Amazonian forests functional resistance to a selective logging disturbance

Camille Piponiot*,a, TmFO authors, Bruno Héraulta,1

^a Cirad, UR Forets et Societes, Montferrier-sur-Lez, France ^b INPHB, Yamoussoukro, Cote d'Ivoire

Abstract

This is the abstract.

It consists of two paragraphs.

Introduction

Tropical forests are crucial for most global ecological cycles. They hold xx% of the total carbon in terrestrial ecosystems and are estimated to store xx Gg C.yr⁻¹, about xx% of total anthropogenic carbon emissions, playing a major role in climate change mitigation (ref IPCC xxx). Tropical forests act as precipitation relays through vegetation transpiration, acting as a buffer against droughts in adjacent regions [some numbers] (refs: (???), etc). Tropical forests also harbour xx% of known terrestial species. The future of tropical forests will thus largely determine the functioning of Earth ecosystems and, in turn, human well-being.

The future of tropical forests is however highly uncertain: since the midtwentieth century, humans have triggered rapid changes in the global environment (???). Tropical forests are being clearcut for agricultural or mining purposes at unprecedented rates, and most remaining forests have or will be heavily impacted by human activities (???). Disturbances such as droughts, fires, selective logging, or hunting, are increasing in intensity and frequency (???). Human disturbances modify forest functioning, but the intensity, direction and duration of these changes are still largely unknown.

One predomininat human activity in tropical forest is the selective logging of a few merchantable trees: xxx Mha are selectively logged every year in the tropics, and XXx% of tropical forests have been logged at least once. Because selective logging focuses on a few individual trees (typically 5-10 trees per ha), XXX% of the forest cover is maintenained after logging operations. Damage to the forest is concentrated in infrastructure (roads and skid trails to get machines in then logs out of the forest), and in logging gaps created by tree felling.

Disturbances such as selective logging can affect the composition and dynamics of tropical forests: change the global functioning of the ecosystem. // forest

^{*}Corresponding Author

Email addresses: camille.piponiot@gmail.com (Camille Piponiot), bruno.herault@cirad.fr (Bruno Hérault)

recovery after a disturbance -> carbon stocks (Piponiot et al. 2016), tree size distribution [xx], species composition (Avila et al. 2015), biodiversity [xx]

notion of resilience: measure of how well an ecosystem can cope with disturbances and return to its original (pre-disturbance) state. 2 components = change in state (or resistance to a disturbance) + return time (Hodgson, McDonald, and Hosken 2015). [introduce our conceptual framework, disturbance intensity]

functional traits = xxx (definition). characterisation of ecosystem functioning \rightarrow importance to understand how they are affected by disturbances. functional strategies and tradeoffs in forests: leaf and wood economic spectrum, stature, and seed dispersal strategy; explain most of the variation (Baraloto et al. 2012, Costa-Saura et al. (2019)). selective logging disturbance -> canopy openings, light -> colonisation by small-seed light-wood species (Poorter and Rose 2005,Poorter et al. (2019)) cf successional theory -> changes in functional composition (Carreño-Rocabado et al. 2012).

environmental control: soil, climate, disturbance history -> affects functional composition (Costa-Saura et al. 2019) and response to disturbance. => spatial variation. example: Amazon = largest tropical forest biome on Earth (50% of tropical rainforests, total area: 600 Mha). -> 2 large scale gradients that control the dynamics of old-growth forests: dryness gradient (NW-SE) (Davidson et al. 2012) that constraints vegetation growth, and a tree mortality gradient (SW-NE) (Johnson et al. 2016) due to lower soil stability (C. a. Quesada et al. 2012) and higher frequency of windstorms (Espírito-Santo et al. 2014) in the southwestern part of Amazonia.

Here we assess the resistance of 4 functional traits (namely wood density, seed mass, specific leaf area and maximum tree diameter) to selective logging in Amazonia. We calibrate an original Bayesian hierarchical model with data from xxx permanent forest plots from 12 long-term experimental sites. Our research questions are: (i) how is the functional composition of Amazonian forests affected by disturbances such as selective logging? (ii) are some functional traits more resistant than others? (iii) does the functional resistance vary across Amazonia, and what factors could explain those variations?

Methods

Study sites

Our study includes data from twelve long-term (8–30 year) experimental forest sites located in the Amazon Basin and the Guiana Shield (Figure XXX). All sites are located in tropical forests with mean annual precipitation ≥ 1000 mm. Sites were logged once and permanent forest plots (xx-xx ha per site) were censused at least once before and at least twice after logging. For each site, we extracted the climatic water deficit from Chave et al. (???), at a 30 arc-seconds resolution. [kriging -> smort]

• environmental covariates: table? maps in SM?

