Sustainability of Brazilian forest concessions

# Introduction

Since the 1970s, selective logging has established itself as the main silvicultural system in tropical regions. This system is based on very simple rules: the exploitation of a few commercial trees having reached a minimum cutting diameter and letting the forest recover during a rotation period generally between 25 and 35 years. In the Amazon, selective logging regulations typically set a rotation cycle of 20 to 35 years with a logging intensity varying from 15 to 30 m of harvested timber per ha. However, several studies showed that under such extraction regimes, less than 50% of the timber extracted can recover within this rotation duration (Sist and Ferreira 2007; Putz et al. 2012). A recent study simulating the timber recovery in all the region confirmed this result and showed that even under long rotation cycles of 65 years and a logging intensity of 20 m.ha, logged forests could recover at most 70% of their initial timber (Piponiot et al. 2019). Current harvest regimes can only be sustained over multiple cycles if high-value slow-growing hardwoods are replaced by species of fast growth and low density, which are very little valued in the current market (Alder and Silva 2000; Keller et al. 2004; Phillips et al. 2004; Gardingen, Valle, and Thompson 2006; Schulze, Grogan, and Vidal 2008).

Although reduced impact logging techniques were seen as a promising alternative to reduce the damage of logging and consequently to improve timber volume recovery (Schulze, Grogan, and Vidal 2008), most of the studies assessing the long-term impacts of such techniques in the tropics - including the Amazon - showed that timber volume will recover at best 50% of its pre-logging value within the rotation cycle duration fixed by legislation (Sist and Ferreira 2007; Putz et al. 2012; Avila et al. 2017).

Despite the low recovery of timber stocks in logged forests, selective logging is still a widespread and economically viable land use in the Amazon. Around 75% of the five hundred million ha of forests are still intact (Potapov et al. 2017) and have accumulated highly valuable timber over centuries. Moreover, illegal logging is widespread in the region and often results in forest degradation (Brancalion et al. 2018; Finer et al. 2014): it is therefore difficult to assess the true state of Amazon forests, and their current potential for timber production. In the absence of changes in logging practices and enforcement of logging regulations, it is very likely that most logged forests will have a dramatic reduction in timber yields (Putz et al. 2012; Piponiot et al. 2019), decreasing their chance of meeting the demand for timber products.

In 2006, the Brazilian Forest Service (SFB) was created to implement a very ambitious system of long-term logging concessions (Brazil 2006). The concession system set up by the SFB aims to provide a legal framework for sustainable timber production in the Amazon while reducing illegal logging and concentrating Amazonian timber production within those concessions. Today Brazilian forest concessions cover 1.6 million ha in the Amazon, with a maximum potential area estimated at 60 million ha (Bomfim et al. 2016). The current timber production in Brazilian forest concessions is 221 thousand m per year, representing only 2% of the timber extracted in the Brazilian Amazon (SFB 2019). The forest management system remains based on selective logging and the capacity of natural production forests of the Amazon under concession to meet rising demands for wood products on a long-term basis must be questioned urgently.

In this study we used an Amazon-wide timber recovery model developed by Piponiot et al. (2019) to estimate the total timber volume that could be produced in Brazilian logging concessions under varying cycle lengths, logging intensities and pool of commercial species. We identified the conditions under which selective logging was sustainable from a timber production point of view and what its production capacity was in relation to the demand for wood.

First, this paper aims to assess which logging regimes (logging intensity and rotation length) are sustainable, i.e. are able to ensure a long-term and constant timber production in the Brazilian Amazon. Second, based on the characteristics of the identified sustainable logging regimes and the potential area of forest concessions in the Brazilian Amazon, we assess if the potential annual timber production is in adequacy with the present timber demand estimated at 11 Mm.yr (Vidal et al. 2020; SFB 2019).

# Methods

## Study areas - Brazilian concessions

Our study focuses on the Brazilian forest concessions. These concessions are located in public forests and currently cover an area of 1.6 Mha in the Brazilian Amazon, of which 1.05 Mha are concessions, managed by the SFB, and 0.6 Mha are managed by state-level agencies (SFB 2019). We retrieved the map of current concessions and the map of all public forests from the Brazilian Forest Service and IDEFLOR websites (Serviço Florestal Brasileiro 2020; Serviço Florestal Brasilieiro 2019; IDEFLOR-BIO n.d.). We defined the area of all potential concessions as the area of all public forests that (i) are in the Brazilian Amazon biome, (ii) are designated for sustainable use, and (iii) are not community forests, indigenous territories or military areas [as defined in SFB (2019), p. 112; Figure 1].

