.12**	**0.11**

Source: Coppead/UFRJ (2006) and Aprosoja (2016). The Coppead/UFRJ values were updated to 2015 by IGP-M.

2.4. Cost-benefit analysis

Cost-benefit analysis consists of assessing the advantage or disadvantage of an investment decision by comparing the expected total cost with the expected financial benefits throughout the duration of the project. In most cases, the result should allow a comparison with other investments. Therefore, this analysis uses common financial indicators such as Internal Rate of Return (IRR) and Net Present Value (NPV).

In order to evaluate the cost-benefit of forest restoration, we considered: the cost of implementing the restoration through various methods and scenarios; opportunity costs in restored areas; and the potential revenues from logging in LR areas and payment for carbon sequestration. In addition to the return indicators (IRR and NPV), we calculated the financial risk of timber exploitation in LR. We did not consider other potential financial benefits, such as Payment for Environmental Services (PES) for water and REDD+, because there is little market information (such as price and demand), institutional uncertainties in the application of these mechanisms on a large scale, and lack of effective programs in these areas in Pará. Board 1 summarizes the cost-benefit structure of this report and the following section describes the financial indicators used.



Graphic 1. Framework of cost-benefit analysis considered in the economic assessment of forest restoration in Pará.

2.4.1. Technical-financial indicators and risk calculation

Calculation of the NPV for timber harvest in areas to be restored. In financial analysis, the NPV is a commonly used indicator to evaluate the net return on capital in the period determined for the project. However, here we also use a variation of the simple NPV, the annualized NPV (ANPV), which represents the annual equivalent gain. The use of this variation allowed us to compare the return on timber with other soil usage that has different production cycles and evaluation of the return, for example, agriculture, which has annual cycles. Such a comparison is important to understand the competitiveness of logging in restoration.

NPV consists of the cash flow of an activity, discounting a rate relative to the opportunity cost of capital, according to the formula below:

$$NPV = \frac{\sum(B - C)}{(1 + i)^t} - I$$

Where:

B are the financial gains and *C,* the costs over a predetermined period (*t*); *i* is the discount rate; and *I,* the initial investment in the activity under analysis.

We used the following mathematical formula to deduce the ANPV from the NPV:

$$ANPV = NPV \cdot \frac{i(1+i)^t}{(1+i)^t - 1}$$

The discount rate considered was 8.5% p.a., which is the median interest rate for the main lines of credit for restoration in Pará. The two main credit lines for restoration are the ABC Plan and the FNO biodiversity (Fundo Constitucional para a Região Norte, in Portuguese), with rates ranging from 7.5% to 10% p.a., depending on the borrower's rating. The discount rate used was between the Weighted Average Capital Cost (WACC) calculated for recent studies by the Verena Project (WRI, 2016) and the Instituto Escolhas (2015), or 13.5% and 7.87% p.a. respectively.

Internal rate of return (IRR). The IRR expresses the interest rate supported by the investment, or the rate of return that equates the NPV to zero. This indicator is commonly used for the evaluation and selection of investments, because it allows an easy comparison between enterprises with different characteristics. Where the IRR is less than the discount rate, the NPV is negative (non-viable investment).

***Calculation of financial risk by the Monte Carlo method*.** The risk analysis evaluated the probability of profit from logging in the various models proposed. To measure how much the economic indicators used by the model are sensitive to uncertainties, we use a stochastic Monte Carlo approach. In this approach, we selected the variables with the greatest impact on the model: productivity, cost and sale price of timber. For each of these variables we selected a random value in the range of 20% greater or less than the average to be used in the NPV calculation. The random selection of values and NPV calculation was repeated 1,000 times for each restoration model, and after this, it was verified how many times the models showed a loss (NPV negative), or the percentage probability of non-feasibility. We emphasize, however, that this indicator represents the financial risk, not including commercial, institutional, climatic and other external risks to the business.

2.5. Assessment of land opportunity costs

We defined opportunity cost as the loss of potential revenue/gain from agriculture and livestock due to opting for the restoration alternative, that is, losses to the agricultural and livestock economy. Thus, the greater the opportunity cost, the greater the economic impact of replacing a given agricultural activity with restoration. The evaluation of the opportunity cost in areas destined for restoration considers the net agricultural and livestock revenue that will be lost in these areas in the long term. This value is expressed by the land prices or by the NPV of each rural activity. Due to the imprecision and inconsistencies of the available data, we used an average between the land price and the average net revenue of the agricultural crops. The use of the average value between the net revenue and the land prices allows a reduction in uncertainties and information bias, normalizing the data.

We also estimated the agricultural and livestock production (in tonnes) that will be affected by the restoration and the productive area (ha) lost to the restoration. In order to calculate the affected livestock production, we considered the area to be reduced by restoration multiplied by the average rate of livestock capacity (~1.3 cattle/ha); then we replicated the cattle/hectare ratio for the areas to be restored. Capacity was estimated from the total herd in 2014 (IBGE, n.d. b) divided by the pasture area estimated by TerraClass (Inpe, 2014). In order to calculate the agricultural production affected, we considered the area to be reduced due to restoration multiplied by the average yield of temporary and permanent crops according to IBGE (n.d. c), except coconut, counting as unit and not kilograms. Pineapple was converted to kilos, considering 1.2 kg per unit.

The opportunity cost assessment considers APP for the entire state (Nunes et al, in press), but LR estimates are based only on the properties registered in the CAR, located in areas suitable for registry, up to the end of 2014, totaling 60% of the state's area suitable for registry (Nunes et al, 2016).

2.5.1. Estimate of weighted net revenue from agricultural and livestock activities

For the weighted net revenue estimates of agricultural crops (in BRL/ha), we used the municipal production value data from IBGE (n.d. *b*; n.d. *c*) and the costs of Conab (2015) and Embrapa (n.d.). Since the cost data are state and non-municipal, we used the average cost in the Amazon states (BRL/kg/ha) multiplied by the average crop yield, in Kg/ha (IBGE, n.d *b*; n.d *c*). All price and cost information was updated to 2015 by the IGP-M (a Brazilian inflation index).

Below is the mathematical representation of how we calculated the weighted net revenue of the agricultural areas in Pará in each municipality.

$$\sum_{n=1}^{n} R_{c,m} = \left[\left(\frac{v_{c,m}}{a_{c,m}}\right) - \left(C_c \cdot r_{c,m}\right)\right] \cdot \left(\frac{a_{c,m}}{a_{t,m}}\right)$$

Where:

$R_{c,m}$ = weighted net revenue of a crop *c* in a municipality *m* (BRL/ha);

$v_{c,m}$ = total value of production (BRL) of a crop *c* in a municipality *m*, according to IBGE (n.d *b*; n.d *c*);

$a_{c,m}$ = planting area (ha) for a crop *c* in a municipality *m*, according to IBGE (n.d *b*; n.d *c*);

C_c = production costs (BRL/kg) for a crop *c*, according to Conab (2015) and Embrapa (n.d.);

$r_{c,m}$ = production yield (Kg/ha) for a crop *c* in a municipality *m*, according to IBGE (n.d *b*; n.d. *c*);

$a_{t,m}$ = total planting area (ha) of agricultural crops in a municipality *m*, according to the IBGE (n.d. b; n.d. *c*).

We could not find information for ten permanent and temporary crops, which amounted to 0.6% of the planting area in 2015: avocado, guaraná, lime, papaya, mandarin and urucum as permanent crops; and tobacco, jute and mallow as temporary crops, are all lacking production cost information. Due to the low representation in the planting area, we considered there was no loss in disregarding such crops in the calculation of net revenue from agricultural land use.

For the calculation of the net revenue in the pasture areas, we totaled the estimated revenues of milk and beef production in the municipalities. To estimate the slaughter revenue, we considered the statewide slaughter (Kg converted to arroba – approx. 15kg) by the percentage participation of these municipalities in the state herd, then multiplied this by the arroba price in 2014 (Cepea, n.d.) and divided by the pasture area of the municipalities (Inpe, 2014). To estimate the dairy farming revenue, we considered the following calculation in each municipality:

$$R_m = \frac{\left[\left(\frac{v_m}{q_m}\right) - C\right] \cdot q_m}{a_m}$$

Where:

R_m = net revenues from dairy farming in a municipality *m* (BRL/ha);

v_m = total value of production (BRL) from dairy farming in a municipality *m*, according to the IBGE (n.d *b*; n.d *c*);

a_m = total area of pasture (ha) in a municipality *m*, according to Terra Class (Inpe, 2014);

C = milk production costs (BRL/liter), which averaged between the values of Conab (2015) and the Imazon field survey in the municipalities of Paragominas and São Félix do Xingu, were estimated at BRL 1.27;

q_m = total production (liters) of milk in a municipality *m*, according to IBGE (n.d *b*; n.d *c*).

2.5.2. Definition of the land prices

The land prices (BRL/hectare) used were drawn from the Agrianual (Agrianual, 2015) periodic survey. The land prices varies according to municipality and land use/cover (Appendix II). To estimate the agricultural production affected, we consider the productivity per hectare of the agricultural crops per municipality, according to IBGE (n.d *a*; n.d *b*; and n.d *c*). Appendix II presents the land prices for the municipalities of Pará.

2.5.3. Classification of land use and land cover in the areas of forest deficit

In order to classify the land use in the area to be restored, we replicated the percentage distribution of the land use of different agricultural crops in each municipality. The classes of land use were the same as the TerraClass Project. From the estimated area of different usage in the APP and LR to be restored, we calculated the total opportunity cost and production affected by the restoration. Following, the calculation to estimate the land use and land cover of APP and LR deficits, by municipality:

Calculation of agricultural areas reduced by restoration, by municipality:

$$A_{l,m} = A_t . P_l . p_{l,m}$$

Where:

$A_{l,m}$ = agricultural area reduced by restoration, by municipality;

A_t = total area of forest deficit in: LR (according Nunes et al, 2016); minimum APP and maximum APP (According to Nunes et al, in press).

P_l = percentage of the agricultural area estimated in TerraClass (Inpe, 2014) in relation to the area considered for restoration (annual agriculture, deforestation, mining, reforestation and pasture). As pasture, we considered the classes: Herbaceous Pasture, Shrubby Pasture, Regeneration with Pasture, and Pasture with exposed soil, defined in the TerraClass project;

$p_{l,m}$ = percentage of agricultural area for the state of Pará in each municipality evaluated individually.

Calculation of non-agricultural areas (annual agriculture, deforestation, mining, reforestation and pasture) affected by restoration, by municipality:

$$A_{u,m} = A_t . P_u . p_{u,m}$$

Where:

$A_{u,m}$ = area affected by restoration, by municipality and by land use/class (annual agriculture, deforestation, mining, reforestation and pasture). As pasture, we consider the classes of TerraClass (Inpe, 2014): Herbaceous Pasture, Shrubby Pasture, Regeneration with Pasture, and Pasture with exposed soil;

A_t = total area of forest deficit in: LR (according to Nunes et al, 2016); minimum APP and maximum APP (according to Nunes et al, in press);

P_u = percentage of the total area for each land use/class that will be affected in relation to the total area of uses considered to be recoverable (annual agriculture, deforestation, mining, reforestation and pasture). As pasture, we consider the classes: Herbaceous Pasture, Shrubby Pasture, Regeneration with Pasture, and Pasture with exposed soil;

$p_{u,m}$ = percentage of the total land use to be estimated in the municipality.

2.6. Estimate of Agroforestry Systems (AFS) Revenue

To evaluate the economic and financial gain of AFS, we used economic data in the available literature and identified a wide variety of AFS arrangements with various species of fruit, timber and non-timber products. We selected three studies to illustrate the estimate of financial gain with AFS: Varela & Santana (2009), Francez & Rosa (2011) and Paraense et al (2013). We chose these papers because of their economic data available and for being case studies in the state of Pará. In total, the selected papers cover 24 productive arrangements with 25 different species.

Varela & Santana (2009) present data for Tomé-açu (near the region Bragantina - northeast Pará), for 16 species. Francez & Rosa (2011) present data for the Bragantina region, for 13 species. Finally, Paraense et al. (2013) present data from the consortium of species *Swietenia macrophylla* (known as mahogany) and *Theobroma cacao* (known as cocoa), in Medicilância, in the Transamazonica highway.

2.7. Analysis of habitat availability

To compare the cost of restoration with its ecological effectiveness, we used the cost-effectiveness analysis approach, relating the total cost of restoration with the indicators of habitat availability for fauna. Cost-effectiveness analysis is used when the benefits of the investment/expenditure cannot be measured in monetary terms, or in cases where the attempt to exact a monetary measure would be complicated or subject to some dispute.

2.7.1. Definition of the sample design

The Pará state area was divided into hexagons of 10,000 ha, where each hexagon represented a different landscape, that is, a unit of analysis. We used two criteria to define the size of the hexagons: i) the analysis unit should be large enough to quantify habitat availability for the species with the highest dispersion capacity; and (ii) other studies in Brazil that have modeled habitat availability have used hexagons of the same size to represent landscapes (e.g. Crouzeilles et al, 2014, Almeida-Gomes et al, 2016). The analysis only considers the hexagons with more than 50% of area within Pará. In total, we calculated habitat availability in 12,400 hexagons corresponding to 143 municipalities. We considered the municipality of Mojuí dos Campos as still being part of Santarém, since it was officially created in 2012.

2.7.2. Estimate of habitat availability

Habitat availability is based on Graph Theory, which considers a graph as a set of vertices or spots that can represent any element (e.g. forest remnants or fragments) and can be connected by links (e.g., biological flow) (Crouzeilles et al, 2013). Habitat availability depends on an attribute of the forest fragment (e.g. size or quality of the remnant forest) and on the connectivity of that fragment in the landscape, influenced by the dispersal capacity of the species.

Landscape connectivity is the degree to which the landscape facilitates the movement of individuals between vertices (Taylor et al., 1993). Landscape connectivity can be divided into structural, determined by the physical arrangement of landscape elements; and functional, determined by the response of the species to the elements of the landscape (Crouzeilles et al, 2010, 2013). In some cases, the structural connectivity occurs, but not the functional connectivity, and the opposite is also feasible (Crouzeilles et al, 2013). For example, two forest remnants may be connected by a forest corridor (there is structural connectivity), but the species may not use this corridor because it is very narrow, so there is no functional connectivity.

Habitat availability was estimated from the Probability of Connectivity index (PC; Saura & Pascual-Hortal, 2007). There are two input data needed to quantify this index: the size of the forest remnants (or vertex) and the distance between the fragments. The sizes of forest remnants were considered as the fragment attribute, and the Euclidean distance between the borders of two fragments, as the distance attribute. Being that the probability of direct dispersion (q_{ij}) between two fragments $_i$ and $_j$ is the following:

$$q_{ij} = \exp(-\beta d_{ij})$$

In which: d_{ij} is the distance between the fragment $_i$ and $_j$ and 1/β is the average capacity of dispersion of the species. The *PC* is calculated as:

$$PC = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} ai\ .aj\ .\ Pij*}{AL^2}$$

In which: *n* is the number of fragments, a_i and a_j are the respective attributes of the fragment (size of remnant forest), $Pij*$ is the maximum likelihood of the product of all possible paths between the forest fragments a_i and a_j, and AL^2 is the square of the geographical area of the landscape (Saura & Pascual-Hortal, 2007). The probability of a species incurring a path — defined as a possible trajectory from one fragment to another — is the product of the probabilities of linkage through dispersion to all forest fragments in a path. Thus, the maximum probability is also the path with the highest probability of linkage among all the connection possibilities between two specific fragments. PC values can range from 0 (no available habitats) to 1 (the entire landscape is occupied by habitat, or forest).

The relative contribution of habitat availability was compared by varying the scenarios (current situation and future APP restoration scenarios) and the dispersal capacity of the species. The current situation considered the current amount and configuration of forest remnants, while the future scenarios considered the current situation of the remnants plus the riparian APP to be restored to the environmental compliance of rural properties. Moreover, two future scenarios were considered: minimum APP and maximum APP. In order to evaluate how habitat availability varies according to the dispersion capacity, we simulated various dispersion capacities of 100, 1,000 and 3,000m for hypothetical species. These values represent species that have low, medium and high dispersion capacity (e.g. Crouzeilles et al, 2010, 2014).

As the objective of this step was to evaluate the effect of the dispersion capacity, the other ecological requirements of the species were constant, such as the minimum size of the fragment detected. Therefore, all the species simulated and compared were specialized and could be used on remnants ≥3 ha. The dispersion values corresponded to the average dispersion capacity of the fauna species, resulting from a 50% probability of direct transit between two forest fragments generated by a negative exponential function (See previous equations). We used the APP restoration map from Nunes et al (in press) to represent remnant forest as fragments of habitats potentially available for simulated species. We performed the habitat availability analysis using R 2.12 environment software (R Development Core Team 2011) and *Conefor Sensinode* command line version 2.5.8 (www.conefor.org; Saura & Torné, 2009).

3. RESULTS

3.1. Costs of restoration

3.1.1. Implementation cost under various conditions and scenarios

The cost of forest restoration in Pará in 2015 ranged from BRL 2,280 to BRL 11,243/ha, depending on the method adopted (Figure 3, Appendix I). We considered the same restoration cost per hectare in APP and LR, because although the seedlings used in APP are different from the species in LR, the average cost is the same for native species. These costs include planting in year one and maintenance and monitoring for the next two years. In practice, costs per hectare should be reduced for large-scale restoration, since the fixed costs associated with labor and the purchase of supplies are spread in the greater production of seedlings. For example, we noticed that the average cost of native seedlings decreased from BRL 1.50 to BRL 0.48/unit when comparing the experiments of the Laboratory of Ecology and Forest Restoration (LERF) of Esalq/USP on farms in Paragominas with larger areas of the Amata reforestation company. The cost structure was based on LERF/Esalq field information from Paragominas (PA) and consultations with private companies operating in the Amazon (Appendix I).

Large-scale seed and seedling production is important to reduce costs and increase supplies for the restoration of the state's environmental deficits. According to Ipea (2015), Pará has the third largest number of nurseries in Brazil (106), but if we reproduce the average productivity of the nurseries surveyed in the north region for the state of Pará, 440,000 seedlings/nursery/year[1], we estimate that the supply does not meet the annual demand for areas to be restored. If the 3 Mha of deficit were restored with total planting, the annual demand would be 249 million seedlings per year, against 46 million annual seedlings produced — 106 seedlings multiplied by 440 thousand seedlings/year — or five times the annual average seed capacity of Pará. Obviously, the biggest problem is how to turn this potential demand for restoration into effective demand, since many producers are still waiting for the Environmental Reserve Quotas (CRA) or other cheaper compensation mechanisms.

The definition of the restoration method depends on the soil condition, the situation of the surroundings (e.g. if there are sources of propagation – seed and seedlings — in the vicinity), history of intensity of soil usage and natural regeneration potential of the area (Brancalion, 2015, TNC, 2013). For example, total planting of the area (method I in Table 2) should occur in areas with no potential for natural regeneration of vegetation (low resilience). This usually occurs in areas that have seen long periods of agricultural use or grazing. The enrichment options (method II and III in Table 2) will occur in areas with some resilience, but low species density, low diversity and the need for invasive species control. Finally, the options for conducting natural regeneration (methods IV and V) are indicated for areas with high natural regeneration potential and high resilience, in which area isolation is only necessary if there are disturbance factors present (e.g. enclosure due the presence of cattle). We did not consider the proximity of the area to forest fragments that can affect the resilience of the restored area, lowering the planting cost.

[1] Ipea (2015) interviewed representatives of 25 nurseries in the north, with a total capacity of 11.19 million seedlings, an average of 440 thousand seedlings per nursery.

In this way, the definition of the best restoration method should follow specialized technical guidance. To estimate the total costs of the restoration, we considered the scenarios proposed by Planaveg (Brazil, 2014) for the distribution of area to be restored according to the various restoration methods (Table 2).

Table 2. Description of the restoration methods considered in the analyses and corresponding percentage area in different Planaveg scenarios

Method	Description	Scenario A	Scenario B	Scenario C
I	Total planting of the area (1,666 individuals/ha), with fencing	30%	20%	10%
II	High enrichment and high density planting (800 ind./ha)	15%	15%	15%
III	Low enrichment planting and low density (400 ind./ha)	15%	15%	15%
IV	Natural regeneration with isolation of the area by fencing	20%	25%	30%
V	Natural regeneration with abandonment of pasture (no fencing)	20%	25%	30%

Source: Adapted from Planaveg (Brazil, 2014).