For sites with plots ≤ 1 ha, data from those with the same treatment 113 were aggregated to mitigate the small plot effect on the variation in density of large trees.

Functional trait data compilation

Traits chosen:

- DBH95: DBH 95th percentile (per species) as a proxy of the stature
- logSeedMass: median seed mass (log-transformed) as a proxy of the dispersal strategy
- \bullet SLA: median specific leaf area, as a proxy of the assimilation strategy and leaf economic spectrum
- \bullet WD: median wood density, as a proxy of growth rate and mechanical support

retrieved from xxx and estimated for each individual: by species or genus or plot mean (see explanation package BIOMASS)

Selective logging typically targets big trees (DBH \geq 40 cm) belonging to a small group of species with commercial value. Those species usually have particular functional trait values, such as large maximum diameters and high wood density [xx]. The functional composition of the biggest trees is thus artificially modified because of the selectivity of harvests. Because we are more interested in the indirect effects of selective logging on the functional composition, i.e. the functional changes induced by tree felling and canopy openings, we excluded trees with DBH > 35 cm from the analysis.

Mean weighted trait: (weighted with biomass)

$$MWT_{k,c,p,s} = \frac{\sum_{i \in I_{c,p,s}} (T_{k,i} \cdot agb_i)}{\sum_{i \in I_{c,p,s}} (agb_i)}$$
(1)

with $T_{k,i}$ the value of trait k (either DBH95, logSeedMass, SLA, or WD) for individual tree i, agb_i the above ground biomass of individual tree i, and $I_{c,p,s}$ all live trees with $DBH \geq 10$ cm and ≤ 35 cm at census c in plot p in site s.

The aboveground biomass of each individual was estimated using the package BIOMASS (Réjou-Méchain et al. 2017) (details xx).

Model calibration

For each trait k, the mean biomass-weighted trait of small trees (MWT) trajectory at census c in plot p in site s was modelled as:

$$dMWT_{k,c,p,s} = \frac{MWT_{k,c,p,s} - MWT0_{k,p,s}}{T0_{k,p,s}} \sim \mathcal{N}\left(\mu_{k,c,p,s} , \left(\frac{\sigma_k}{size_p}\right)^2\right) \quad (2)$$

with

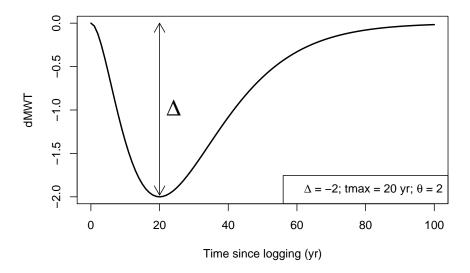


Figure 1: Example of predicted relative MWT change (dMWT) after a disturbance.

$$\mu_{k,c,p,s} = \Delta_{k,p,s} \cdot \left(\frac{t_c}{tmax_{k,p,s}} \cdot exp\left(1 - \frac{t_c}{tmax_{k,p,s}}\right)\right)^{\theta_{k,p,s}} \tag{3}$$

- c the census, and t_c the time since logging (in years) at census c,
- $T0_{k,p,s}$ the pre-logging trait value of the community in plot p in site s.
- $\Delta_{k,p,s}$ is the maximum value (relative to the final value) of the hump that follows logging and the creation of logging gaps. $\Delta_{k,p,s} \sim \mathcal{N}(\mu_{\Delta ks}, \sigma_{\Delta}^2)$, with $\mu_{\Delta ks}$ and σ_{Δ} are respectively the mean and standard deviation of Δ for trait k in site s.
- $tmax_{k,p,s}$ is the time when the maximum value of the hump is reached. $tmax_{k,p} = 0$ for control plots and in logged plots $tmax_{k,p} \sim \mathcal{N}(\mu m_k, \sigma m^2)$ where μm_k and σm are respectively the mean and standard deviation of tmax for trait k.
- θ_k is a shape parameter that controls the width of the hump; when it increases, the hump is narrower.
- $size_p$ is the size of plot p

 $\Delta_{k,p,s}$ is the maximum change of trait k after the disturbance: its absolute value is expected to increase with disturbance intensity. We thus modelled it as:

$$\Delta_{k,p,s} = loss_p \cdot (\lambda_{0,k} + \sum_{k} \lambda_{m,k} Cov_{m,s})$$
(4)

 $loss_p$ is the relative above ground biomass loss after logging in plot p, as a proxy of the disturbance intensity; it is estimated as the difference between the pre-logging above ground biomass and the minimum biomass in the first 4 years after logging, divided by the pre-logging above ground biomass. $Cov_{m,s}$ is the value of covariate m (either the mortality rate or the climatic water deficit) in site s.