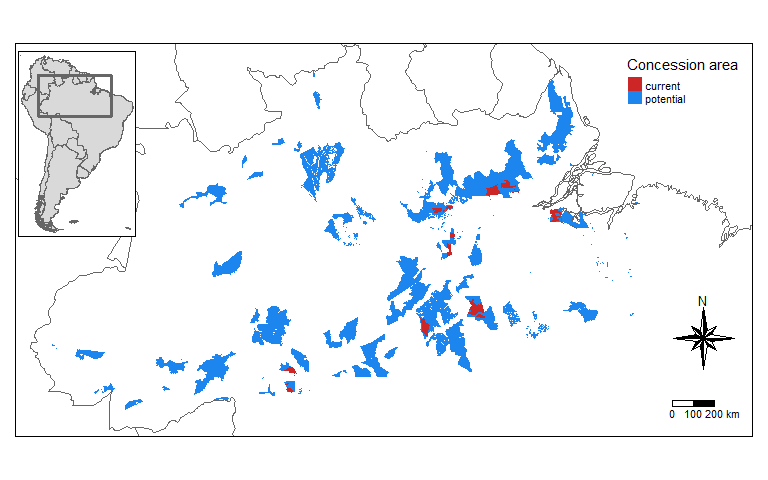


Figure 1: Plot of Brazilian Amazon forest concessions. Current federal concessions are in red; potential concessions (public forests designated for sustainable use) are in blue.

## The VDDE model

In this study we used the volume dynamics with differential equations (VDDE) model (Piponiot et al. 2018). The VDDE model focuses on the total volume, i.e. the volume of all live trees with diameter at breast height (DBH) 50 cm (the standard minimum cutting size in the Amazon Basin). By contrast, only a portion of this volume is composed of commercial species and will be referred to as commercial volume. Two variables are explicitly modelled: the total volume and the proportion of commercial volume , from which the commercial volume can be inferred.

In this study, we defined three input variables, that can be set for each simulation: the logging intensity, the logging cycle length, and the initial proportion of commercial volume . Low values of represent highly selective logging where only the most valuable species are logged; by contrast, high values of mean that most species are logged. Other parameters of the VDDE model are **spatially defined** at a 1 resolution. The model was calibrated at the Amazon Basin scale in a Bayesian framework with data from 3500 ha of forest plots, among which 845 ha are from 15 sites monitored for as long as 30 years after being subjected to selective logging (Sist et al. 2015; Piponiot et al. 2019). This means that predictions of commercial volume recovery depend on the location, and show some spatial variability across the Amazon Basin (Piponiot et al. 2019).

Each logging cycle is composed of two steps: (i) the logging itself is a function of the logging intensity and the characteristics of the forest; and (ii) the post-logging volume recovery phase is a function of the logging cycle length, and of the characteristics of the forest. The logging lowers the total volume and the proportion of commercial volume. The total volume and proportion of commercial species then increase during the recovery phase (Piponiot et al. 2019). These two steps are sequentially repeated to simulate 200 years of logging cycles.

Errors are propagated by drawing all parameter values from their calibrated distribution (from Piponiot et al. 2019), and simulating logging cycles with these parameter values. This process is repeated 100 times and summary statistics (median and 95% credibility interval) are calculated at each time step.

## Testing scenarios

In this study we tested 27 different scenarios by using all combinations of the following inputs: (i) initial proportion of commercial volume: 20% (highly selective), 50% (intermediate) or 90% (not selective); (ii) logging intensity: 10 m.ha (low), 20 m.ha (intermediate) or 30 m.ha (high); (iii) length of cutting cycles: 20 years (short), 35 years (intermediate) or 60 years (long). These scenarios are then applied to 2 different definitions of concessions area: the area of current concessions, or the area of all potential concessions (see section: “Study areas”).

For each scenario we simulated 1000 years of logging cycles, and determined the duration of constant production , i.e. the time when timber stocks are not sufficient to maintain a constant timber production (Figure 2).