3.1.2. Transport Costs

We estimated that the cost of seedling transportation may increase from 1% to 11% of the restoration cost per hectare depending on distance from the main seedling producing regions of Pará (Figure 2). We determined the transport distance from three nursery poles in the regions of Paragominas, Medicilândia and Bragantina region (extended to Tomé-açu), evidenced by the Ipea survey on native seedlings and seed production in Brazil (Ipea, 2015). The results are close to the freight cost of agricultural supplies in the regions, for example freight cost in southeastern Pará ranges from BRL 200 to BRL 300/ton, according to some producers[2]. However, we point out that the regions with the highest transport costs (southeast and western in the state) are probably those with higher resilience and potential for natural regeneration. This is due to the recent history of deforestation and the greater proximity to large forest fragments. That is, they are probably some regions where there will be little or no demand for seed and seedlings from distant places. For the economic modeling of the total restoration cost in Pará, we chose to be conservative and considered a value of BRL 200/ha for seedling freight (Appendix I).

[2] Personal communication with some farmers from the Rural Producers Union of São Félix do Xingu municipality.

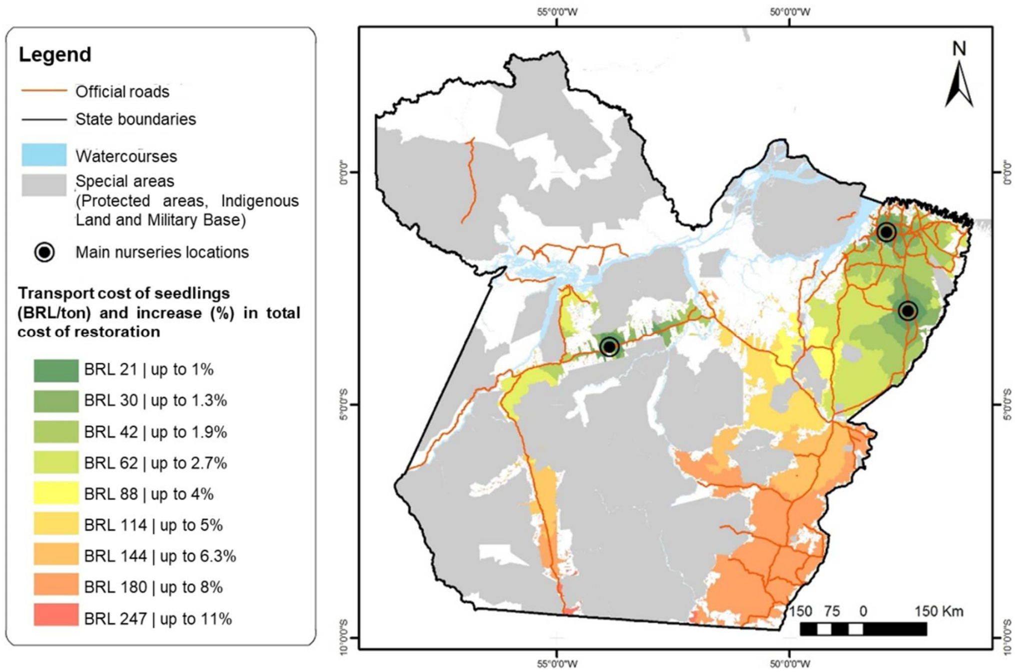


Figure 2. Map of transport costs for seedlings from the main nursery sites mapped by Ipea. The cost per tonne is approximately the same cost per hectare if we consider that a tonne is equivalent to the same amount of seedlings for planting a hectare (about 1,666) (values were updated to 2015 by the IGP-M).
Source: prepared by the authors using data from Ipea (2015), Brandão & Souza (2006), Coppead/UFRJ (2006) and Aprosoja (2016).

3.1.3. Legal Reserve restoration costs on registered property

Considering the different Planaveg scenarios (see Table 2), the restoration of ~2.3 million hectares of LR in Pará will demand between BRL 5.2 billion and BRL 6.9 billion[3] (Table 3). We considered these costs to be spread over 22 years (Table 3, Figure 3), since the Brazilian Forest Code determines that the restoration can occur over 20 years (at least 10% of the area every two years). However, after the period defined by law, we also considered two further years of expenses for maintenance of the last 10% of restored area in year 20. Thus, the annual investment volume for LR restoration in Pará ranges from BRL 236 million to BRL 268 million (in present value), considering that the cost per hectare of the restoration depends on the condition and method adopted, varying from BRL 2.2 thousand to BRL 11 thousand/ha (Figure 4, Appendix I). Appendix I shows the table with details of these costs.

[3] Present Value for 2015, with discount rate of 8.5% per annum.

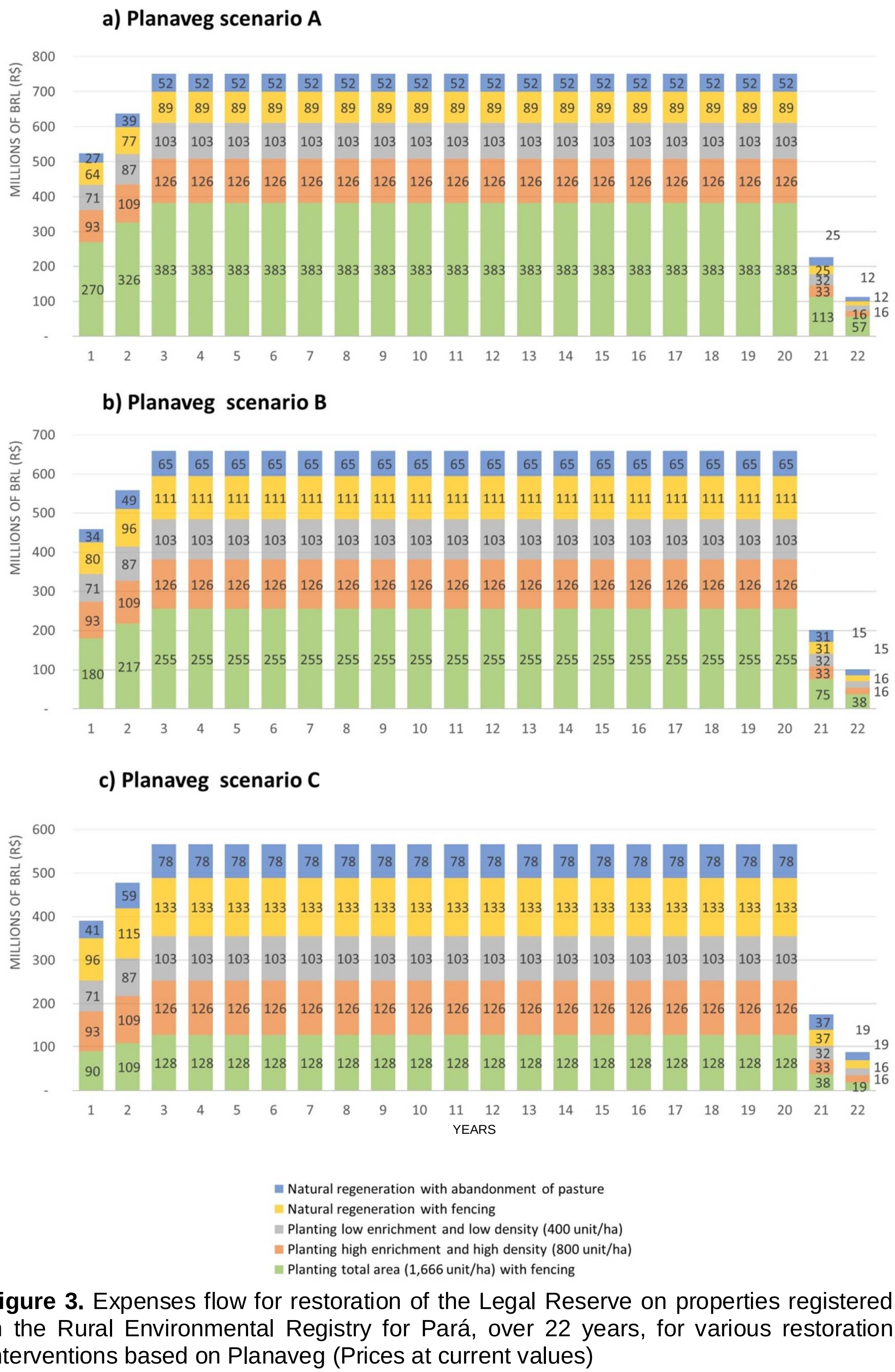


Figure 3. Expenses flow for restoration of the Legal Reserve on properties registered in the Rural Environmental Registry for Pará, over 22 years, for various restoration interventions based on Planaveg (Prices at current values)

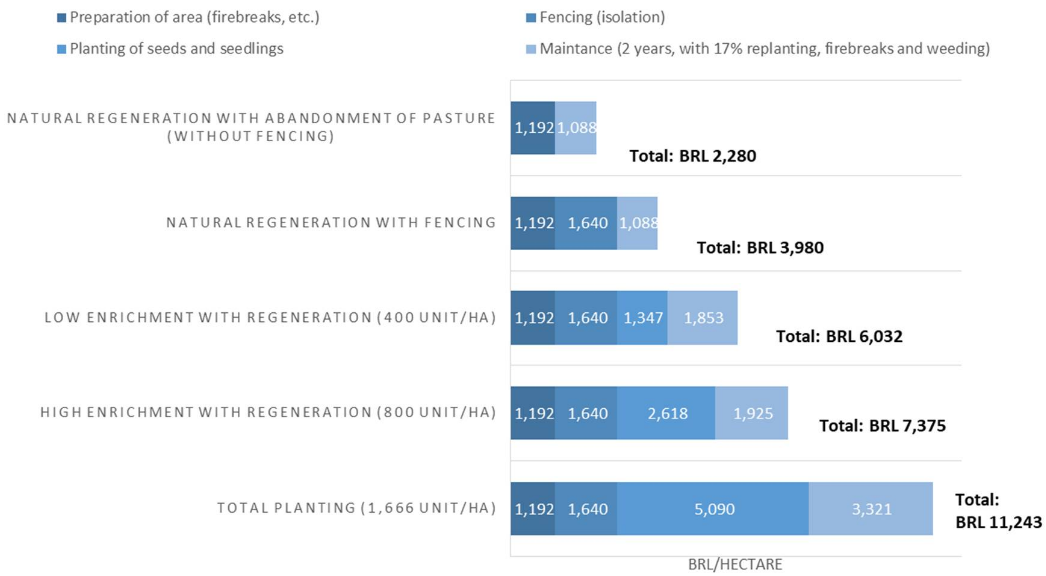


Figure 4. Restoration costs (BRL/ha) for various methods, without logging

Table 3. LR restoration costs for property registered in the Rural Environmental Registry (CAR) for Pará, for Planaveg scenarios considering different restoration methods described in Table 2. Current prices and present value (rate of 8.5% p.a.)

Restoration Method (see Table 2)	Cost of implementation and maintenance (BRL/ha)[4]	Scenario A			Scenario B			Scenario C		
		Total area considered (ha)	%	Total cost (BRL billions, over 22 years)	Total area considered (ha)	%	Total cost (BRL billions, over 22 years)	Total area considered (ha)	%	Total cost (BRL billions, over 22 years)
I	11,243	680,730	30 %	7.7	453,820	20 %	5.1	226,910	10 %	2.6
II	7,375	340,365	15 %	2.5	340,365	15 %	2.5	340,365	15 %	2.5
III	6,032	340,365	15 %	2.1	340,365	15 %	2.1	340,365	15 %	2.1
IV	3,920	453,820	20 %	1.8	567,275	25 %	2.2	680,730	30 %	2.7
V	2,280	453,820	20 %	1.0	567,275	25 %	1.3	680,730	30 %	1.6
Total in current prices		**2,269,100**		**15.0**	**2,269,100**		**13.2**	**2,269,100**		**11.3**
Total in Present Value				**6.9**			**6.1**			**5.2**

Source: based on Planaveg methods and scenarios and restoration area based on an Imazon study (Nunes et al, 2016)

3.1.4. APP restoration costs throughout the entire state

The APP deficit for the state of Pará is between 760,000 and 1 million hectares (Nunes et al, in press), demanding between BRL 2.5 billion and BRL 4.4 billion over eleven years (Present Value for 2015 at 8.5% p.a., Table 4 and Figure 5) depending on the method and the area considered (minimum or maximum APP). We projected restoration costs for various scenarios, according to Planaveg's prediction of the utilization of various restoration techniques (see Table 2). Decree N°. 1,379 (Pará, 2015) defines a term of nine years for the

[4] Appendix I details costs for various restoration methods.

implementation of APP restoration, although we considered two additional years of expenses for maintenance of these areas. The advance of CAR in the coming years, as well as accurate mapping of areas with natural regeneration potential and regional surveys of restoration costs, will be important for the more accurate definition of APP restoration costs and for planning the restoration on a large scale.

The municipalities of the state with the largest area and demand for investment for APP restoration are also those with high rates of deforestation and appear on the federal blacklist for priority enforcement (Appendix III). Among the top ten are São Félix do Xingu, Altamira, Marabá, Novo Repartimento. For these municipalities, joint actions by the government and private sector are considered urgent to develop the governance and the planning of forest restoration projects.

Table 4. APP restoration costs in Pará, for various Planaveg scenarios considering various restoration methods. Current values and present value (rate of 8.5% p.a.)

	Restoration Method (see Table 2)	Cost of implementation and maintenance (BRL/ha)[5]	Scenario A			Scenario B			Scenario C		
			Total area considered (ha)	%	Total cost (BRL billions, over 11 years)	Total area considered (ha)	%	Total cost (BRL billions, over 11 years)	Total area considered (ha)	%	Total cost (BRL billions, over 11 years)
Minimum APP restoration area	I	11,243	227,970	30%	2.6	151,980	20%	1.7	75,990	10%	0.9
	II	7,375	113,985	15%	0.8	113,985	15%	0.8	113,985	15%	0.8
	III	6,032	113,985	15%	0.7	113,985	15%	0.7	113,985	15%	0.7
	IV	3,920	151,980	20%	0.6	189,975	25%	0.7	227,970	30%	0.9
	V	2,280	151,980	20%	0.3	189,975	25%	0.4	227,970	30%	0.5
	Total in Current Prices		**759,900**		**5,0**	**759.900**		**4,4**	**759.900**		**3,8**
	Total in Present Value				**3,3**			**2,9**			**2,5**
Maximum APP restoration area	I	11,243	321,418	30%	3.6	214,278	20%	2.4	107,139	10%	1.2
	II	7,375	160,709	15%	1.2	160,709	15%	1.2	160,709	15%	1.2
	III	6,032	160,709	15%	1.0	160,709	15%	1.0	160,709	15%	1.0
	IV	3,920	214,278	20%	0.4	267,848	25%	1.0	321,418	30%	1.3
	V	2,280	214,278	20%	0.5	267,848	25%	0.6	321,418	30%	0.7
	Total in current prices		**1,071,392**		**6.7**	**1,071,392**		**6.2**	**1,071,392**		**5.4**
	Total in Present Value				**4.4**			**4.1**			**3.5**

Source: Methods and scenarios are based on Planaveg and area to be restored are based on an Imazon study (Narayanan et al., in press).

[5] Table 2 details the costs for various restoration methods.

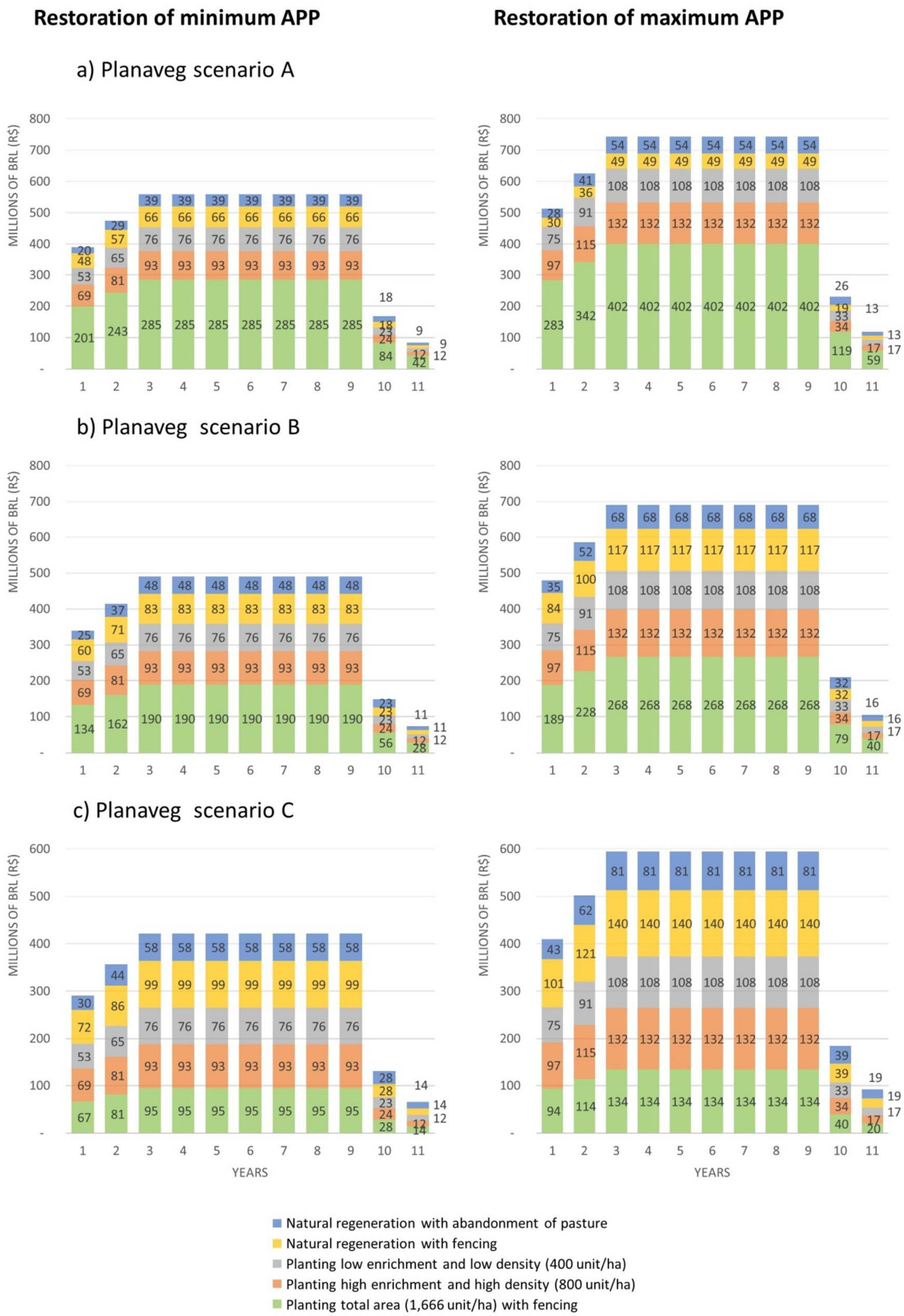


Figure 5. Expenses flow for APP forest restoration in the state of Pará, over 11 years, for different restoration interventions based on Planaveg (Prices at current values)

3.2. Opportunity costs of land

We estimated the opportunity costs associated with the restoration of APP and LR in the state of Pará at between BRL 4.8 billion and BRL 5.3 billion (BRL 1.18 billion to BRL 1.6 billion for APP, and BRL 3.7 billion for LR), as well as a reduction of approximately 2.3 million hectares in area with agricultural use in LR and additional 700 thousand to 1 million hectares in APP that may have agricultural use (Tables 5 and 6). To estimate the opportunity costs of land, we used an average between the weighted net revenue of agricultural crops and the land prices (Figure 6). In general, it is safer to assert that the final value of the opportunity cost should lie between the land price and the expected net revenue from agriculture and livestock economic activity. Based on land use and land cover (Inpe, 2014), we identified that the western region of the state and the region of northeast (also known as Salgado Paraense) present a lower opportunity cost, which leads to the conclusion that these areas will be the cheapest for compensation (Figure 7).

From a strictly economic point of view, restoration should start with the regions with the lowest opportunity costs, allowing a longer period for the implementation of programs to compensate the losses resulting from the restoration in the regions with greater land value. However, the environmental effectiveness of restoration should be considered, i.e. where there are greater gains for biodiversity conservation, climate, carbon, further fragmentation, etc. The common census is that areas with greater fragmentation, deforestation and opportunity cost (due to the presence of agriculture and infrastructure) are also the more degraded areas and will have the greater environmental gain from the restoration. Thus, section 3.4 of this report focuses on cost-effectiveness assessment, identifying areas with greater environmental gain for restoration.