Predictions

coarsest resolution of input maps: 1 degree grid (stem mortality) -> final prediction maps resolution => cwd values (xx resolution) aggregated to a 1 degree grid, average value.

uncertainties: variation in cwd values inside one pixel // stem mortality: distribution of kriged predictions for each pixel

• parameters posterior

=> 1000 iterations : values of covariates and parameters are randomly selected in their distribution and predictions of maximum relative CWD change (Δ) are estimated.

Results

Trait change predictions fitness $tmax \in [7, 31]$ yr (95% confidence interval)

Traits variation and resistance to logging

Figure 2

Spatial configuration and predictions

Discussion

- direction of changes: expected or not?
- which traits are predicted to be more resistant

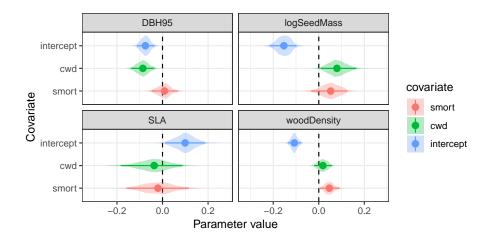


Figure 2: Violin plots of covariates effect on maximum relative MWT change per trait. intercept is the value when all covariates are null; smort is the effect of the stem mortality; cwd is the effect of the climatic water deficit. Dots represent the median value, and the segments are the 95% confidence intervals. All covariates were scaled and centered.

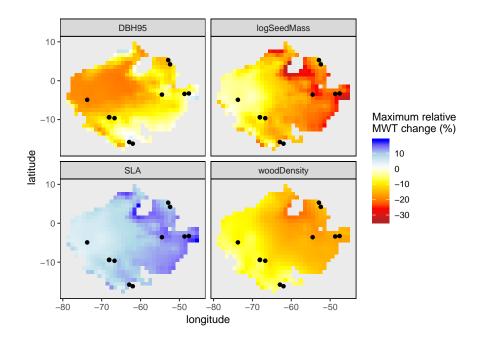


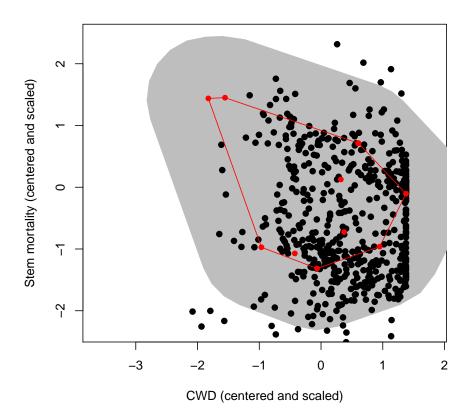
Figure 3: Prediction maps of maximum relative CWD change (i.e. resistance to disturbance) by trait. Warm colors (from yellow to red) show a decreases in MWT; blue colors show an increase in MWT. Black dots are study sites location. Pixels with

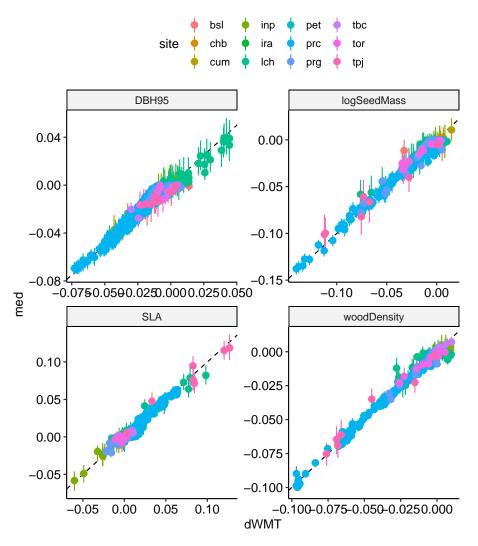
Supplementary material

Choice of pixels on prediction maps

goal: represent only pixels that have covariates values close enough to our range of calibration (ie TmFO sites conditions).

Scaled covariates -> convex hull around TmFO sites values -> buffer of 1 (scaled: equivalent to 1 standard deviation) -> all points outside this buffer were removed.