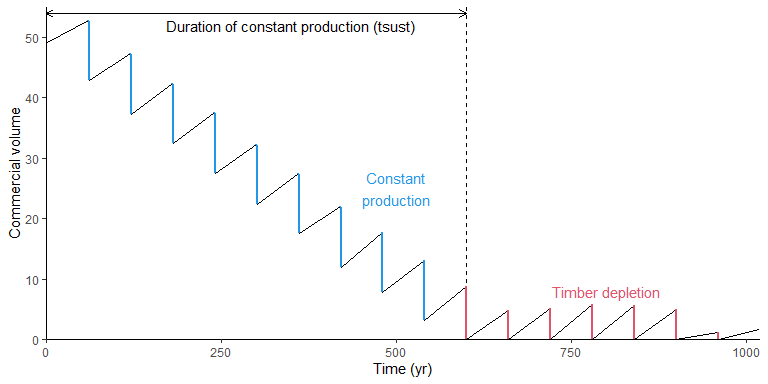


Figure 2: Illustration of the duration of constant production. The x-axis represents the time since the first logging event, and the y-axis represents the evolution of commercial volume as simulated by the model with a logging intensity of 10 m.ha and a logging cycle of 60 years. At each logging event, the commercial volume decreases because of timber harvests (blue segments). If the logging cycles are not long enough to recover its pre-logging value, the commercial volume decreases until it is not sufficient to maintain a constant production (red segments). The time taken to reach this limit is the duration of constant production.

# Results

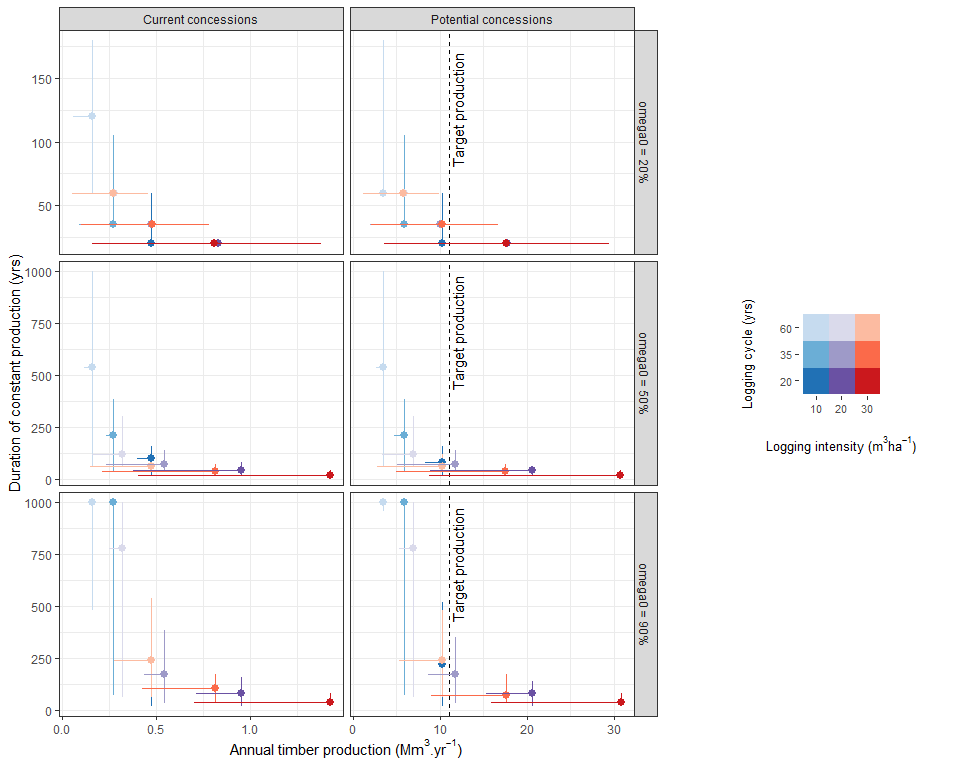


Figure 3: Tradeoff between timber production and sustainability. The x-axis is the annual timber production under each scenario, and in all areas considered in the scenario (left panels: current concessions; right panels: potential concessions). The y-axis is the duration of constant production in each scenario, in years. The points are the median value over all simulations for each scenario; the vertical and horizontal error bars are the 95% credibility intervals. Colors represent logging rules (3 logging intensities x 3 logging cycle lengths) and the 3 values of initial proportion of commercial volume (omega\_0) are represented by different panels, in increasing order from top to bottom. The target production of timber is 11 Mm.yr, corresponding to the current timber production in Brazilian Amazonian forests. Only a few scenarios in the right panels (all potential concessions) are above this target, and all of them have a median duration of constant production lower than 200 years.