APP restoration in Pará will reduce the state's agriculture and livestock production area by between 5.3% and 7.5% (Table 5), with an equivalent opportunity cost ranging from 4.5% to 6.3% of the total value of production. APP restoration will also affect between 1.6% to 2.2% of agricultural production and 4.6% to 6.4% of the livestock herd. Concomitant to this, we estimated that LR restoration will reduce the state's agricultural production area by approximately 15.7%, affecting 14% of the land value (opportunity cost, in Table 6). The LR areas to be restored will affect 8.1% of agricultural production and 15.8% of the livestock herd. The reduction of agricultural area by large-scale restoration can have two effects: i) increase the value of agricultural land by reducing the supply of these areas, which could mitigate the opportunity costs; and/or (ii) to stimulate further deforestation as a result of increased land value in areas with less monitoring and control.

However, production-related losses can easily be offset by increased productivity. For example, cattle ranching has the potential to increase productivity from 75 kg/ha to 300 kg/ha and meet the demand for meat from the Amazon without further deforestation (Barreto & Silva, 2013). Thus, the implementation of restoration should be integrated into programs that encourage the adoption of technologies and good agricultural practices, especially in cattle ranching, which accounts for 95% of the total APP restoration. In addition, restoration planning should prioritize, where possible, areas of low agricultural aptitude.

Table 5. Opportunity costs of land for APP restoration in Pará. Land use and land cover information from 2012 (Amounts (BRL) updated for 2015 by the IGP-M)

Land use and land cover classes[6]	Total area in Pará (ha)	Area reduced by restoration (hectares)			
		APP minimum	**% of area reduced***	**APP maximum**	**% of area reduced**
Annual agriculture	318,777	16,853	5.3%	23,761	7.5%
Deforestation 2012	168,816	8,925	5.3%	12,583	7.5%
Mining	54,590	2,886	5.3%	4,069	7.5%
Forestry	140,929	7,450	5.3%	10,504	7.5%
Pasture	13,690,806	723,786	5.3%	1,020,475	7.5%
Total	**14,373,919**	**759,900**	**5.3%**	**1,071,392**	**7.5%**
		Opportunity cost of land (BRL Millions)			
		Minimum APP restoration	**% of the total value of production/ revenue**	**Maximum APP restoration**	**% of the total value of production/revenue**
Annual agriculture		52	4.8%	73	6.8%
Deforestation 2012		18	5.9%	25	8.4%
Mining		6	3.6%	8	5.1%
Reforestation		15	3.6%	21	5.1%
Pasture		1,096	4.5%	1,529	6.3%
Total		**1,186**	**4.5%**	**1,656**	**6.3%**
		Production affected by restoration			
	Total production	**Minimum APP restoration**	**% compromised**	**Maximum APP restoration**	**% compromised**
Annual agriculture (ton.)	10.886.635	170,173	1.6%	239,929	2.2%
Deforestation 2012	-	-		-	
Mining	-	-		-	
Forestry	-	-		-	
Pasture (herd)	18,605,051	846,830	4.6%	1,193,955	6.4%

Source: Developed by the author with the data from Agrianual (Agrianual, 2015), TerraClass (Inpe, 2014), IBGE (n.d. *b*; n.d. *c*), Embrapa (n.d.) and Conab (2015).
* *The percentage values were fixed and proportional for all classes due to the data used and estimates provided in the municipal scale APP.*

[6] We disregarded usage classes that will not be restored and forest areas, namely: non-observed area, urban area, forest, mosaic of uses, non-forest, others and secondary vegetation. In the case of secondary vegetation there may be a need for forest enrichment, but this class of usage was disregarded in the opportunity cost analysis because there were no economic losses in these areas. The deforestation, mining and reforestation classes do not have partial or complete productive information. As pasture, we considered the classes: Herbaceous Pasture (high productivity), Shrubby Pasture (low productivity), Pasture with Regeneration, and Pasture with exposed soil.

Table 6. Opportunity cost of land for LR restoration in Pará (Land use/Land cover information in 2012. Values (BRL) updated to 2015 by the IGP-M)

Land use and land cover classe[7]	**Total area in Pará (ha)**	**Area reduced by restoration of LR (ha)**	**% of total area***
Annual agriculture	318,777	50,075	15.7%
Deforestation 2012	168,816	26,576	15.7%
Mining	54,590	8,594	15.7%
Forestry	140,929	22,186	15.7%
Pasture	13,690,806	2,155,320	15.7%
Total	**14,373,919**	**2,262,751**	**15.7%**
		Opportunity cost of land (BRL Millions)	**% of the total value of production/revenue**
Annual agriculture		136	12.6%
Deforestation 2012		51	17.3%
Mining		17	10.5%
Forestry		43	10.5%
Pasture		3,437	14.1%
Total		3,684	14.0%
	Total production	**Production in the area to be restored**	**% compromised**
Annual agriculture (ton.)	10,886,635	878,985	8.1%
Deforestation 2012		-	
Mining		-	
Forestry		-	
Pasture (herd)	18,605,051	2,931,235	15.8%

Source: Prepared by the author with the data from Agrianual (Agrianual, 2015), TerraClass (Inpe, 2014), IBGE (n.d. b; n.d. c), Embrapa (n.d.) and Conab (2015).

** The percentage values were fixed and proportional for all classes due to the data used and estimates provided in the municipal scale APP*

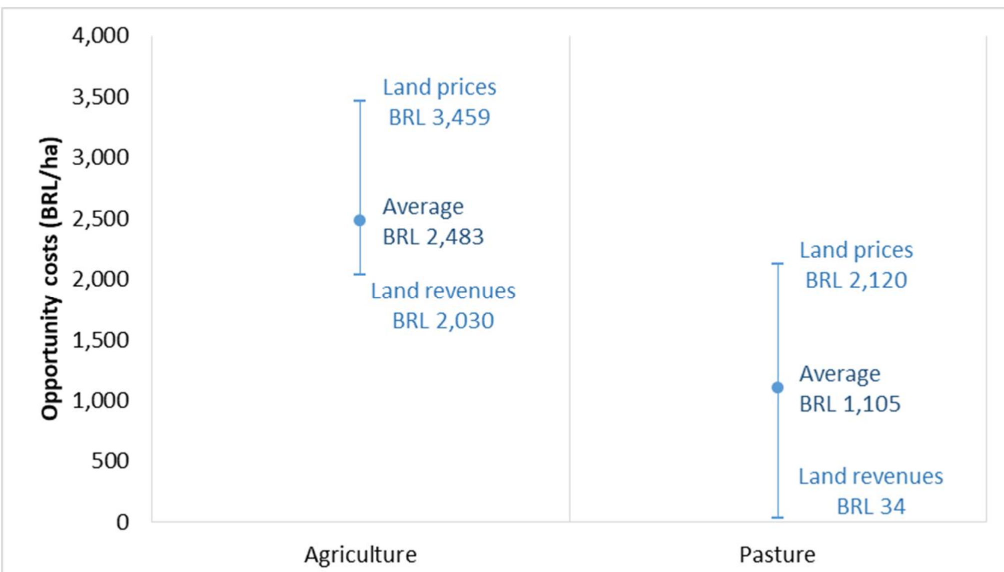


Figure 6. Average estimate of the opportunity costs of land in Pará for agriculture and pastures, using three approaches: 1) weighted net revenue from agricultural crops and livestock (milk and beef); 2) land prices; and 3) Average of the previous two

Source: Developed by the author with the data from Agrianual (Agrianual, 2015), TerraClass (Inpe, 2014), IBGE (n.d. b; n.d. c)), Embrapa (n.d.) and Conab (2015).

[7] Previous Idem nota.

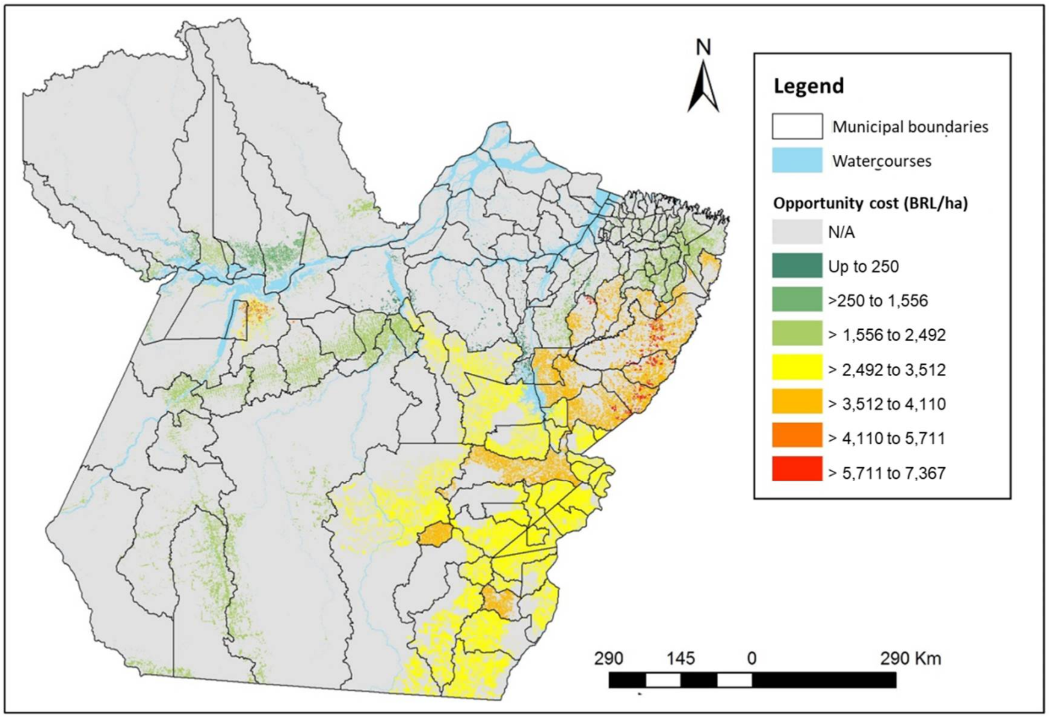


Figure 7. Map of opportunity costs of land for restoration in Pará. The values change according to municipality and land use (Values (BRL) updated to 2015)
Source: Developed by the author with the data from Agrianual (Agrianual, 2015), TerraClass (Inpe, 2014), IBGE (n.d. b; n.d. c), Embrapa (n.d.) and Conab (2015).

3.3. Financial benefits of restoration

3.3.1. Potential revenue from carbon sequestration in LR

We estimated a potential revenue of BRL 4.8 billion (in present value) from carbon sequestration in the LR areas to be restored over 22 years (Figure 8). Revenue would cover 70-92% of restoration costs depending on the scenario predicted by Planaveg (Figure 8 and Appendix IV). The average cost of the restoration would fall to: BRL 2,010/ha in Planaveg scenario A; BRL 1,263/ha in Planaveg scenario B; and BRL 405/ha in Planaveg scenario C. In Pará, we believe that the most likely scenario for in the majority of regions is C, due to the high potential for natural regeneration. Appendix IV presents the table with the values of these costs, revenues and sequestration of CO_2 equivalent.

Nevertheless, the major importance of carbon sequestration is the contribution to Brazilian climate change mitigation targets, committing Brazil to international agreements, because there are, in fact, many uncertainties about the carbon credit market and its regulation. To calculate the potential revenue from carbon sequestration, we considered the price of USD 5.00/tCO_2 equivalent, given by BNDES (2014) in the Amazon Fund. This amount converted into Brazilian currency corresponds to BRL 12.95/tCO_2 equivalent[8], which is high when compared to international trends, but was the reference value found in a government institution (BNDES) for private beneficiaries[9]. An example of how the price of carbon has fluctuated is the Chicago Climate Exchange, in which the value fell from approximately USD 4.00 in 2009 to USD 0.10 per tonne in 2010; a value that, if used in our modeling, would pay less than 2% of the cost of restoration in Pará (Figure 8). This reduction in carbon prices was due to a lack of faith in the market after COP-15 in Copenhagen and to the financial crisis of 2008 and 2009. The volume of transactions on the Chicago Climate Exchange fell from 60 million tonnes in 2010 to 66 thousand tonnes in 2013 (ICE, 2016). Despite this, the BNDES value is the official reference we have for carbon payment.

We did not consider other potential sources of revenue here, such as the Payment for Environmental Services (PES) related to water or even payment for avoiding deforestation (REDD+). In addition, when the market for environmental reserve quotas is regulated in the state, it will facilitate the compensation of the deficit in areas with forest assets (forest surplus beyond that required by law), reducing the area to be restored and lowering the total cost of the restoration in the state. In this scenario, carbon sequestration resulting from restoration is also reduced along with the corresponding potential revenue.

To estimate the carbon sequestration and CO_2 equivalent, we used the growth rates of the species and the average maturity time of the trees in the different species groups – short, medium and long cycle (Table 7). The estimates are, in fact, conservative, since we estimated that at the end of the 11-year cycle the equivalent carbon sequestrated is 92 ton/ha, while the average carbon per hectare stipulated by the Brazilian emissions inventory is 124 ton/ha in the Amazon (Brazil, 2010). According to the IPCC (2006), the convention is that carbon corresponds to 50% of biomass and carbon dioxide (CO_2) is equivalent to approximately 3.66 times the value of that carbon.

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[8] Due to the exchange variation, we have used the average price of the dollar in the last three years, or BRL 2.59 to US$ 1.00. Data from the Brazil Central Bank, available at: <http://www4.bcb.gov.br/pec/taxas/port/ptaxnpesq.asp?id=txcotacao>.

[9] There is a broad discussion about who should be the beneficiary of carbon credit, such as traditional communities, government, or private parties and land settlers. For more, see authors such as Wunder et al (2008), Altmann (2011), Lima (2009) and Brito & Lima (2011).

Table 7. Above-ground biomass and indicators used to calculate carbon sequestration.

Species group	Average Annual Increment AAI (m³/ind./year)	Average density (ton./m³)	Average Annual Increment (AAI) (m³/ha/year)	Biomass equivalent (ton./ha)	Carbon seq. (ton./ha/year)	tCO_2 equivalent	Average time of seq. (years)
Short	0.03	0.64	21.9	14.0	7.0	25.6	10
Medium	0.03	0.57	11.7	6.6	3.3	12.2	14
Long	0.02	0.64	7.3	4.7	2.3	8.5	20

Source: Developed by the author based on information from the IPCC (2006) and information compiled in the Guide to trees with economic value (Campos-Filho & Sartorelli, 2015).

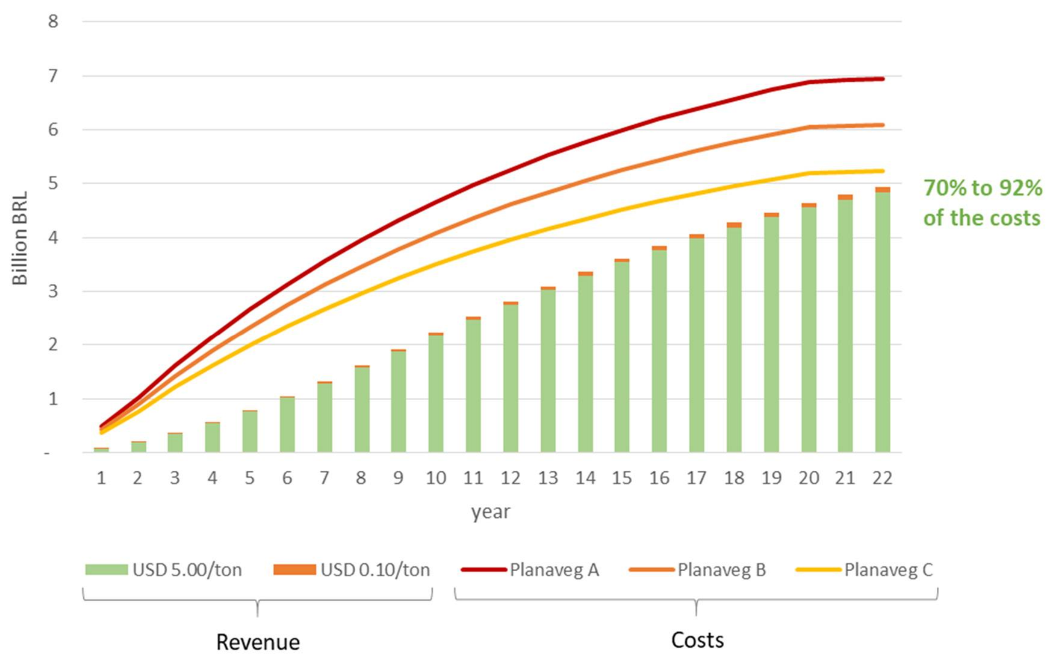

Figure 8. Cumulative present value of costs (in various Planaveg scenarios) and potential revenue from carbon credit in LR to be restored in the properties registered in the CAR. Revenue was estimated for two price scenarios: USD 5/tCO_2 by the BNDES and USD 0.10/tCO_2 by the Chicago Climate Exchange (Exchange rate of BRL 2.59; discount rate of 8.5% p.a.).

3.3.2. Potential revenue from carbon sequestration in APP

Our estimate of potential revenue from carbon sequestration in restored APP ranged from BRL 1.8 billion to BRL 2.6 billion in 11 years (Figures 9 and 10), in present values. According to the Forest Code, the size of the APP to be restored depends on the size of the rural property, so we calculated the cost and benefit values for the minimum and maximum APP. Carbon sequestration revenues offset up to 74% of APP restoration expenditure (Figure 9, Figure 10). Appendix IV shows the table with the values of these costs, revenue and sequestration of CO_2 equivalent.

The price of tCO_2 that would cover the restoration costs was estimated at between BRL 14.81 and BRL 19.64 over 11 years in the restored APP, for the various Planaveg scenarios — BRL 14.81/tCO_2 in Planaveg scenario A, BRL 17.23/tCO_2 in Planaveg scenario B and BRL 19.64/tCO_2 in Planaveg scenario C. For this calculation, we crossed the costs in Table 4 with the estimates of CO_2 equivalent sequestration from Appendix IV, and the values did not vary as a function of the restored APP size. Although the carbon sequestration revenue did not pay for the restoration, the average cost of the restoration would be reduced to: BRL 1,485 to BRL 1,824/ha in Planaveg scenario A; BRL 1,074 to BRL 1,515/ha in Planaveg scenario B; and between BRL 664 and BRL 936/ha in Planaveg scenario C (Appendix IV).

We used the same tCO_2 price and conversions applied in the estimation for LR restoration. To estimate the sequestrated carbon and CO_2 equivalent, we used the growth rates of the species and average maturity time of the trees in the different species groups - short, medium and long cycle (Table 7).

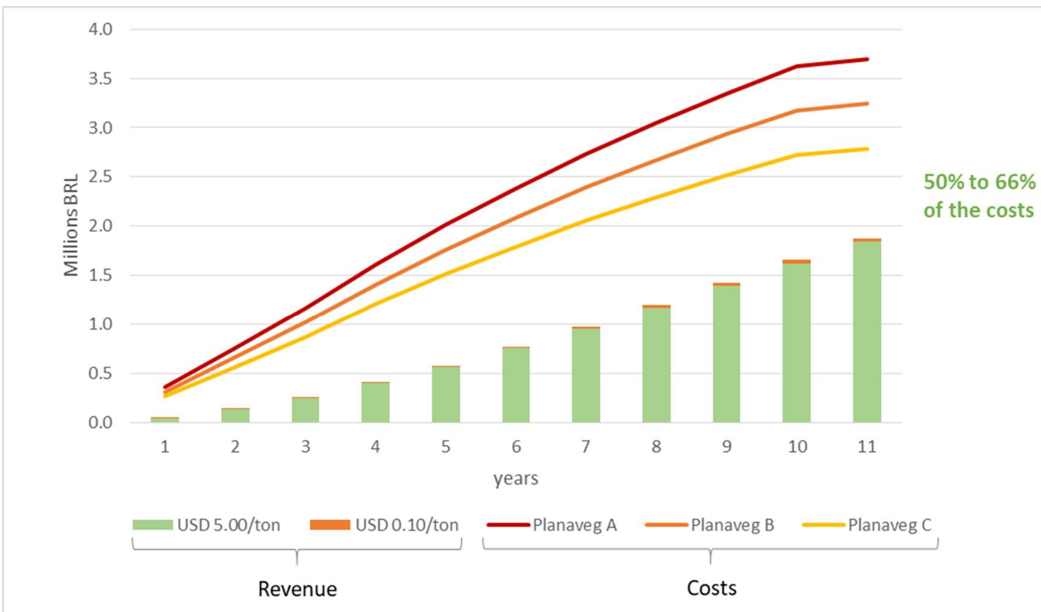

Figure 9. Cumulative present value of costs (for various Planaveg scenarios) and potential revenue per carbon credit in minimum APP to be restored in the state of Pará. Revenue was estimated for two price scenarios: USD 5/tCO_2 by the BNDES and USD 0.10/tCO_2 by the Chicago Climate Exchange (Exchange rate of BRL 2.59; discount rate of 8.5% p.a.)

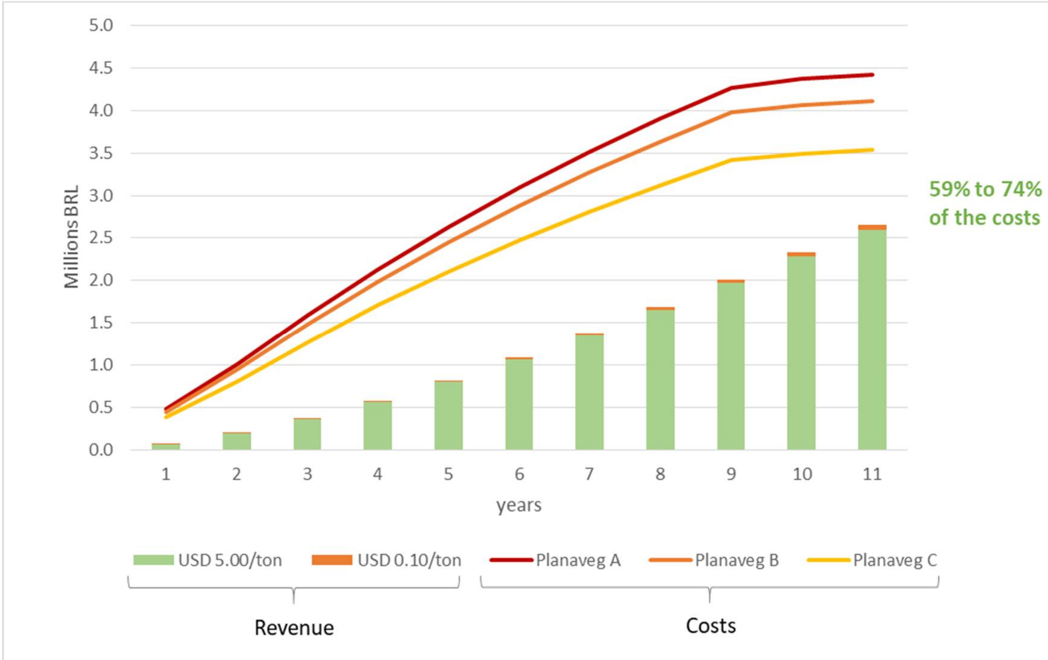

Figure 10. Cumulative present value of costs (for various Planaveg scenarios) and potential revenue per carbon credit in maximum APP to be restored in the state of Pará. Revenue was estimated for two price scenarios: USD 5/tCO_2, by the BNDES and USD 0.10/tCO_2, by the Chicago Climate Exchange (Exchange rate of BRL 2.59; discount rate of 8.5% p.a.)

3.3.3. Potential revenue from logging in the Legal Reserve

We estimated the financial gains and risks of logging in an area to be restored based on the legal premise of logging in an area destined for forest landscape restoration (Law N°. 12.65 /2012). We considered the timber harvest in 50% of the LR area to be restored, according to the experience of the Bioflora Company (specialized in restoration, located in the state of São Paulo) and producers in the municipality of Paragominas (Pará). However, the Forest Code does not restrict the area from timber harvest of native species. It only restricts the planting of exotic species to a limit of 50% of the area. We considered six productive arrangements for native planting restoration[10], described in Tables 8 and 9. We point out that, although these models are in compliance with the law, there is no information on the efficiency of restoration models with logging in biodiversity conservation.

[10] These species were analyzed according to the availability of the information on prices, productivity and field studies by Amata and LERF/Esalq, in the State of Pará. Timber price information was extracted from Fatos Florestais 2010 (Imazon, 2010) and updated by IGP-M for 2015; while the productive information (timber harvest time, Annual Average Increase, etc.) was extracted from the Guide to trees with economic value (Campos-Filho & Sartorelli, 2015). For the modeling, we excluded species that are not found in the Amazon, with no information of the AAI and with a production period of more than 20 years.

The ANPV of logging in LR varied between BRL -962 (negative) and BRL 2,110 per hectare in the different economic models considered (Figure 11). Restoration implementation costs are higher in models with logging, from BRL 16,655 to BRL 33,826/ha (Table 8 and Figure 12), but there is a financial return. The cumaru (*Dipteryx alata*), cedar (*Cedrela fissilis*) and copaíba (*Copaifera langsdorffii*) show losses due to low IRR, that is lower than the discount rate (8.5% p.a.). In the cases of species with a cycle of up to 10 years, such as the marupá (*Simarouba amara*) and paricá (*Schizolobium amazonicum),* the annualized NPV was competitive with the average gains for intensified livestock and agriculture. Livestock in the Amazon shows gains (in ANPV) that range from negative, in more extensive practices, to BRL 1,700/ha in intensified areas (Silva & Barreto, 2014); while agriculture has an average revenue of BRL 1,500/ha in current values for 2014 (Agrianual 2015). Despite the competitive return of the marupá and paricá, sustainable forest management and forestry are less attractive than agriculture due to the low liquidity of timber, that is, revenue in 10 to 20 years, whereas agriculture provides annual returns. Moreover, commercial timber competes with logging, often illegal in the Amazon, which creates unfair competition. Thus, it is likely that in most cases this activity will be complementary or secondary on agriculture and livestock farms that want to put LR to some economic use. In general, for sustainable forest management to become a reality, governments need to curb the illegal logging that generates unfair competition.

The costs of restoration with sustainable forest management include first-year planting, monitoring and maintenance of areas in the second year prior to the year of harvesting, and expenditure on replanting seedlings in the harvesting year (Figure 12, Appendix I). The increase in costs occurs because of the need for annual maintenance and monitoring of the area up to date of harvesting. In addition, after harvesting, replanting of seedlings that replace removed trees should occur.

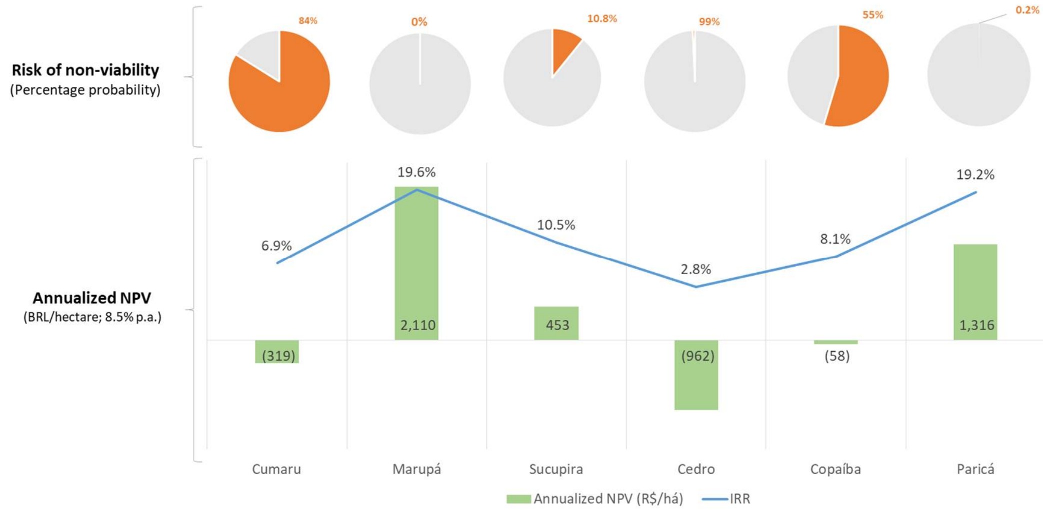

Figure 11. Annual Net Present Value (ANPV), Internal Rate of Return (IRR) and risk of financial non-viability (percentage probability) for restoration with sustainable forest management of different timber species. Discount rate: 8.5% per annum. The risk analysis repeats the NPV calculation a thousand times with fluctuation in the values of price (BRL/m³), cost and productivity (m³/ha). Species assessed: cumaru (*Dipteryx alata*); marupá (*Simarouba amara*); sucupira (*Bowdichia virgilioides*); cedar (*Cedrela fissilis*); copaíba (*Copaifera langsdorffii*); paricá (*Schizolobium amazonicum*)

Source: Prepared the author with field data from Paragominas, combined with information from the LERF (Esalq), Bioflora, Amata, Imazon and Agroicone.

Table 8. Revenue (BRL/ha) and productivity for different restoration models with logging in 50% of the area.

Exploited species	**Productivity (m³/ind.)**	**AAI (m³/ha/year)**	**Total production (m³/ha); 833 ind.**	**Total cost (BRL/ha) ****	**Gross revenue (BRL/ha)**			
					Year 7	**Year 10**	**Year 15**	**Year 20**
Cumaru (*Dipteryx alata*)	0.263	11.0	219.1	16,655				73,933
Marupá (*Simarouba amara*)	0.338	28.1	281.4	20,618		60,767		
Sucupira (*Bowdichia virgilioides*)	0.291	16.2	242.7	27,222			66,166	
Cedar (*Cedrela fissilis*)	0.234	9.7	194.8	33,826				45,736
Copaíba (*Copaifera langsdorffii*)	0.475	19.8	395.5	16,655				85,406
Paricá* (*Schizolobium amazonicum*)	0.206	24.5	171.8	20,618	33.333			

Source: Developed with data from Paragominas, combined with information from Bioflora, Ricardo Ribeiro Rodrigues (Esalq) and Imazon (2010) and compiled from information in the Guide to trees with economic value (Campos-Filho & Sartorelli, 2015).

** Only the paricá data is from Amata.** Detailed description of the costs in Table 14**Erro! Fonte de referência não encontrada.***.

Table 9. Restoration models with planting of native species and logging of 833 individuals per hectare, in 50% of the LR to be restored.

Model	Spacing and quantity planted	Harvest cycle (years)	AAI (m^3/ha/year)	Total production (m^3/ha) - 833 ind./ha	Average timber price * (BRL/m^3)
Cumaru (*Dipteryx alata*)	3m x 2m; 1,666 individuals/ hectare	20	11.0	219.1	337.4
Marupá (*Simarouba amara*)		10	28.1	281.4	215.9
Sucupira (*Bowdichia virgilioides*)		15	16.2	242.7	272.6
Cedar (*Cedrela fissilis*)		20	9.7	194.8	234.8
Copaíba (*Copaifera langsdorffii)*		20	19.8	395.5	215.9
Paricá* (*Schizolobium amazonicum*)		7	24.5	171.8	194.0

Source: Developed with field data from Paragominas, combined with information consulted with Bioflora, Ricardo Ribeiro Rodrigues (Esalq) and Imazon (2010) and compiled from information in the Guide to trees with economic value (Campos-Filho & Sartorelli, 2015).
** 2009 prices in the state of Pará updated to 2015 by the IGP-M. Data from Imazon (Fatos Florestais 2010). ** Only the paricá data is from Amata.*

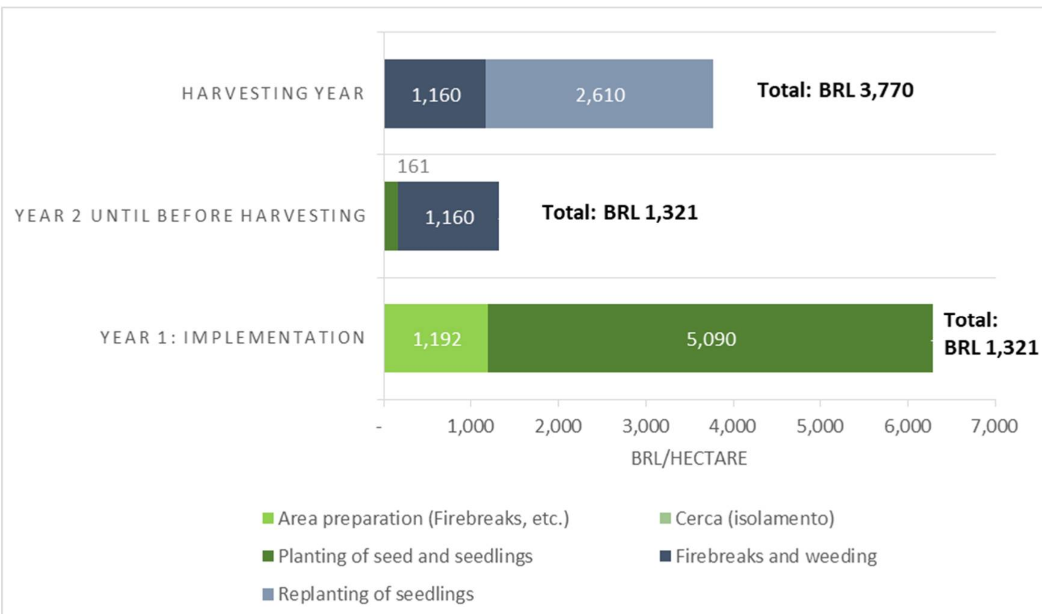

Figure 12. Costs of implementation and maintenance of restoration with logging, in BRL/ha (Appendix I presents the table with details of these costs)

3.3.3.1. Sensitivity analysis of the restoration models with logging

The main uncertainty in the restoration with forest management lies in the volatile prices of the native wood market and in the productivity, since there is little development of technologies for commercial exploitation of these species. For example, paricá productivity is shown to be close that of the Verena Project (WRI, 2016) found in the Amata areas (~25 m^3/ha/year), but below the productivity of the Simbyosis company planting areas (10 m^3/ha/year), according to WRI (2016). Among the explanations for this variation are: i) edaphoclimatic factors, since Amata and Simbyosis act in different regions, in the Amazon and Atlantic Rainforest (State of Bahia), respectively; and ii) research and development time, since the Simbyosis area is recent (~5 years) in comparison to Amata's time and investment in this species.

Given these uncertainties, we estimated the financial risk for these models shows economic non-viability between ~0% and 99% depending on the timber species used in the LR (See Figure 11). The risk analysis repeats the NPV calculation a thousand times with variation in the values of timber price (BRL/m^3), cost and productivity (m^3/ha). In addition to this analysis, we tested the sensitivity of these investments to the main uncertainty factors, and we noted that the highest variation in NPV was due to the interest rate and the selling price of the wood (Figure 13). This demonstrates that the financing model is important because the interest rate (or discount rate) represents the investor's expected return and can define the viability and effectiveness of the restoration. Furthermore, it is possible to implement mechanisms of incentive for restoration by reducing interest rates on financing in order to progressively compensate producers that are restoring forest deficits. This type of mechanism is provided for in Article 41 of Law N^o.12,651/2012, but has yet to be developed by specialists. In this sensitivity test we used 7.5% p.a. as the minimum interest rate for the ABC Forest Restoration Plan, while the maximum rate was 13.5% p.a., defined by the Weighted Average Cost of Capital (WACC) stipulated in Verena Project (WRI, 2016).

We have shown there is a lack of market studies that would help us understand the sensitivity of price to the increase in the supply of native wood. Among other barriers, forestry and logging in LR require specialized labor to gain scale and a large volume of capital for initial investment. These economic barriers, combined with the distance for supplies and seedlings, can make it difficult and unfeasible to implement restoration models with economic exploitation of the restored area.

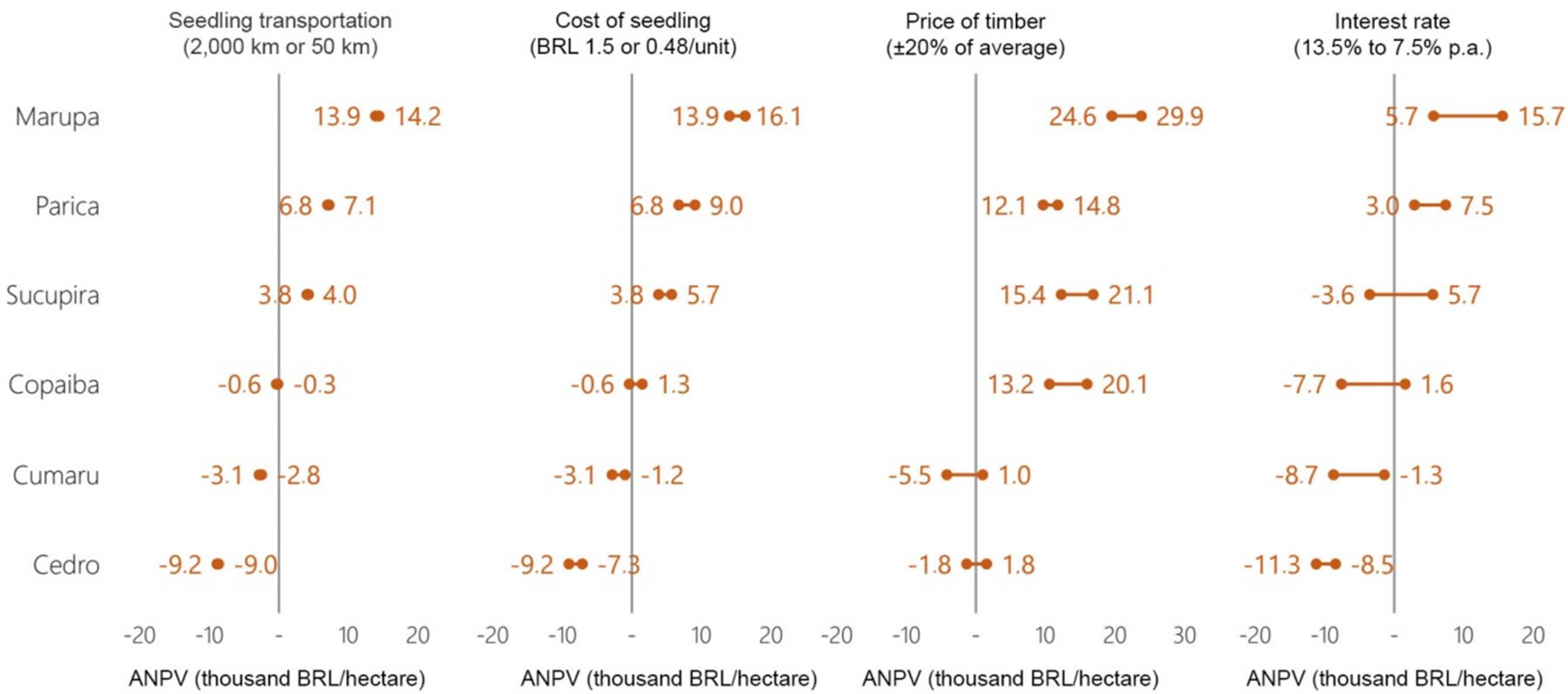

Figure 13. Minimum and maximum value of the Annual Net Present Value (ANPV) corresponding to the variation of four uncertainties, in restoration models with logging of different species. Discount rate of 8.5% p.a., seedling price of BRL 1.5 in cases without variation of these factors. Species assessed: cumaru (*Dipteryx alata*), marupá (*Simarouba amara*), sucupira (*Bowdichia virgilioides*), cedar (*Cedrela fissilis*), copaíba (*Copaifera langsdorffii*), paricá (*Schizolobium amazonicum*)

Source: Prepared by the author with field data from Paragominas, combined with information from LERF (Esalq), Bioflora, Amata, Imazon and Agroicone.

3.3.4. Potential revenue from Agroforestry Systems (AFS)

Based on the literature, we identified the financial return from AFS in the state of Pará. In two instances, the average return was close to BRL 2,000/ha. In a third study, the value reached BRL 5,354/ha for mahogany exploitation (Figure 14). Varela & Santana (2009) demonstrated an average return of BRL 1,962/ha in 18 AFS studies in Tomé-açu; while Francez & Rosa (2011) presented a similar return of BRL 2,226/ha in the Bragantina region (Figure 14). Only Varela & Santana (2009) presented cases of negative return, in five of 18 AFS. In the third arrangement shown in Figure 14, from Paraense et al. (2013), mahogany exploration raises ANPV to approximately BRL 5,000 per hectare (Figure 14). However, we have shown that the cash flow of this last study presents an average of BRL 1,424/ha per year until the year prior to the exploitation of mahogany.

In Pará, three regions stand out for their adoption of AFS: in the northeast, from the municipality of Tomé-açu to the Bragantina region; in the region of São Félix do Xingu, southeast of Pará; and in the Transamazônica highway, in the vicinity of the municipality of Medicilândia (to the west of the state, along the Transamazônica Highway). Fruit-based AFS are predominant in Tomé-açu and Bragantina, and in the southeast and in the Transamazônica region cocoa stands out due to the support of institutions such as Ceplac and non-profit organizations.