Table 1: Sustainability of all 27 scenarios, characterized by the duration of constant timber production (yrs, last 2 columns). The first 3 columns correspond to the input variables: the proportion of commercial volume (%); logging intensity (m.ha); logging cycle length (yr). The 2 last columns are the duration of constant timber production in current concession areas and in all potential concessions, as the median value of all iterations, followed by the 95% credibility interval (between parentheses).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Comm. volume | Log. intensity | Log. cycle | Duration of constant production - Current concession area | Duration of constant production - Potential concession area |
| 20% | 10 m3/ha | 20 yr | 20 yr (20-60) | 20 yr (20-60) |
| 20% | 10 m3/ha | 35 yr | 35 yr (35-105) | 35 yr (35-105) |
| 20% | 10 m3/ha | 60 yr | 120 yr (60-180) | 60 yr (60-180) |
| 20% | 20 m3/ha | 20 yr | 20 yr (20-20) | 20 yr (20-20) |
| 20% | 20 m3/ha | 35 yr | 35 yr (35-35) | 35 yr (35-35) |
| 20% | 20 m3/ha | 60 yr | 60 yr (60-60) | 60 yr (60-60) |
| 20% | 30 m3/ha | 20 yr | 20 yr (20-20) | 20 yr (20-20) |
| 20% | 30 m3/ha | 35 yr | 35 yr (35-35) | 35 yr (35-35) |
| 20% | 30 m3/ha | 60 yr | 60 yr (60-60) | 60 yr (60-60) |
| 50% | 10 m3/ha | 20 yr | 100 yr (20-160) | 80 yr (20-160) |
| 50% | 10 m3/ha | 35 yr | 210 yr (35-385) | 210 yr (35-385) |
| 50% | 10 m3/ha | 60 yr | 540 yr (60-1000+) | 540 yr (60-1000+) |
| 50% | 20 m3/ha | 20 yr | 40 yr (20-80) | 40 yr (20-60) |
| 50% | 20 m3/ha | 35 yr | 70 yr (35-140) | 70 yr (35-140) |
| 50% | 20 m3/ha | 60 yr | 120 yr (60-300) | 120 yr (60-300) |
| 50% | 30 m3/ha | 20 yr | 20 yr (20-40) | 20 yr (20-40) |
| 50% | 30 m3/ha | 35 yr | 35 yr (35-70) | 35 yr (35-70) |
| 50% | 30 m3/ha | 60 yr | 60 yr (60-120) | 60 yr (60-120) |
| 90% | 10 m3/ha | 20 yr | 240 yr (20-520) | 220 yr (20-520) |
| 90% | 10 m3/ha | 35 yr | 1000+ yr (70-1000+) | 1000+ yr (70-1000+) |
| 90% | 10 m3/ha | 60 yr | 1000+ yr (480-1000+) | 1000+ yr (960-1000+) |
| 90% | 20 m3/ha | 20 yr | 80 yr (20-160) | 80 yr (20-140) |
| 90% | 20 m3/ha | 35 yr | 175 yr (35-385) | 175 yr (35-350) |
| 90% | 20 m3/ha | 60 yr | 780 yr (60-1000+) | 780 yr (60-1000+) |
| 90% | 30 m3/ha | 20 yr | 40 yr (20-80) | 40 yr (20-80) |
| 90% | 30 m3/ha | 35 yr | 105 yr (35-175) | 70 yr (35-175) |
| 90% | 30 m3/ha | 60 yr | 240 yr (60-540) | 240 yr (60-480) |

None of the scenarios with an initial proportion of commercial volume of 20% are sustainable after the first logging cycle (Figure 3; Table 1). The present logging practices in the Brazilian Amazon with a proportion of commercial species not exceeding 20%, a mean logging intensity of 15-20 m.ha and a rotation cycle of 35 years are therefore not sustainable as there will be a significant decrease in timber production at the second cycle (< 20 m.ha).