AFS offer an alternative to the restoration and improvement of productive and economic conditions in small farms, which depend on greater liquidity (rapid cash flow for day-to-day expenditures) for subsistence. Nevertheless, there are limits to the scale of AFS implementation, since this type of production is labor-intensive and expenditures can make the activity unfeasible on a large scale. Rosa et al (2009) also relate the adoption of AFS to educational, organizational and sociocultural issues. For estimating the AFS revenue in this study, we considered its implementation in only 50% of the LR deficit area (223,000 ha) on smallholders (with up to four fiscal modules) and settlements identified in Nunes et al (2016). Thus, the average potential return can reach BRL 446 million (based on the average revenue of 2,000/ha), with a variation of up to BRL 600 million according to the arrangement of associated species.

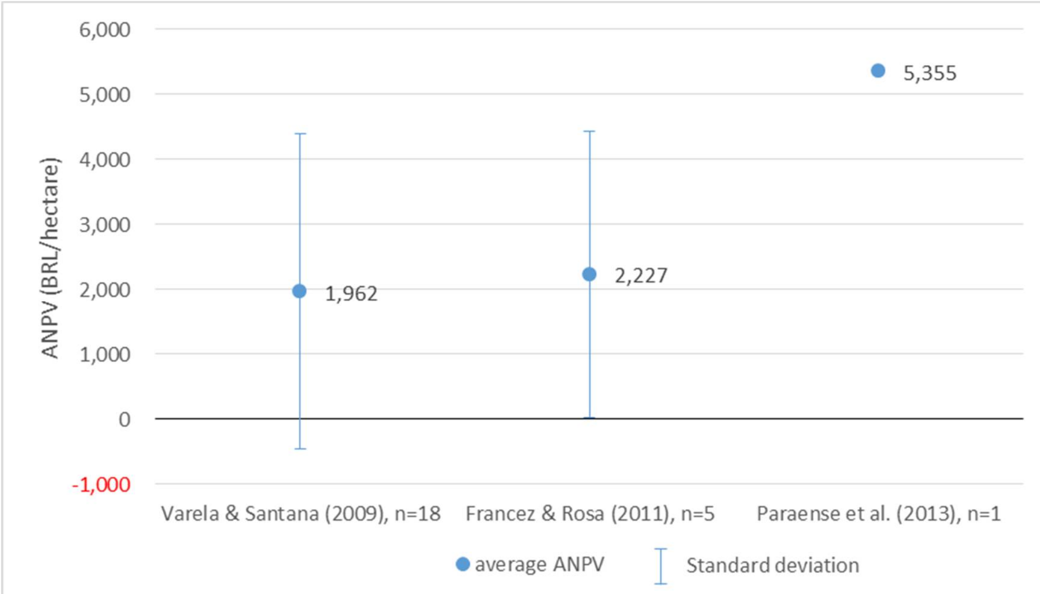

Figure 14. Annual Net Present Value (BRL/ha) of Agroforestry Systems for various productive arrangements and species (‘*n*’ is the number of arrangements or combinations of species analyzed at each job. The values were corrected for 2015 and the discount rate was adjusted to 8.5% p.a.)

Source: adapted from Varela & Santana (2009), Francez & Rosa (2011) and Paraense et al (2013).

3.4. Habitat availability

Habitat availability changed according to the scenarios (current situation or APP restoration) and different dispersion capacities for species of fauna (100, 1,000 and 3,000m) (Table 10). In Pará, the habitat availability indicator increased with the recovery of APP in the three species dispersion categories (Table 10), although it did not vary between the minimum or maximum APP scenarios restored. The variance was 4%, with the standard deviation of 20% in all scenarios.

Due to the different conditions, habitat availability also varied in 143 municipalities (Figure 15). In general, the municipalities of the eastern portion had the lowest percentage values of habitat availability, while the municipalities of the northwest had the highest percentage values. This behavior was expected because eastern Pará has the highest concentration of APP to be recovered, while the west has the highest concentration of preserved APP (Nunes et al, in press). In general, species with a greater dispersal capacity (Figure 15) have greater habitat availability, as they have a greater range and mobility between fragments. We found that in the current scenario, the municipalities of the western part of the state (i.e. Oriximiná, Santarém and Jacareacanga) are of greater importance for the species with the greatest dispersion (3,000 m).

The municipalities that gained the most habitat were those located to the south of the island of Marajó; the municipalities of Alenquer and Monte Alegre, in the Calha Norte, northwest of the state; and the municipalities of the central-south, such as Altamira, Novo Progresso and São Félix do Xingu (Figure 15). APP restoration increased habitat availability by approximately 5% compared to the current scenario (Table 10), although habitat gain did not vary as a function of the restored APP width (minimum and maximum APP scenarios — Figure 15). This is not to say that APP size is not important for conservation, as we are evaluating general classes of species according to the dispersion capacity. In fact, if we evaluate individually, several species, such as jaguars and other large animals, need larger corridors, and so are unlikely to use corridors five meters wide for movement (Crouzeilles et al, 2015). In addition, there are other implications for conservation due to the width of APP, such as silting, retention of agricultural residues and water availability, which were not evaluated in this work.

In highly forested landscapes (>60% of habitat availability), the connectivity of the fragments tends to be high and the increase in forest cover will add little to habitat availability (Pardini et al., 2010; Crouzeilles & Curran, 2016). In contrast, in landscapes with low forest cover (<20%), connectivity tends to be very low and restoration of small forest areas may not be sufficient to increase connectivity in the landscape (Pardini et al., 2010; Crouzeilles & Curran, 2016). Therefore, the restoration tends to present greater gain to the landscape functionality when carried out in areas with intermediate habitat availability, between 20% and 50% (Pardini et al., 2010; Crouzeilles & Curran, 2016). In Pará, this region covers the municipalities of Cumaru, Altamira, Ourilândia, Parauapebas, São Félix and Novo Progresso (in the central region and towards the south of the state). The explanation is that these municipalities present a combination of large and close forest fragments when compared to the eastern region (smaller and scattered fragments) or the western region (large fragments with a higher degree of connectivity).

Table 10. Average habitat availability corresponding to the scenarios (current situation and future scenarios of APP restoration) and species with various dispersion capacities (100, 1,000 and 3,000m). Appendix V lists, by municipality, the habitat availability.

Dispersion of species	**Habitat availability scenarios**		
	Current situation	APP minimum	APP maximum
100	22.0%	26.2%	26.4%
1,000	25.6%	29.9%	30.2%
3,000	26.4%	30.5%	30.6%

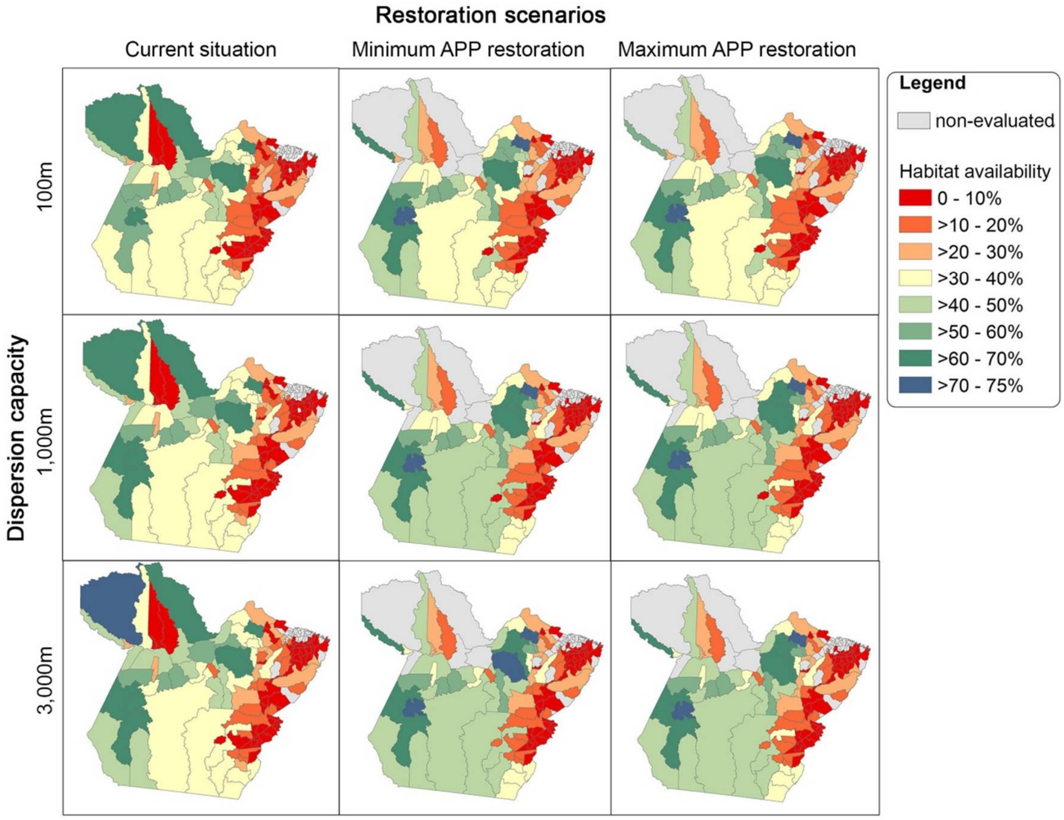

Figure 15. Current situation of habitat availability in the municipalities of Pará, for two future scenarios of APP restoration (minimum and maximum), and for species with different dispersion capacities (100, 1,000 and 3,000m). The non-evaluated municipalities presented topology problems in the forest remnant map utilized, making it impossible to calculate the correct habitat availability. Appendix V lists, by municipality, the habitat availability.

When comparing forest restoration expenditure (Planaveg scenarios described above) with the gain in landscape connectivity in these restored areas, we concluded that each BRL 1 million spent on restoration generates an approximate 1% increase in habitat availability (Table 11). This environmental gain falls by half when the maximum area of APP is restored, since the connectivity between fragments is established even in minimal APP areas and the APP increase can generate more costs than environmental effectiveness in this case. Few municipalities in the Marajó region had gains above 1% (Appendix VI), although costs in this region should be underestimated as soil biophysical conditions (i.e. floodplain areas) can hamper planting and species management. The cost-effectiveness indicator (expenditure on restoration divided by the gain in habitat availability) considered the average costs in the various Planaveg scenarios and the size of the APP to be restored (Table 11); indicators of habitat availability in municipalities.

Table 11. Average gain in habitat availability for each BRL 1 million spent on restoration (cost-effectiveness), in addition to the variance and standard deviation, in the different restoration scenarios. Appendix VI lists, by municipality, the relationship between cost and increased availability of forest habitat restoration

	Planaveg A			Planaveg B			Planaveg C		
	Dispersion: 100m	Dispersion: 1,000m	Dispersion: 3,000m	Dispersion: 100m	Dispersion: 1,000m	Dispersion: 3,000m	Dispersion: 100m	Dispersion: 1,000m	Dispersion: 3,000m
Minimum APP restoration									
Average	0.8%	0.8%	0.7%	0.9%	0.9%	0.9%	1.0%	1.0%	1.0%
Variance	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.3%	0.3%	0.3%
Standard Deviation	4.0%	4.0%	4.2%	4.5%	4.5%	4.7%	5.3%	5.2%	5.5%
Maximum APP restoration									
Average	0.3%	0.4%	0.4%	0.3%	0.4%	0.4%	0.3%	0.4%	0.4%
Variance	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Standard Deviation	1.5%	1.6%	2.0%	1.5%	1.6%	2.0%	1.5%	1.6%	2.0%

4. SUMMARY OF COSTS AND BENEFITS

This study estimated the total cost (opportunity cost plus implementation cost) to restore environmental deficits in Pará at between BRL 12.6 to BRL 16.7 billion (BRL 3.7 to BRL 6.1 billion for APP and an additional BRL 8.9 to BRL 10.6 billion for LR - Figure 16). We estimated the potential carbon credit gains at between BRL 6.4 and BRL 7.2 billion (BRL 1.8 to BRL 2.6 billion for APP and BRL 4.8 billion for LR - Figure 16), which would pay for the restoration implementation costs by up to 92% for LR and up to 74% for APP, depending on the Planaveg scenarios. Logging would pay for the LR restoration with a profit of up to BRL 2,110/ha (ANPV) in the case of marupá (*Simarouba amara*), or up to BRL 47.7 billion if we extrapolate this activity to 50% of the LR deficits registered in the CAR (Figure 16). AFS can enable the restoration of LR for small properties, but there are economic limitations for their large-scale implementation and uncertainties about where they can be effectively deployed. Thus, we estimated the financial benefit of AFS only for LR deficits on small properties (Nunes et al, 2016), classified up to four fiscal modules. With an average financial return of BRL 2,000/ha, these systems can generate up to BRL 446 million for the deficits of small producers in LR (with a standard deviation of BRL 600 million to BRL — 30 million depending on the productive arrangement of associated species). As an ecological benefit, we evaluated that habitat availability for fauna tends to increase with APP restoration and the cost-effectiveness ratio is approximately 1% of habitat increase for each BRL 1 million spent with restoration.

We emphasize that there are limits and obstacles to the large-scale adoption of the two activities that enabled the restoration of LR at the property level (AFS and logging). Although AFS are economically viable, with proven returns in the literature, labor intensive usage is an obstacle to large-scale adoption of these systems. The adoption of forestry management in an area to be restored can pay for the cost of restoration and environmental compliance of farms with forest deficits and is feasible on a large scale. However, we emphasize that logging is an activity of low liquidity and high risk compared to other agricultural activities, especially while there is still competition from illegal timber, so we cannot overestimate the adoption of this practice throughout the territory of Pará. The cost of transportation and difficulty of access in some regions should not be the greatest challenge, since the regions with the highest freight cost are also the areas with the greatest potential for natural regeneration due to proximity to large forest fragments and low fragmentation.

We emphasize that the LR deficit should not be fully resolved through restoration, since part of the deficits may be offset by areas outside the property with a surplus, reducing the total cost of large-scale restoration. Nunes et al. (2016) estimated a potential 11.3 Mha for compensation in Pará, which is five times greater than the deficit estimated here for that state. However, there is a lack of regulation and incentives to establish the marketing of these surpluses (e.g. through the CRAs market). In the case of Pará, which has more than half of its territory protected by law, the potential for natural regeneration is enormous. This would put the state in an even lower cost scenario with regard to restoration, closer to the Planaveg C scenario. Therefore, we consider this scenario as a reference in the summary of Figure 16.

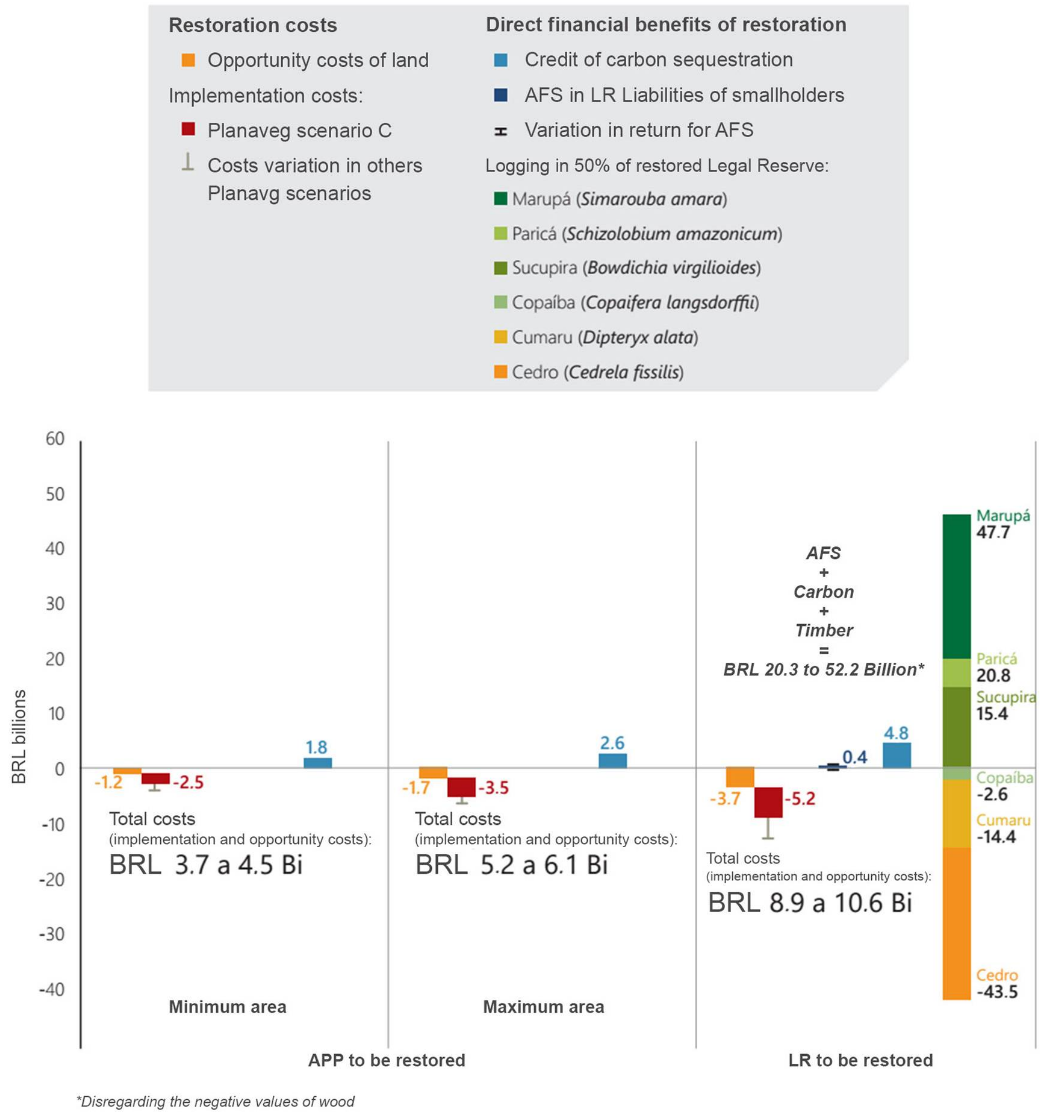

Figure 16. Comparative summary of the total costs and benefits evaluated (in present value), for LR and APP deficits subject to restoration in Pará, in billions of reais (BRL) (Figures for 2015, discount rate of 8.5% p.a.)

5. RECOMMENDATIONS

5.1. Recommendations for the restoration supply chain

Investing in Research and Development (R&D) for native production. The financial risk associated with native species is still high due to the uncertainties of the market, mortality rate and varied growth of the seedlings produced. For example, the production of native species should replicate the lessons of production of exotic species such as eucalyptus, which have already gone through a long period of genetic improvement and technological development to increase plant productivity.

Structure the value chain towards marketing and valorization of products from restored areas. Sustainable forest management in LR may pay for the cost of restoration in part or in full. Nevertheless, the value chain for native timber and forest products (e.g., non-timber such as fruits, oils and AFS) needs to be strengthened. This task involves several steps: establishment of a network of seed gatherers and production of seedlings; connecting the main actors involved with restoration; training and technical assistance; improving access to credit; mapping the demand and supply of regional products to identify opportunities that stimulate production.

Establish a state-level restoration strategy, using the map of priority conservation areas and coordinating actions with the agricultural sector. The government should define priority areas for restoration based on criteria that maximize environmental benefits and minimize conflicts with food production. For example, defining areas for restoration based on greater gains for biodiversity conservation (habitat availability) and the lower opportunity cost. Environmental agencies should develop coordinated actions and programs with agriculture agencies (government departments, Emater, etc.) to reduce institutional risks and offset the 20% of productive area that will be reduced with restoration. This type of spatial planning will allow maximum environmental benefit and minimal competition for land use.

5.2. Recommendations for policies that affect restoration

Validate the CAR and monitor compliance with the Forest Code. The environmental deficit can only be estimated accurately with a reliable CAR database, which will define the effective demand for restoration and/or compensation, and help to establish a compensation market. In addition, the CAR will permit better monitoring of compliance with the Forest Code, directing the policies of incentive or inspection for rural property and forest conservation planning of landscapes.

Establish a strategy for forest credit within the state's ABC plan and other financial mechanisms. Currently there are several financing lines for restoration and environmental regulation, although access to these resources is limited. At the state level, the government has the responsibility to promote actions that advance the national plan for Low Carbon Agriculture (ABC), which includes a line of credit for restoration. Producer awareness and training of technicians are part of the actions foreseen by the ABC Plan and the state government can create strategies to encourage restoration from this.

Implement mechanisms that will motivate restoration by landowners. Carbon credit may partially pay for the cost of large-scale restoration, but there is still a lack of financial mechanisms for funding and to ensure legal certainty for finance contracts of this type. Furthermore, the state government can develop incentive programs for producers who want to invest in restoration or are linked to the production of seed and seedlings. A good example can be found in the government of Espírito Santo's reforestation program (Benini et al., 2016), which supports restoration on private properties with the mapping of priority areas, definition of the most profitable forest arrangements with native species and payment of part of materials for restoration (e.g. lime, fertilizers, etc.). Furthermore, it is possible to implement incentive mechanisms for restoration by reducing interest rates on financing in order to progressively compensate producers who are restoring forest deficits.

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Appendix I. Detailing the costs of restoration

Table 12. Costs of restoration using various methods without logging in BRL/ha

			Total planting (1,666 ind/ha) com fencing		Planting with high enrichment and high density (800 ind/ha)		Planting with low enrichment and low density (400 ind/ha)		Natural regeneration with fencing around areas		Natural regeneration with abandonment of pasture (without fencing)	
Description	Units	Unit value	Quant.	Total value (R$/ha)	Quant.	Total value (R$/ha)	Quant.	Total value (R$/ha)	Quant.	Total value (R$/ha)	Quant.	Total value (R$/ha)
Total cost over 3 years				11,243		7,375		6,032		3,920		2,280
Implementation (year 1)				7,922		5,450		4,179		2,832		1,192
Preparation of area (firebreaks etc.)				1,192		1,192		1,192		1,192		1,192
Technical assistance (with costs)	daily	250	1.5	375	1.5	375	1.5	375	1.5	375	1.5	375
Herbicide	liter/ha	18	1.5	27	1.5	27	1.5	27	1.5	27	1.5	27
Machinery (tractor and others)	hour/ha	50	3	150	3	150	3	150	3	150	3	150
Labor (tractor driver and others)	daily	80	0.5	40	0.5	40	0.5	40	0.5	40	0.5	40
Field labor (with costs)	daily	60	10	600	10	600	10	600	10	600	10	600
Fencing (isolation)				1,640		1,640		1,640		1,640		
Wire, stakes, other	Km	5500	0.2	1,100	0.2	1,100	0.2	1,100	0.2	1,100		
Field labor (with costs)	daily	60	9	540	9.0	540	9	540	9	540		
Planting of seed and seedlings				5,090		2,618		1,347				
Technical assistance (with costs)	daily	250	1	240	2	500	1	250				
Native seedlings	unit	1.5	1,666.00	2,499	800	1,200	400	600				
Seeds	Kg	35			1.0	35	1	35				
Nitrogenous fertilizer, ammonium sulphate (base 30g + coverage 60g/furrow	Kg/ha	1.2	134	161	64	77	32	38				
Phosphate fertilizer (P205, base 30g by seed)	Kg/ha	1.2	100	120								
Potassium chlorate KCL (base 30g + coverage 60g/furrow	Kg/ha	1.2	150	180	72	86	36	43				
Seed freight	daily	200	1	200								
Machinery (tractor and others)	hour/ha	50			4	200	2	100				
Labor (tractor driver and others)	daily	80			0.5	40	0.5	40				
Field labor (with costs) - opening furrows, crowning, planting and fertilizing	daily	60	28	1,680	8	480	4	240				
Maintenance (quantity for 2 years)				3,321		1,925		1,853		1,088		1,088
Firebreaks and weeding				1,160		1,160		1,088		1,088		1,088
Herbicide	litre/ha	18	10	180	10	180	6	108	6	108	6	108
Technical assistance (with costs)	daily	250	2	500	2	500	2	500	2	500	2	500
Field labor (with costs)	daily	60	8	480	8	480	8	480	8	480	8	480
Replanting of seed and seedlings (approx. 17% mortality)				2,161		765		765		765		
Technical assistance (with costs)	daily	250	4	1,000	1	250	1	250		250		
Native seedlings	unit	1.5	280	420								
Seeds	Kg	35			1	35	1	35				
Nitrogenous fertilizer, ammonium sulphate (base 30g + coverage 60g/furrow	Kg/ha	1.2	17	20								
Phosphate fertilizer (P205, base 30g)	Kg/ha	1.2	17	20								
Potassium chlorate KUL (base 30g + coverage 60g/furrow	Kg/ha	1.2	17	20								
Seed freight	daily	200	1	200								
Field labor (with charges) - distribution of seedlings and planting	daily	60	8	480	8	480	8	480				

Source: Field data and consultations with the Amata and Bioflora companies, and Ricardo Rodrigues (Esalq).

Table 13. Costs of implantation and maintenance of restoration with logging in BRL/ha

			Year 1: Implementation		Year 2 until before extraction of timber		Year of extraction	
Description	Units	Unit value	Quant.	Total value (R$/ha)	Quant.	Total value (R$/ha)	Quant.	Total value (R$/ha)
Total cost over 3 years				6,282		1,321		3,770
Implementation (year 1)				6,282		161		
Preparation of area (firebreaks etc.)				1,192				
Technical assistance (with costs)	daily	250	1.5	375				
Herbicide	liter/ha	18	1.5	27				
Machinery (tractor and others)	hour/ha	50	3	150				
Labor (tractor driver and others)	daily	80	0.5	40				
Field labor (with costs)	daily	60	10	600				
Fencing (isolation)								
Wire, stakes, other	Km	5,500	0					
Field labor (with costs)	daily	60	0					
Planting of seed and seedlings				5,090		161		
Technical assistance (with costs)	daily	250	1	250				
Native seedlings	unit	1.5	1,666	2,499				
Nitrogenous fertilizer, ammonium sulphate (base 30g + coverage 60g/furrow	Kg/ha	1.2	134	161	134	161		
Phosphate fertilizer (P205, base 30g by seed)	Kg/ha	1.2	100	120				
Potassium chlorate KCL (base 30g + coverage 60g/furrow	Kg/ha	1.2	150	180				
Seed freight	daily	200	1	200				
Field labor (with costs) - opening furrows, crowning, planting and fertilizing	daily	60	28	1,680				
Maintenance and replanting						1,160		3,770
Firebreaks and weeding						1,160		1,160
Herbicide	litre/ha	18			10	180	10	180
Technical assistance (with costs)	daily	250			2	500	2	500
Field labor (with costs)	daily	60			8	480	8	480
Replanting of seed and seedlings (approx. 17% mortality)								2,610
Technical assistance (with costs)	daily	250					2	500
Native seedlings	unit	1.5					883	1,250
Nitrogenous fertilizer, ammonium sulphate (base 30g + coverage 60g/furrow	Kg/ha	1.2					50	60
Phosphate fertilizer (P205, base 30g)	Kg/ha	1.2					50	60
Potassium chloride KCL (base 30g + coverage 60g/furrow	Kg/ha	1.2					50	60
Seed freight	daily	200					1	200
Field labor (with charges) - distribution of seedlings and planting	daily	60					8	480

Source: Developed with field data from paragominas, combined with information from LERF (Esalq) and the Bioflora and Amata companies.

Appendix II. Land prices in the Pará municipalities in 2014

Municipal	Agricultural land	Pasture	Forest	Average land prices
ABAETETUBA	1,556	1,758	500	1,447
ABEL FIGUEIREDO	-	3,512	1,754	2,926
ACARÁ	1,556	1,758	500	1,447
AFUÁ	-	250	-	250
ÁGUA AZUL DO NORTE	-	3,512	1,754	2,926
ALENQUER	5,711	1,363	1,127	2,492
ALMEIRIM	5,711	1,654	1,127	2,492
ALTAMIRA	5,711	1,654	1,127	2,492
ANAJÁS	-	250	-	250
ANANINDEUA	1,556	1,758	500	1,447
ANAPU	-	3,512	1,754	2,926
AUGUSTO CORRÊA	1,556	1,758	500	1,447
AURORA DO PARÁ	1,556	1,758	500	1,447
AVEIRO	5,711	1,654	1,127	2,492
BAGRE	-	250	-	250
BAIÃO	-	250	-	250
BANNACH	-	3,512	1,754	2,926
BARCARENA	1,556	1,758	500	1,447
BELÉM	1,556	1,758	500	1,447
BELTERRA	5,711	2,600	1,127	2,492
BENEVIDES	1,556	1,758	500	1,447
BOM JESUS DO TOCANTINS	-	3,512	1,754	2,926
BONITO	1,556	1,758	500	1,447
BRAGANÇA	1,556	1,758	500	1,447
BRASIL NOVO	5,711	1,654	1,127	2,492
BREJO GRANDE DO ARAGUAIA	-	3,512	1,754	2,926
BREU BRANCO	7,367	4,033	2,559	4,110
BREVES	-	250	-	250
BUJARU	1,556	1,758	500	1,447
CACHOEIRA DO PIRIÁ	7,367	4,033	2,559	4,110
CACHOEIRA DO ARARI	-	250	-	250
CAMETÁ	-	250	-	250
CANÃA DOS CARAJÁS	-	3,512	1,754	2,926
CAPANEMA	1,556	1,758	500	1,447
CAPITAO POÇO	1,556	1,758	500	1,447
CASTANHAL	1,556	1,758	500	1,447
CHAVES	-	250	-	250
COLARES	1,556	1,758	500	1,447
CONCEIÇÃO DO ARAGUAIA	-	3,512	1,754	2,926
CONCÓRDIA DO PARÁ	1,556	1,758	500	1,447
CUMARU DO NORTE	-	3,512	1,754	2,926
CURIONÓPOLIS	-	3,512	1,754	2,926
CURRALINHO	-	250	-	250
CURUÁ	5,711	1,654	1,127	2,492
CURUÇA	1,556	1,758	500	1,447
DOM ELISEU	7,367	4,033	2,559	4,110
ELDORADO DOS CARAJÁS	-	3,512	1,754	2,926
FARO	5,711	1,654	1,127	2,492
FLORESTA DO ARAGUAIA	-	3,512	1,754	2,926
GARRAFÃO DO NORTE	1,556	1,758	500	1,447
GOIANÉSIA DO PARÁ	7,367	4,033	2,559	4,110
GURUPÁ	-	250	-	250
IGARAPÉ-AÇU	1,556	1,758	500	1,447
IGARAPÉ-MIRI	1,556	1,758	500	1,447
INHANGAPI	1,556	1,758	500	1,447
IPIXUNA DO PARÁ	7,367	4,033	2,559	4,110
IRITUIA	1,556	1,758	500	1,447
ITAITUBA	5,711	1,654	1,127	2,492
ITUPIRANGA	-	3,512	1,754	2,926
JACAREACANGA	5,711	1,654	1,127	2,492
JACUNDÁ	-	3,512	1,754	2,926

JURUTI	5,711	1,654	1,127	2,492
LIMOEIRO DO AJURU	-	250	-	250
MÃE DO RIO	1,556	1,758	500	1,447
MAGALHÃES BARATA	1,556	1,758	500	1,447
MARABÁ	-	3,717	1,754	2,926
MARACANÃ	1,556	1,758	500	1,447
MARAPANIM	1,556	1,758	500	1,447
MARITUBA	1,556	1,758	500	1,447
MEDICILÂNDIA	5,711	1,654	1,127	2,492
MELGAÇO	-	250	-	250
MOCAJUBA	1,556	1,758	500	1,447
MOJU	1,556	1,758	500	1,447
MONTE ALEGRE	5,711	1,363	1,127	2,492
MUANÁ	-	250	-	250
NOVA ESPERANÇA DO PIRIÁ	7,367	4,033	2,559	4,110
NOVA IPIXUNA	-	3,512	1,754	2,926
NOVA TIMBOTEUA	1,556	1,758	500	1,447
NOVO PROGRESSO	5,711	1,654	1,127	2,492
NOVO REPARTIMENTO	-	3,512	1,754	2,926
ÓBIDOS	5,711	1,654	1,127	2,492
OEIRAS DO PARÁ	-	250	-	250
ORIXIMINÁ	5,711	1,363	1,127	2,492
OURÉM	1,556	1,758	500	1,447
OURILÂNDIA DO NORTE	-	3,512	1,754	2,926
PACAJÁ	-	3,512	1,754	2,926
PALESTINA DO PARÁ	-	3,512	1,754	2,926
PARAGOMINAS	7,367	4,033	2,559	4,110
PARAUAPEBAS	-	3,512	1,754	2,926
PAU D'ARCO	-	3,512	1,754	2,926
PEIXE-BOI	1,556	1,758	500	1,447
PIÇARRA	-	3,512	1,754	2,926
PLACAS	5,711	1,654	1,127	2,492
PONTA DE PEDRAS	-	250	-	250
PORTEL	-	250	-	250
PORTO DE MOZ	-	250	-	250
PRAINHA	5,711	1,654	1,127	2,492
PRIMAVERA	1,556	1,758	500	1,447
QUATIPURU	1,556	1,758	500	1,447
REDENÇÃO	-	3,650	1,754	2,926
RIO MARIA	-	3,512	1,754	2,926
RONDON DO PARÁ	7,367	4,033	2,559	4,110
RURÓPOLIS	5,711	1,654	1,127	2,492
SALINÓPOLIS	1,556	1,758	500	1,447
SALVATERRA	-	250	-	250
SANTA BÁRBARA DO PARÁ	1,556	1,758	500	1,447
SANTA CRUZ DO ARARI	-	250	-	250
SANTA ISABEL DO PARÁ	1,556	1,758	500	1,447
SANTA LUZIA DO PARÁ	1,556	1,758	500	1,447
SANTA MARIA DAS BARREIRAS	-	3,512	1,754	2,926
SANTA MARIA DO PARÁ	1,556	1,758	500	1,447
SANTANA DO ARAGUAIA	-	3,512	1,754	2,926
SANTARÉM	5,711	2,600	1,127	2,492
SANTARÉM NOVO	1,556	1,758	500	1,447
SANTO ANTONIO DO TAUÁ	1,556	1,758	500	1,447
SÃO CAETANO DE ODIVELAS	1,556	1,758	500	1,447
SÃO DOMINGOS DO ARAGUAIA	-	3,512	1,754	2,926
SÃO DOMINGOS DO CAPIM	1,556	1,758	500	1,447
SÃO FELIX DO XINGU	-	3,150	1,754	2,926
SÃO FRANCISCO DO PARÁ	1,556	1,758	500	1,447
SÃO GERALDO DO ARAGUAIA	-	3,512	1,754	2,926
SÃO JOÃO DA PONTA	1,556	1,758	500	1,447
SÃO JOÃO DE PIRABAS	1,556	1,758	500	1,447
SÃO JOÃO DO ARAGUAIA	-	3,512	1,754	2,926
SÃO MIGUEL DO GUAMÁ	1,556	1,758	500	1,447

SÃO SEBASTIÃO DA BOA VISTA	-	250	-	250
SAPUCAIA	-	3,512	1,754	2,926
SENADOR JOSE PORFÍRIO	-	3,512	1,754	2,926
SOURE	-	250	-	250
TAILÂNDIA	7,367	4,033	2,559	4,110
TERRA ALTA	1,556	1,758	500	1,447
TERRA SANTA	5,711	1,654	1,127	2,492
TOME-AÇU	7,367	4,033	2,559	4,110
TRACUATEUA	1,556	1,758	500	1,447
TRAIRÃO	5,711	1,654	1,127	2,492
TUCUMÃ	-	3,533	1,754	2,926
TUCURUÍ	-	250	-	250
ULIANÓPOLIS	7,367	4,033	2,559	4,110
URUARÁ	5,711	1,654	1,127	2,492
VIGIA	1,556	1,758	500	1,447
VISEU	1,556	1,758	500	1,447
VITÓRIA DO XINGU	5,711	1,654	1,127	2,492
XINGUARA	-	3,512	1,754	2,926

Appendix III. Estimation of minimum and maximum APP restoration and restoration costs in various scenarios, by municipality

Municipal	Min. area	Max. area	Restoration costs (BRL millions)					
			Planaveg A		Planaveg B		Planaveg C	
			Mín.	Max.	Mín.	Max.	Mín.	Max.
ABAETETUBA	439	831	2.9	5.2	2.6	4.8	2.2	4.2
ABEL FIGUEIREDO	1204	2317	8.0	14.5	7.0	13.5	6.0	11.6
ACARÁ	1366	2317	9.0	14.5	7.9	13.5	6.8	11.6
AFUÁ	202	332	1.3	2.1	1.2	1.9	1.0	1.7
ÁGUA AZUL DO NORTE	22031	30902	145.9	193.2	128.0	179.5	110.1	154.4
ALENQUER	5238	7416	34.7	46.4	30.4	43.1	26.2	37.0
ALMEIRIM	4835	6272	32.0	39.2	28.1	36.4	24.2	31.3
ALTAMIRA	24853	32422	164.6	202.7	144.4	188.4	124.1	162.0
ANAJÁS	294	561	1.9	3.5	1.7	3.3	1.5	2.8
ANANINDEUA	214	648	1.4	4.1	1.2	3.8	1.1	3.2
ANAPU	9007	11049	59.7	69.1	52.3	64.2	45.0	55.2
AUGUSTO CORRÊA	328	850	2.2	5.3	1.9	4.9	1.6	4.2
AURORA DO PARÁ	1938	3095	12.8	19.4	11.3	18.0	9.7	15.5
AVEIRO	3748	5702	24.8	35.7	21.8	33.1	18.7	28.5
BAGRE	314	680	2.1	4.3	1.8	4.0	1.6	3.4
BAIÃO	2844	4836	18.8	30.2	16.5	28.1	14.2	24.2
BANNACH	15221	21127	100.8	132.1	88.4	122.7	76.0	105.5
BARCARENA	197	506	1.3	3.2	1.1	2.9	1.0	2.5
BELÉM	472	1378	3.1	8.6	2.7	8.0	2.4	6.9
BELTERRA	1470	2404	9.7	15.0	8.5	14.0	7.3	12.0
BENEVIDES	200	483	1.3	3.0	1.2	2.8	1.0	2.4
BOM JESUS DO TOCANTINS	3995	5921	26.5	37.0	23.2	34.4	20.0	29.6
BONITO	1274	2409	8.4	15.1	7.4	14.0	6.4	12.0
BRAGANÇA	797	1798	5.3	11.2	4.6	10.4	4.0	9.0
BRASIL NOVO	6934	8685	45.9	54.3	40.3	50.5	34.6	43.4
BREJO GRANDE DO ARAGUAIA	3806	6145	25.2	38.4	22.1	35.7	19.0	30.7
BREU BRANCO	6121	10109	40.5	63.2	35.6	58.7	30.6	50.5
BREVES	223	468	1.5	2.9	1.3	2.7	1.1	2.3
BUJARU	156	330	1.0	2.1	0.9	1.9	0.8	1.6
CACHOEIRA DO PIRIÁ	3077	4573	20.4	28.6	17.9	26.6	15.4	22.8
CACHOEIRA DO ARARI	38	92	0.3	0.6	0.2	0.5	0.2	0.5
CAMETÁ	474	1127	3.1	7.0	2.8	6.5	2.4	5.6
CANAA DOS CARAJÁS	10437	14438	69.1	90.3	60.6	83.9	52.1	72.1
CAPANEMA	969	2175	6.4	13.6	5.6	12.6	4.8	10.9
CAPITÃO POÇO	2864	5079	19.0	31.8	16.6	29.5	14.3	25.4
CASTANHAL	598	1196	4.0	7.5	3.5	6.9	3.0	6.0
CHAVES	195	389	1.3	2.4	1.1	2.3	1.0	1.9
COLARES	17	46	0.1	0.3	0.1	0.3	0.1	0.2
CONCEIÇÃO DO ARAGUAIA	11355	17879	75.2	111.8	66.0	103.9	56.7	89.3
CONCÓRDIA DO PARÁ	161	337	1.1	2.1	0.9	2.0	0.8	1.7
CUMARU DO NORTE	39785	49129	263.5	307.2	231.1	285.4	198.7	245.4
CURIONÓPOLIS	10483	17058	69.4	106.7	60.9	99.1	52.4	85.2
CURRALINHO	427	755	2.8	4.7	2.5	4.4	2.1	3.8
CURUÁ	921	1605	6.1	10.0	5.4	9.3	4.6	8.0
CURUÇÁ	154	321	1.0	2.0	0.9	1.9	0.8	1.6
DOM ELISEU	8981	11221	59.5	70.2	52.2	65.2	44.9	56.1
ELDORADO DOS CARAJÁS	12776	19997	84.6	125.0	74.2	116.2	63.8	99.9
FARO	1017	1778	6.7	11.1	5.9	10.3	5.1	8.9
FLORESTA DO ARAGUAIA	7613	12807	50.4	80.1	44.2	74.4	38.0	64.0
GARRAFÃO DO NORTE	1517	2888	10.0	18.1	8.8	16.8	7.6	14.4
GOIANÉSIA DO PARÁ	7900	12486	52.3	78.1	45.9	72.5	39.5	62.4
GURUPÁ	240	390	1.6	2.4	1.4	2.3	1.2	1.9
IGARAPÉ-AÇU	640	1133	4.2	7.1	3.7	6.6	3.2	5.7
IGARAPÉ-MIRI	399	722	2.6	4.5	2.3	4.2	2.0	3.6
INHANGAPI	145	339	1.0	2.1	0.8	2.0	0.7	1.7
IPIXUNA DO PARÁ	4886	7584	32.4	47.4	28.4	44.1	24.4	37.9
IRITUIA	1698	3151	11.2	19.7	9.9	18.3	8.5	15.7
ITAITUBA	15318	22780	101.5	142.4	89.0	132.3	76.5	113.8
ITUPIRANGA	14779	19354	97.9	121.0	85.9	112.4	73.8	96.7
JACAREACANGA	4808	7640	31.8	47.8	27.9	44.4	24.0	38.2
JACUNDÁ	5556	8505	36.8	53.2	32.3	49.4	27.8	42.5