Scenarios with a proportion of commercial volume of 50% show longer duration of constant production. The most sustainable one with a constant production of timber during 540 yr (60-1000+) allows a logging intensity of 10 m.ha every 60 years (Table 1; Figure 3). Scenarios with a proportion of 90% of commercial species are among the most sustainable.

Only 4 out of all 27 scenarios have a median duration of constant production greater or equal to 500 years which can be considered as sustainable *sensu stricto*. Three of these scenarios have an initial proportion of commercial volume of 90%, and two correspond to low intensity logging (10 m.ha) with a rotation cycle of 60 years (Table 1). Logging regulations in the Brazilian Amazon include minimum logging cycles of 35 years. Under these regulations, the duration of constant production is 210 yr (35-385) if 50% of the volume is commercial, and 1000+ yr (70-1000+) if 90% of the volume is commercial (i.e. a true sustainable production). However these scenarios imply low logging intensities of 10 m.ha and a higher proportion of commercial timber species than in the present. According to our simulations and considering the 95% credibility interval, the most sustainable scenario is the one with an initial proportion of 90% of commercial species allowing a logging intensity of 10 m.ha every 60 years (Table 1).

The current timber production in the Amazon is around 11 Mm per year (Vidal et al. 2020; SFB 2019). Current concessions are not able to satisfy this demand alone for more than one cutting cycle (Figure 3). The maximum production under the current concession areas is 1.43 Mm only during the first harvesting and a proportion of commercial species of 90%. Under the present practices (20 m.ha) every 35 years and 20% of commercial species), the annual production during the first harvest reach 0.47 Mm only. Finally, under current concession area four scenarios can be considered as sustainable (duration of constant production > 500 years). The highest sustainable production is recorded under an extraction rate of 20 m.ha every 60 years with a 90% proportion of commercial species (Figure 3).

When considering all potential concession areas (35 Mha), the annual production of 11 Mm.yr could be sustained at best during 175 yr (35-350) following a scenario with 90% of commercial species, a logging intensity of 20 m.ha and a rotation cycle of 35 years (Figure 3; Table 1). There are two others scenarios close to 11 Mm with a sustained duration of 250 years (Figure 3), with a logging intensity of 10 and 30 m.ha and a logging cycle length of 20 and 60 years, respectively.

# Discussion

* methods: optimistic hypotheses -> to be considered when interpreting results -> Camille
* According to the results of our simulations, several challenges must be faced to reach sustained timber production within the concession systems in the Brazilian Amazon. First, the proportion of commercial species must increase considerably at least to 50% but ideally to 90%. Second, the logging intensity must be reduced to 10 m.ha and the rotation cycle to 60 years. Third, the area of current concessions is obviously insufficient to reach an annual production of 11 Mm and it is urgent to increase drastically concession area to its maximum potential of 35 Mha. However, the potential concession area of 35 Mha show strong limitation to ensure a annual sustainable production of 11 Mm on a long term basis as our simulations suggest that this production can be sustained for at best 170 years with a 90% proportion of commercial species.
* This study confirms that the present regulation fixing a rotation cycle of 35 years cannot ensure a long term sustainable timber production. Although previous studies already demonstrated the need to change the present extraction rates (Sist and Ferreira 2007, Putz et al. 2008, other refs) our paper is the first one suggesting and assessing different options of logging practices. The main challenge to move towards more sustainable practices is undoubtedly to increase the proportion of commercial species from presently 20 % to 90%. This must involve drastic changes at all level but particularly in the industrial and market sectors. At present, the wood transformation industry is still technically very poorly developed and very rudimentary (refs?). Less than 30% of the logs entering the saw mill is transformed, the remaining 70% are wasted and burned. However, the lack of wood transformation technology is certainly linked to the lack of market demand on diversified wood products in the region. To be developed (Jack ? Edson ?)
* increasing the area of concessions: current trends, challenges and opportunities
* initial proportion of commercial species: what effect could harvesting 90% of all trees > 50 cm DBH could have on the profitability of selective logging?
* initiating a forest transition -> new ways of producing timber: plantations, active restoration, silviculture
* what effects could silviculture have on sustainability? -> needs to be investigated (introduce next paper)

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