JURUTI	1889	3541	12.5	22.1	11.0	20.6	9.4	17.7
LIMOEIRO DO AJURU	36	82	0.2	0.5	0.2	0.5	0.2	0.4
MÃE DO RIO	711	1436	4.7	9.0	4.1	8.3	3.6	7.2
MAGALHÃES BARATA	73	143	0.5	0.9	0.4	0.8	0.4	0.7
MARABÁ	24260	30499	160.7	190.7	140.9	177.2	121.2	152.4
MARACANÃ	224	417	1.5	2.6	1.3	2.4	1.1	2.1
MARAPANIM	183	364	1.2	2.3	1.1	2.1	0.9	1.8
MARITUBA	153	455	1.0	2.8	0.9	2.6	0.8	2.3
MEDICILÂNDIA	5739	8165	38.0	51.1	33.3	47.4	28.7	40.8
MELGAÇO	313	493	2.1	3.1	1.8	2.9	1.6	2.5
MOCAJUBA	281	760	1.9	4.8	1.6	4.4	1.4	3.8
MOJU	3506	5092	23.2	31.8	20.4	29.6	17.5	25.4
MOJUÍ DOS CAMPOS	2601	4213	17.2	26.3	15.1	24.5	13.0	21.0
MONTE ALEGRE	5218	7835	34.6	49.0	30.3	45.5	26.1	39.1
MUANÁ	227	616	1.5	3.9	1.3	3.6	1.1	3.1
NOVA ESPERANÇA DO PIRIÁ	2288	3967	15.2	24.8	13.3	23.0	11.4	19.8
NOVA IPIXUNA	3170	4825	21.0	30.2	18.4	28.0	15.8	24.1
NOVA TIMBOTEUA	715	1274	4.7	8.0	4.2	7.4	3.6	6.4
NOVO PROGRESSO	22496	27567	149.0	172.4	130.7	160.2	112.4	137.7
NOVO REPARTIMENTO	23307	31869	154.4	199.3	135.4	185.1	116.4	159.2
ÓBIDOS	4721	7127	31.3	44.6	27.4	41.4	23.6	35.6
OEIRAS DO PARÁ	572	1164	3.8	7.3	3.3	6.8	2.9	5.8
ORIXIMINÁ	4045	5993	26.8	37.5	23.5	34.8	20.2	29.9
OURÉM	753	1537	5.0	9.6	4.4	8.9	3.8	7.7
OURILÂNDIA DO NORTE	12919	15887	85.6	99.3	75.1	92.3	64.5	79.4
PACAJÁ	16628	19910	110.1	124.5	96.6	115.7	83.1	99.5
PALESTINA DO PARÁ	2740	5011	18.1	31.3	15.9	29.1	13.7	25.0
PARAGOMINAS	17339	20792	114.9	130.0	100.7	120.8	86.6	103.9
PARAUAPEBAS	3570	6756	23.6	42.2	20.7	39.2	17.8	33.7
PAU D'ARCO	4749	8043	31.5	50.3	27.6	46.7	23.7	40.2
PEIXE-BOI	636	1401	4.2	8.8	3.7	8.1	3.2	7.0
PIÇARRA	12954	19793	85.8	123.8	75.3	115.0	64.7	98.9
PLACAS	7128	9588	47.2	59.9	41.4	55.7	35.6	47.9
PONTA DE PEDRAS	46	139	0.3	0.9	0.3	0.8	0.2	0.7
PORTEL	3977	6128	26.3	38.3	23.1	35.6	19.9	30.6
PORTO DE MOZ	2380	3475	15.8	21.7	13.8	20.2	11.9	17.4
PRAINHA	4405	6486	29.2	40.6	25.6	37.7	22.0	32.4
PRIMAVERA	302	588	2.0	3.7	1.8	3.4	1.5	2.9
QUATIPURU	90	221	0.6	1.4	0.5	1.3	0.4	1.1
REDENÇÃO	13481	19663	89.3	122.9	78.3	114.2	67.3	98.2
RIO MARIA	18251	25489	120.9	159.4	106.0	148.1	91.2	127.3
RONDON DO PARÁ	7370	10853	48.8	67.9	42.8	63.1	36.8	54.2
RUROPÓLIS	5444	7934	36.1	49.6	31.6	46.1	27.2	39.6
SALINÓPOLIS	328	532	2.2	3.3	1.9	3.1	1.6	2.7
SALVATERRA	171	404	1.1	2.5	1.0	2.3	0.9	2.0
SANTA BÁRBARA DO PARÁ	47	129	0.3	0.8	0.3	0.7	0.2	0.6
SANTA CRUZ DO ARARI	22	37	0.1	0.2	0.1	0.2	0.1	0.2
SANTA ISABEL DO PARÁ	327	620	2.2	3.9	1.9	3.6	1.6	3.1
SANTA LUZIA DO PARÁ	1155	2359	7.7	14.7	6.7	13.7	5.8	11.8
SANTA MARIA DAS BARREIRAS	23790	33646	157.6	210.4	138.2	195.5	118.8	168.1
SANTA MARIA DO PARÁ	541	1274	3.6	8.0	3.1	7.4	2.7	6.4
SANTANA DO ARAGUAIA	24804	35064	164.3	219.2	144.1	203.7	123.9	175.2
SANTARÉM	2280	3871	15.1	24.2	13.2	22.5	11.4	19.3
SANTARÉM NOVO	134	314	0.9	2.0	0.8	1.8	0.7	1.6
SANTO ANTÔNIO DO TAUÁ	103	257	0.7	1.6	0.6	1.5	0.5	1.3
SÃO CAETANO DE ODIVELAS	62	147	0.4	0.9	0.4	0.9	0.3	0.7
SÃO DOMINGOS DO ARAGUAIA	5242	7417	34.7	46.4	30.5	43.1	26.2	37.1
SÃO DOMINGOS DO CAPIM	888	1521	5.9	9.5	5.2	8.8	4.4	7.6
SÃO FELIX DO XINGU	72204	79778	478.3	498.8	419.5	463.5	360.7	398.5
SÃO FRANCISCO DO PARÁ	397	815	2.6	5.1	2.3	4.7	2.0	4.1
SÃO GERALDO DO ARAGUAIA	11672	17711	77.3	110.7	67.8	102.9	58.3	88.5
SÃO JOÃO DA PONTA	91	156	0.6	1.0	0.5	0.9	0.5	0.8
SÃO JOÃO DE PIRABAS	306	595	2.0	3.7	1.8	3.5	1.5	3.0
SÃO JOÃO DO ARAGUAIA	2062	3469	13.7	21.7	12.0	20.2	10.3	17.3
SÃO MIGUEL DO GUAMÁ	991	1826	6.6	11.4	5.8	10.6	5.0	9.1
SÃO SEBASTIÃO DA BOA VISTA	831	1170	5.5	7.3	4.8	6.8	4.2	5.8
SAPUCAIA	5813	10079	38.5	63.0	33.8	58.6	29.0	50.3
SENADOR JOSÉ PORFÍRIO	3839	5333	25.4	33.3	22.3	31.0	19.2	26.6

SOURE	62	212	0.4	1.3	0.4	1.2	0.3	1.1
TAILÂNDIA	4857	6548	32.2	40.9	28.2	38.0	24.3	32.7
TERRA ALTA	90	205	0.6	1.3	0.5	1.2	0.4	1.0
TERRA SANTA	870	1184	5.8	7.4	5.1	6.9	4.3	5.9
TOMÉ-AÇU	1772	2748	11.7	17.2	10.3	16.0	8.9	13.7
TRACUATEUA	420	860	2.8	5.4	2.4	5.0	2.1	4.3
TRAIRÃO	5218	7756	34.6	48.5	30.3	45.1	26.1	38.7
TUCUMÃ	8376	14270	55.5	89.2	48.7	82.9	41.8	71.3
TUCURUÍ	4584	7671	30.4	48.0	26.6	44.6	22.9	38.3
ULIANÓPOLIS	12406	15246	82.2	95.3	72.1	88.6	62.0	76.2
URUARÁ	11741	15326	77.8	95.8	68.2	89.0	58.7	76.6
VIGIA	79	201	0.5	1.3	0.5	1.2	0.4	1.0
VISEU	3029	5265	20.1	32.9	17.6	30.6	15.1	26.3
VITÓRIA DO XINGU	5654	7787	37.5	48.7	32.8	45.2	28.2	38.9
XINGUARA	10803	19031	71.6	119.0	62.8	110.6	54.0	95.1

Source: Nunes et al (in press).

Appendix IV. Carbon sequestration and potential net revenue (in present value) from carbon sequestration

Table 14. Costs and revenue (in Present Value) potential for carbon credit in the LR to be restored on real estate registered in the CAR

	Annual area to be restored	**tCO_2 sequestrated[11] and revenue (BRL millions)**		**Cost of restoration[12] (BRL millions)**			**Annual NPV (BRL millions)**		
		Tons of annual CO_2 equivalent sequestration	**Revenue (BRL), in Present Value**	**Scenario A**	**Scenario B**	**Scenario C**	**Scenario A**	**Scenario B**	**Scenario C**
Year 1	113,455	5,260,984	63	484	423	361	-422	-360	-298
Year 2	113,455	10,521,968	116	544	476	408	-428	-360	-292
Year 3	113,455	15,782,952	161	591	518	446	-430	-358	-285
Year 4	113,455	21,043,936	198	545	478	411	-348	-281	-214
Year 5	113,455	26,304,920	228	503	442	380	-275	-213	-151
Year 6	113,455	31,565,904	253	465	408	350	-212	-155	-98
Year 7	113,455	36,826,889	272	429	376	323	-157	-104	-51
Year 8	113,455	42,087,873	287	396	347	299	-109	-60	-11
Year 9	113,455	47,348,857	298	365	321	276	-67	-22	23
Year 10	113,455	52,609,841	306	337	296	254	-32	10	51
Year 11	113,455	54,961,087	295	311	273	235	-16	22	60
Year 12	113,455	57,312,333	284	287	252	217	-4	32	67
Year 13	113,455	59,663,579	273	265	233	200	7	40	73
Year 14	113,455	62,014,825	262	245	215	185	17	47	77
Year 15	113,455	62,984,354	245	226	198	170	19	47	75
Year 16	113,455	63,953,882	230	209	183	157	21	47	73
Year 17	113,455	64,923,410	215	193	169	145	23	47	70
Year 18	113,455	65,892,938	202	178	156	134	24	46	68
Year 19	113,455	66,862,467	189	164	144	124	25	45	65
Year 20	113,455	67,831,995	177	151	133	114	26	44	63
Year 21	-	62,571,011	151	42	37	33	109	113	118
Year 22	-	57,310,027	127	19	17	15	108	110	112
Total	**2.269.100**		**4,831**	**6,951**	**6,094**	**5,237**	**-2,120**	**-1,263**	**-405**
Cost/benefit ratio (% of restoration potentially paid by carbon credit)							**70%**	**80%**	**92%**

Source: Prepared by the author considering: USD 5,00/tCO_2 equivalent; exchange rate of BRL 2.59; discount rate of 8.5% p.a.

[11] We multiplied the value of tCO_2 equivalent by the annual area restored in each species group (short, medium and long cycle) during the average time of sequestration of each species (See Table 7). In our model, the short-term species (average growth time of 10 years) occupy 50% of the area, medium-term species, 25% (average growth time of 14 years) and long-term species, 25% of the area (average growth time of 20 years). The amount planted is 1,666 individuals per hectare.

To calculate the total cost of restoration, we multiplied the price (BRL/ha) of each restoration method by the corresponding area in the various Planaveg scenarios

[12] To calculate the total cost of restoration, we multiplied the price (BRL/ha) of each restoration method by the corresponding area in the various Planaveg scenarios

Table 15. Costs and revenue (in Present Value) potential of carbon credit in minimum APP to be restored in the State of Pará

	Annual area to be restored	tCO_2 sequestrated[13] and revenue (millions of BRL)		Cost of restoration[14] (BRL millions)			NPV annual (BRL millions)		
		Annual sequestration of CO2 equivalent tonne	Revenue (BRL mi), in Present Value	Scenario A	Scenario B	Scenario C	Scenario A	Scenario B	Scenario C
Year 1	84.433	3,915,230	47	360	314	268	-314	-268	-222
Year 2	84.433	7,830,460	86	405	354	304	-318	-268	-217
Year 3	84.433	11,745,690	120	440	386	332	-320	-266	-212
Year 4	84.433	15,660,920	147	406	356	306	-259	-209	-159
Year 5	84.433	19,576,150	170	375	329	283	-205	-159	-113
Year 6	84.433	23,491,380	188	346	303	261	-158	-115	-73
Year 7	84.433	27,406,610	203	319	280	241	-117	-77	-38
Year 8	84.433	31,321,840	214	295	258	222	-81	-45	-9
Year 9	84.433	35,237,070	222	272	239	205	-50	-17	17
Year 10		39,152,300	228	76	67	59	152	160	169
Year 11		40,902,100	219	35	31	27	185	188	192
Total	**759,900**		**1,843**	**3,328**	**2,918**	**2,507**	**-1,485**	**-1,074**	**-664**
Cost/benefit ratio (% of restoration potentially paid by carbon credit)							**55%**	**63%**	**74%**

Source: Prepared by author considering: UD$5.00/tCO2 equivalent; Exchange rate of 2.59 BRL; discount rate of 8.5% p.a.

Table 16. Costs and revenue (in Present Value) potential of carbon credit for the maximum APP to be restored in the state of Pará

	Annual area to be restored	tCO_2 captured[15] and revenue (millions BRL)		Cost of restoration[16] (millions BRL)			Annual NPV (millions BRL)		
		Annual sequestration of CO2 equivalent tonne	Revenue (BRL mi), Present Value	Scenario A	Scenario B	Scenario C	Scenario A	Scenario B	Scenario C
Year 1	119,044	5,520,129	66	474	443	378	-408	-377	-312
Year 2	119,044	11,040,258	122	533	499	428	-411	-377	-306
Year 3	119,044	16,560,387	169	585	544	468	-417	-375	-299
Year 4	119,044	22,080,517	208	540	502	432	-333	-294	-224
Year 5	119,044	27,600,646	239	499	463	398	-259	-224	-159
Year 6	119,044	33,120,775	265	460	428	368	-195	-162	-102
Year 7	119,044	38,640,904	286	425	395	339	-139	-109	-54
Year 8	119,044	44,161,033	301	392	364	313	-91	-63	-12
Year 9	119,044	49,681,162	313	362	336	289	-49	-23	24
Year 10		55,201,291	321	104	95	83	217	226	238
Year 11		57,668,355	309	49	44	38	260	266	271
Total	**1.071.392**		**2,599**	**4,423**	**4,113**	**3,535**	**-1,824**	**-1,515**	**-936**
Cost/benefit ratio (% of restoration potentially paid by carbon credit)							**59%**	**63%**	**74%**

Source: Prepared by author considering: USD 5.00/tCO_2 equivalent; Forex rate BRL 2.59; discount rate of 8.5% p.a.

[13] Idem note 11.
[14] Idem note 12.
[15] Idem note 11.
[16] Idem note 12.

Appendix V. Indicator of habitat availability according to the scenarios (current situation and restoration of APP), species with different dispersion capacities (100, 1000 and 3000 m), by municipality in the state of Pará.

Municipality	Current scenario, dispersion of 100m	Current scenario, dispersion of 1,000m	Current scenario, dispersion of 3,000m	Minimum APP restoration, dispersion of 100m	Minimum APP restoration, dispersion of 1,000m	Minimum APP restoration, dispersion of 3,000m	Maximum APP restoration, dispersion of 100m	Maximum APP restoration, dispersion of 1,000m	Maximum APP restoration, dispersion of 3,000m
ABAETETUBA	0.14	0.18	0.18	0.13	0.17	0.18	0.14	0.17	0.18
ABEL FIGUEIREDO	0.03	0.03	0.03						
ACARÁ	0.14	0.19	0.2	0.14	0.19	0.2	0.14	0.19	0.2
AFUÁ	0.33	0.36	0.37	0.33	0.37	0.38	0.33	0.37	0.38
ÁGUA AZUL DO NORTE	0.09	0.1	0.1	0.12	0.13	0.13	0.12	0.13	0.13
ALENQUER	0.08	0.1	0.1	0.26	0.28	0.28	0.27	0.28	0.28
ALMEIRIM	0.68	0.69	0.69	0.56	0.57	0.57	0.56	0.57	0.57
ALTAMIRA	0.38	0.39	0.4	0.39	0.41	0.42	0.4	0.41	0.42
ANAJÁS	0.7	0.7	0.7	0.71	0.73	0.73	0.71	0.73	0.73
ANANINDEUA				0.1	0.17	0.19	0.1	0.17	0.19
ANAPU	0.48	0.5	0.5	0.52	0.53	0.54	0.52	0.53	0.54
AUGUSTO CORRÊA				0.04	0.05	0.05	0.04	0.05	0.05
AURORA DO PARÁ	0.01	0.02	0.02	0.01	0.02	0.03	0.01	0.02	0.03
AVEIRO	0.54	0.55	0.56	0.58	0.59	0.59	0.57	0.59	0.59
BAGRE	0.67	0.68	0.68	0.68	0.69	0.69	0.68	0.69	0.69
BAIÃO	0.2	0.23	0.23	0.21	0.24	0.24	0.21	0.24	0.24
BANNACH	0.15	0.16	0.17	0.16	0.18	0.18	0.16	0.18	0.18
BARCARENA	0.14	0.19	0.2	0.11	0.16	0.17	0.12	0.16	0.17
BELÉM	0.14	0.22	0.25	0.09	0.14	0.15	0.09	0.14	0.15
BELTERRA	0.27	0.29	0.3	0.32	0.34	0.34	0.32	0.34	0.34
BENEVIDES				0.08	0.13	0.15	0.08	0.14	0.15
BOM JESUS DO TOCANTINS	0.11	0.13	0.13	0.13	0.15	0.15	0.13	0.15	0.15
BONITO	-	0.01	0.01	0	0.01	0.01	0	0.01	0.01
BRAGANÇA	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02
BRASIL NOVO	0.35	0.37	0.38	0.35	0.38	0.38	0.35	0.38	0.38
BREJO GRANDE DO ARAGUAIA	0.04	0.05	0.06	0.04	0.05	0.06	0.04	0.06	0.06
BREU BRANCO	0.11	0.13	0.13	0.11	0.13	0.13	0.11	0.13	0.13
BREVES	0.31	0.38	0.4	0.54	0.62	0.64	0.54	0.62	0.64
BUJARÚ	0.04	0.07	0.08	0.05	0.08	0.09	0.05	0.08	0.09
CACHOEIRA DO ARARI				0.09	0.09	0.09	0.09	0.09	0.09
CACHOEIRA DO PIRIÁ	0.19	0.21	0.22	0.2	0.22	0.22	0.19	0.22	0.22
CAMETÁ	0.1	0.12	0.13	0.09	0.12	0.13	0.1	0.12	0.13
CANAÃ DOS CARAJÁS	0.1	0.1	0.11	0.14	0.14	0.15	0.14	0.15	0.15
CAPANEMA	-	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02
CAPITÃO POÇO	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.04	0.04
CASTANHAL	-	-	0.01	0.01	0.02	0.02	0.01	0.02	0.02
CHAVES	0.24	0.24	0.24	0.25	0.25	0.26	0.25	0.25	0.26
COLARES				0.1	0.14	0.15	0.1	0.14	0.15
CONCEIÇÃO DO ARAGUAIA	0.31	0.33	0.33	0.34	0.36	0.36	0.34	0.36	0.37
CONCÓRDIA DO PARÁ	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.02
CUMARU DO NORTE	0.36	0.37	0.38	0.39	0.41	0.41	0.39	0.41	0.41
CURIONÓPOLIS	0.02	0.03	0.03	0.02	0.03	0.03	0.02	0.03	0.04
CURRALINHO	0.36	0.38	0.39	0.5	0.52	0.52	0.5	0.52	0.52
CURUÁ	0.03	0.05	0.05	0.27	0.28	0.29	0.27	0.29	0.29
CURUÇÁ				0.12	0.17	0.18	0.11	0.17	0.18
DOM ELISEU				0.24	0.26	0.26	0.24	0.26	0.26
ELDORADO DOS CARAJÁS	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02
FARO	0.43	0.45	0.45	0.61	0.62	0.62	0.6	0.61	0.61
FLORESTA DO ARAGUAIA	0.06	0.07	0.07	0.09	0.1	0.1	0.09	0.1	0.1
GARRAFÃO DO NORTE	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
GOIANÉSIA DO PARÁ	0.02	0.04	0.04	0.02	0.04	0.04	0.03	0.04	0.04
GURUPÁ	0.36	0.4	0.41	0.36	0.39	0.41	0.37	0.4	0.42

IGARAPÉ-AÇU				0.01	0.03	0.03	0.01	0.03	0.03
IGARAPÉ-MIRI	0.25	0.28	0.28	0.25	0.28	0.28	0.25	0.28	0.28
INHANGAPI	0.03	0.06	0.07	0.02	0.05	0.06	0.02	0.05	0.06
IPIXUNA DO PARÁ	0.06	0.07	0.08	0.06	0.07	0.08	0.06	0.07	0.08
IRITUIA	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.03
ITAITUBA	0.59	0.61	0.61	0.68	0.69	0.69	0.68	0.69	0.7
ITUPIRANGA	0.11	0.14	0.14	0.12	0.15	0.15	0.12	0.15	0.16
JACAREACANGA	0.39	0.41	0.41	0.42	0.43	0.44	0.42	0.43	0.44
JACUNDÁ	0.02	0.03	0.04	0.02	0.03	0.04	0.02	0.04	0.04
JURUTI	0.46	0.47	0.47						
LIMOEIRO DO AJURU	0.18	0.22	0.24	0.18	0.22	0.24	0.18	0.22	0.24
MÃE DO RIO	-	-	-	0	0	0	0	0	0
MAGALHÃES BARATA				0.12	0.17	0.19	0.12	0.17	0.19
MARABÁ	0.12	0.14	0.15	0.13	0.16	0.16	0.13	0.16	0.16
MARACANÃ				0.08	0.12	0.13	0.08	0.12	0.13
MARAPANIM				0.11	0.15	0.16	0.11	0.15	0.16
MARITUBA	0.11	0.12	0.13	0.12	0.14	0.15	0.11	0.14	0.15
MEDICILÂNDIA	0.45	0.46	0.47	0.47	0.49	0.49	0.47	0.49	0.49
MELGAÇO	0.45	0.51	0.52	0.58	0.64	0.65	0.59	0.64	0.66
MOCAJUBA	0.04	0.05	0.06	0.04	0.05	0.06	0.04	0.05	0.06
MOJU	0.28	0.31	0.32	0.28	0.31	0.32	0.28	0.31	0.32
MONTE ALEGRE	0.05	0.06	0.07	0.15	0.16	0.16	0.16	0.17	0.17
MUANÁ	0.13	0.2	0.22	0.27	0.29	0.3	0.27	0.29	0.3
NOVA ESPERANÇA DO PIRIÁ	0.24	0.26	0.26	0.24	0.26	0.26	0.25	0.26	0.26
NOVA IPIXUNA	0.01	0.02	0.02	0.01	0.02	0.03	0.01	0.03	0.03
NOVA TIMBOTEUA				0.02	0.04	0.05	0.01	0.04	0.05
NOVO PROGRESSO	0.39	0.4	0.41	0.41	0.42	0.43	0.41	0.42	0.43
NOVO REPARTIMENTO	0.18	0.22	0.22	0.2	0.23	0.23	0.2	0.23	0.23
ÓBIDOS	0.39	0.39	0.4	0.42	0.43	0.43	0.42	0.43	0.43
OEIRAS DO PARÁ	0.38	0.39	0.39	0.39	0.4	0.4	0.39	0.4	0.4
ORIXIMINÁ	0.7	0.7	0.71	0.63	0.64	0.64	0.63	0.63	0.64
OURÉM	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.02
OURILÂNDIA DO NORTE	0.38	0.39	0.39	0.41	0.43	0.43	0.41	0.43	0.43
PACAJÁ	0.38	0.39	0.4	0.39	0.41	0.41	0.39	0.41	0.41
PALESTINA DO PARÁ	0.01	0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.03
PARAGOMINAS	0.23	0.24	0.25	0.23	0.25	0.25	0.23	0.25	0.25
PARAUAPEBAS	0.33	0.34	0.35	0.4	0.41	0.41	0.38	0.4	0.4
PAU D'ARCO	0.16	0.16	0.17	0.16	0.17	0.17	0.16	0.17	0.17
PEIXE-BOI				0.01	0.03	0.03	0.01	0.03	0.03
PIÇARRA	0.01	0.01	0.01	0.02	0.03	0.03	0.03	0.03	0.03
PLACAS	0.56	0.57	0.57	0.58	0.59	0.59	0.58	0.59	0.59
PONTA DE PEDRAS	0.01	0.02	0.02	0.14	0.15	0.16	0.14	0.15	0.16
PORTEL	0.66	0.67	0.67	0.7	0.7	0.71	0.69	0.7	0.7
PORTO DE MOZ	0.54	0.54	0.54	0.5	0.51	0.51	0.5	0.51	0.51
PRAINHA	0.44	0.45	0.45						
PRIMAVERA				0.06	0.1	0.11	0.05	0.1	0.1
QUATIPURU				0.18	0.22	0.23	0.17	0.22	0.23
REDENÇÃO	0.27	0.28	0.28	0.33	0.35	0.35	0.33	0.35	0.36
RIO MARIA	0.11	0.12	0.12	0.12	0.13	0.13	0.12	0.13	0.14
RONDON DO PARÁ	0.03	0.04	0.05	0.03	0.04	0.05	0.03	0.05	0.05
RURÓPOLIS	0.36	0.38	0.38	0.46	0.48	0.48	0.46	0.48	0.49
SALINÓPOLIS				0.46	0.49	0.5	0.48	0.5	0.5
SALVATERRA				0.06	0.08	0.08	0.06	0.08	0.08
SANTA BÁRBARA DO PARÁ				0.09	0.15	0.17	0.09	0.15	0.17
SANTA CRUZ DO ARARI	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
SANTA ISABEL DO PARÁ	0.09	0.14	0.16	0.04	0.07	0.07	0.04	0.06	0.07
SANTA LUZIA DO PARÁ	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.02
SANTA MARIA DAS BARREIRAS	0.34	0.36	0.37	0.38	0.39	0.4	0.38	0.39	0.4
SANTA MARIA DO PARÁ	-	-	0.01	0	0.01	0.01	0	0.01	0.01
SANTANA DO ARAGUAIA	0.35	0.37	0.37	0.38	0.4	0.4	0.38	0.4	0.4
SANTARÉM	0.39	0.4	0.41	0.39	0.4	0.41	0.39	0.4	0.41
SANTARÉM NOVO				0.03	0.08	0.09	0.02	0.07	0.09
SANTO ANTÔNIO DO TAUÁ				0.04	0.07	0.08	0.04	0.07	0.08
SÃO CAETANO DE ODIVELAS				0.06	0.11	0.12	0.06	0.11	0.12

SÃO DOMINGOS DO ARAGUAIA	0.03	0.04	0.04	0.03	0.04	0.04	0.03	0.04	0.04
SÃO DOMINGOS DO CAPIM	0.01	0.03	0.04	0.01	0.03	0.04	0.02	0.03	0.04
SÃO FÉLIX DO XINGU	0.36	0.38	0.38	0.39	0.41	0.41	0.39	0.41	0.41
SÃO FRANCISCO DO PARÁ				0.01	0.01	0.02	0.01	0.01	0.02
SÃO GERALDO DO ARAGUAIA	0.04	0.04	0.04	0.04	0.05	0.05	0.04	0.05	0.05
SÃO JOÃO DA PONTA				0.05	0.11	0.12	0.05	0.11	0.12
SÃO JOÃO DE PIRABAS				0.26	0.3	0.31	0.26	0.3	0.31
SÃO JOÃO DO ARAGUAIA	0.03	0.05	0.05	0.04	0.05	0.05	0.04	0.05	0.05
SÃO MIGUEL DO GUAMÁ	0.01	0.03	0.04	0.02	0.03	0.04	0.02	0.03	0.04
SÃO SEBASTIÃO DA BOA VISTA	0.32	0.37	0.4	0.49	0.51	0.52	0.49	0.51	0.52
SAPUCAIA	0.02	0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.03
SENADOR JOSÉ PORFÍRIO	0.46	0.47	0.48	0.49	0.5	0.5	0.49	0.5	0.5
SOURE	0.02	0.02	0.02	0.03	0.04	0.05	0.03	0.05	0.05
TAILÂNDIA				0.25	0.27	0.27	0.25	0.27	0.27
TERRA ALTA				0.01	0.03	0.03	0.01	0.03	0.03
TERRA SANTA	0.24	0.26	0.27	0.3	0.32	0.33	0.3	0.32	0.33
TOMÉ-AÇU	0.12	0.15	0.15	0.12	0.15	0.16	0.12	0.15	0.16
TRACUATEUA	-	0.01	0.01	0.02	0.03	0.03	0.02	0.03	0.03
TRAIRÃO	0.68	0.68	0.69	0.72	0.72	0.72	0.72	0.73	0.73
TUCUMÃ	0.06	0.07	0.08	0.09	0.1	0.11	0.09	0.1	0.11
TUCURUÍ	0.16	0.19	0.2	0.16	0.2	0.2	0.17	0.2	0.21
ULIANÓPOLIS	0.13	0.15	0.15	0.13	0.15	0.16	0.14	0.16	0.16
URUARÁ	0.57	0.57	0.58	0.57	0.58	0.58	0.57	0.58	0.58
VIGIA				0.07	0.1	0.1	0.07	0.1	0.1
VISEU	0.08	0.1	0.1	0.08	0.1	0.1	0.08	0.1	0.1
VITÓRIA DO XINGU	0.11	0.14	0.15	0.12	0.15	0.16	0.12	0.15	0.16
XINGUARA	0.02	0.03	0.03	0.03	0.03	0.04	0.03	0.04	0.04

Appendix VI. Gain in habitat availability for each BRL 1 million spent on restoration (cost-effectiveness), for the various Planaveg restoration scenarios, by municipality

Municipality	Planaveg A, minimum APP restoration	Planaveg B, minimum APP restoration	Planaveg C, minimum APP restoration	Planaveg A, maximum APP restoration	Planaveg B, maximum APP restoration	Planaveg C, maximum APP restoration
ABAETETUBA	0	0	0	0	0	0
ABEL FIGUEIREDO	0	0	0	0	0	0
ACARA	0	0	0	0	0	0
AFUA	0.005	0.006	0.007	0.004	0.004	0.004
AGUA AZUL DO NORTE	0	0	0	0	0	0
ALENQUER	0.005	0.006	0.007	0.004	0.004	0.004
ALMEIRIM	0	0	0	0	0	0
ALTAMIRA	0	0	0	0	0	0
ANAJAS	0.012	0.014	0.016	0.008	0.008	0.008
ANANINDEUA	0	0	0	0	0	0
ANAPU	0.001	0.001	0.001	0.001	0.001	0.001
AUGUSTO CORRÊA	0	0	0	0	0	0
AURORA DO PARÁ	0	0	0	0	0	0
AVEIRO	0.001	0.002	0.002	0.001	0.001	0.001
BAGRE	0.005	0.005	0.006	0.003	0.003	0.003
BAIÃO	0.001	0.001	0.001	0	0	0
BANNACH	0	0	0	0	0	0
BARCARENA	0	0	0	0	0	0
BELÉM	0	0	0	0	0	0
BELTERRA	0.005	0.005	0.006	0.003	0.003	0.003
BENEVIDES	0	0	0	0	0	0
BOM JESUS DO TOCANTINS	0.001	0.001	0.001	0.001	0.001	0.001
BONITO	0	0	0	0	0	0
BRAGANÇA	0.002	0.002	0.003	0.001	0.001	0.001

BRASIL NOVO	0	0	0	0	0	0
BREJO GRANDE DO ARAGUAIA	0	0	0	0	0	0
BREU BRANCO	0	0	0	0	0	0
BREVES	0.16	0.183	0.212	0.09	0.09	0.09
BUJARU	0.01	0.011	0.013	0.005	0.005	0.005
CACHOEIRA DO PIRIÁ	0	0	0	0	0	0
CACHOEIRA DO ARARI	0.026	0.03	0.035	0.006	0.006	0.006
CAMETÁ	0	0	0	0	0	0
CANAA DOS CARAJÁS	0.001	0.001	0.001	0.001	0.001	0.001
CAPANEMA	0.001	0.001	0.001	0.001	0.001	0.001
CAPITÃO POCO	0	0	0	0	0	0
CASTANHAL	0.001	0.001	0.001	0.001	0.001	0.001
CHAVES	0.01	0.012	0.014	0.006	0.006	0.006
COLARES	0	0	0	0	0	0
CONCEIÇÃO DO ARAGUAIA	0	0	0.001	0	0	0
CONCÓRDIA DO PARÁ	0	0	0	0	0	0
CUMARU DO NORTE	0	0	0	0	0	0
CURIONÓPOLIS	0	0	0	0	0	0
CURRALINHO	0.048	0.055	0.064	0.032	0.032	0.032
CURUÁ	0.039	0.044	0.051	0.027	0.027	0.027
CURUÇÁ	0	0	0	0	0	0
DOM ELISEU	0	0	0	0	0	0
ELDORADO DOS CARAJÁS	0	0	0	0	0	0
FARO	0.026	0.029	0.034	0.016	0.016	0.016
FLORESTA DO ARAGUAIA	0.001	0.001	0.001	0	0	0
GARRAFÃO DO NORTE	0	0	0	0	0	0
GOIANÉSIA DO PARÁ	0	0	0	0	0	0
GURUPÁ	0	0	0	0.003	0.003	0.003
IGARAPÉ-AÇU	0	0	0	0	0	0
IGARAPÉ-MIRI	0	0	0	0	0	0
INHANGAPI	0	0	0	0	0	0
IPIXUNA DO PARÁ	0	0	0	0	0	0
IRITUIA	0	0	0	0	0	0
ITAITUBA	0.001	0.001	0.001	0.001	0.001	0.001
ITUPIRANGA	0	0	0	0	0	0
JACAREACANGA	0.001	0.001	0.001	0.001	0.001	0.001
JACUNDÁ	0	0	0	0	0	0
JURUTI	0	0	0	0	0	0
LIMOEIRO DO AJURU	0	0	0	0	0	0
MÃE DO RIO	0	0	0	0	0	0
MAGALHÃES BARATA	0	0	0	0	0	0
MARABÁ	0	0	0	0	0	0
MARACANÃ	0	0	0	0	0	0
MARAPANIM	0	0	0	0	0	0
MARITUBA	0.016	0.019	0.022	0.005	0.005	0.005
MEDICILÂNDIA	0.001	0.001	0.001	0.001	0.001	0.001
MELGAÇO	0.063	0.071	0.083	0.049	0.049	0.049
MOCAJUBA	0	0	0	0	0	0
MOJU	0	0	0	0	0	0
MONTE ALEGRE	0.003	0.003	0.004	0.002	0.002	0.002
MUANÁ	0.069	0.078	0.091	0.029	0.029	0.029
NOVA ESPERANÇA DO PIRIÁ	0	0	0	0	0	0
NOVA IPIXUNA	0	0	0	0	0	0
NOVA TIMBOTEUA	0	0	0	0	0	0
NOVO PROGRESSO	0	0	0	0	0	0
NOVO REPARTIMENTO	0	0	0	0	0	0
ÓBIDOS	0.001	0.001	0.001	0.001	0.001	0.001
OEIRAS DO PARÁ	0.003	0.003	0.003	0.002	0.002	0.002
ORIXIMINÁ	0	0	0	0	0	0
OURÉM	0	0	0	0	0	0
OURILÂNDIA DO NORTE	0	0	0.001	0	0	0
PACAJÁ	0	0	0	0	0	0
PALESTINA DO PARÁ	0	0	0	0	0	0
PARAGOMINAS	0	0	0	0	0	0

PARAUAPEBAS	0.003	0.003	0.004	0.001	0.001	0.001
PAU D'ARCO	0	0	0	0	0	0
PEIXE-BOI	0	0	0	0	0	0
PIÇARRA	0	0	0	0	0	0
PLACAS	0	0	0.001	0	0	0
PONTA DE PEDRAS	0.438	0.499	0.58	0.171	0.171	0.171
PORTEL	0.001	0.002	0.002	0.001	0.001	0.001
PORTO DE MOZ	0	0	0	0	0	0
PRAINHA	0	0	0	0	0	0
PRIMAVERA	0	0	0	0	0	0
QUATIPURU	0	0	0	0	0	0
REDENÇÃO	0.001	0.001	0.001	0.001	0.001	0.001
RIO MARIA	0	0	0	0	0	0
RONDON DO PARÁ	0	0	0	0	0	0
RURÓPOLIS	0.003	0.003	0.004	0.002	0.002	0.002
SALINÓPOLIS	0	0	0	0	0	0
SALVATERRA	0	0	0	0	0	0
SANTA BARBARA DO PARÁ	0	0	0	0	0	0
SANTA ISABEL DO PARÁ	0	0	0	0	0	0
SANTA LUZIA DO PARÁ	0	0	0	0	0	0
SANTA MARIA DAS BARREIRAS	0	0	0	0	0	0
SANTA MARIA DO PARÁ	0.009	0.011	0.012	0.005	0.005	0.005
SANTANA DO ARAGUAIA	0	0	0	0	0	0
SANTARÉM	0.002	0.002	0.003	0.001	0.001	0.001
SANTARÉM NOVO	0	0	0	0	0	0
SANTO ANTÔNIO DO TAUÁ	0	0	0	0	0	0
SÃO CAETANO DE ODIVELAS	0	0	0	0	0	0
SÃO DOMINGOS DO ARAGUAIA	0	0	0	0	0	0
SÃO DOMINGOS DO CAPIM	0	0	0	0	0	0
SÃO FELIX DO XINGU	0	0	0	0	0	0
SÃO FRANCISCO DO PARÁ	0.011	0.013	0.015	0.007	0.007	0.007
SÃO GERALDO DO ARAGUAIA	0	0	0	0	0	0
SÃO JOÃO DA PONTA	0.011	0.013	0.015	0.008	0.008	0.008
SÃO JOÃO DE PIRABAS	0	0	0	0	0	0
SÃO JOÃO DO ARAGUAIA	0	0	0	0	0	0
SÃO MIGUEL DO GUAMÁ	0.001	0.001	0.001	0	0	0
SÃO SEBASTIÃO DA BOA VISTA	0.001	0.001	0.001	0	0	0
SAPUCAIA	0.004	0.004	0.005	0.002	0.002	0.002
SENADOR JOSÉ PORFÍRIO	0	0	0	0	0	0
SOURE	0.065	0.074	0.086	0.022	0.022	0.022
TAILÂNDIA	0.001	0.001	0.001	0.001	0.001	0.001
TERRA ALTA	0	0	0	0	0	0
TERRA SANTA	0	0	0	0	0	0
TOME-AÇU	0.005	0.006	0.007	0.004	0.004	0.004
TRACUATEUA	0.001	0.001	0.002	0.001	0.001	0.001
TRAIRÃO	0	0	0.001	0	0	0
TUCUMÃ	0.001	0.001	0.001	0.001	0.001	0.001
TUCURUÍ	0.001	0.001	0.001	0.001	0.001	0.001
ULIANÓPOLIS	0	0	0	0	0	0
URUARÁ	0	0	0	0	0	0
VIGIA	0.006	0.007	0.008	0.003	0.003	0.003
VISEU	0	0	0	0	0	0
VITÓRIA DO XINGU	0	0	0	0	0	0
XINGUARA	0	0	0	0	0	0