References

Avila, Angela Luciana de, Ademir Roberto Ruschel, João Olegário Pereira de Carvalho, Lucas Mazzei, José Natalino Macedo Silva, José do Carmo Lopes, Maristela Machado Araujo, Carsten F. Dormann, and Jürgen Bauhus. 2015. "Medium-term dynamics of tree species composition in response to silvicultural intervention intensities in a tropical rain forest." *Biological Conservation* 191. Elsevier B.V.: 577–86. doi:10.1016/j.biocon.2015.08.004.

Baraloto, Christopher, Olivier J Hardy, C E Timothy Paine, Kyle G Dexter, Corinne Cruaud, Luke T Dunning, Mailyn-Adriana Gonzalez, et al. 2012. "Using

functional traits and phylogenetic trees to examine the assembly of tropical tree communities." *Journal of Ecology* 100 (3): 690-701. doi:10.1111/j.1365-2745.2012.01966.x.

Carreño-Rocabado, Geovana, Marielos Peña-Claros, Frans Bongers, Alfredo Alarcón, Juan Carlos Licona, and Lourens Poorter. 2012. "Effects of disturbance intensity on species and functional diversity in a tropical forest." *Journal of Ecology* 100 (6): 1453–63. doi:10.1111/j.1365-2745.2012.02015.x.

Costa-Saura, José M., Antonio Trabucco, Donatella Spano, and Simone Mereu. 2019. "A height-wood-seed axis which is preserved across climatic regions explains tree dominance in European forest communities." *Plant Ecology* 0123456789. doi:10.1007/s11258-019-00928-x.

Davidson, Eric a., Alessandro C. de Araújo, Paulo Artaxo, Jennifer K. Balch, I. Foster Brown, Mercedes M. C. Bustamante, Michael T. Coe, et al. 2012. "The Amazon basin in transition." *Nature* 481 (7381): 321–28. doi:10.1038/nature10717.

Espírito-Santo, Fernando D.B., Manuel Gloor, Michael Keller, Yadvinder Malhi, Sassan Saatchi, Bruce Nelson, Raimundo C Oliveira Junior, et al. 2014. "Size and frequency of natural forest disturbances and the Amazon forest carbon balance." *Nature Communications* 5 (March): 3434. doi:10.1038/ncomms4434.

Hodgson, Dave, Jenni L. McDonald, and David J. Hosken. 2015. "What do you mean, 'resilient'?" *Trends in Ecology and Evolution* 30 (9). Elsevier Ltd: 503–6. doi:10.1016/j.tree.2015.06.010.

Johnson, Michelle O., David Galbraith, Manuel Gloor, Hannes De Deurwaerder, Matthieu Guimberteau, Anja Rammig, Kirsten Thonicke, et al. 2016. "Variation in stem mortality rates determines patterns of above-ground biomass in Amazonian forests: implications for dynamic global vegetation models." *Global Change Biology* 22 (12): 3996–4013. doi:10.1111/gcb.13315.

Piponiot, Camille, Plinio Sist, Lucas Mazzei, Marielos Peña-Claros, Francis E Putz, Ervan Rutishauser, Alexander Shenkin, et al. 2016. "Carbon recovery dynamics following disturbance by selective logging in Amazonian forests." *eLife* 5 (C). doi:10.7554/eLife.21394.

Poorter, Lourens, and Simmoné A. Rose. 2005. "Light-dependent changes in the relationship between seed mass and seedling traits: A meta-analysis for rain forest tree species." *Oecologia* 142 (3): 378–87. doi:10.1007/s00442-004-1732-y.

Poorter, Lourens, Danaë M. A. Rozendaal, Frans Bongers, Jarcilene S. de Almeida-Cortez, Angélica María Almeyda Zambrano, Francisco S. Álvarez, José Luís Andrade, et al. 2019. "Wet and dry tropical forests show opposite successional pathways in wood density but converge over time." *Nature Ecology & Evolution.* doi:10.1038/s41559-019-0882-6.

Quesada, C. a., O. L. Phillips, M. Schwarz, C. I. Czimczik, T. R. Baker, S. Patiño, N. M. Fyllas, et al. 2012. "Basin-wide variations in Amazon forest structure and function are mediated by both soils and climate." *Biogeosciences* 9 (6): 2203–46. doi:10.5194/bg-9-2203-2012.

Réjou-Méchain, Maxime, Ariane Tanguy, Camille Piponiot, Jérôme Chave, and Bruno Hérault. 2017. "BIOMASS: An R Package for estimating aboveground biomass and its uncertainty in tropical forests." *Methods in Ecology and*

 $\label{eq:evolution} \textit{Evolution}, \, \text{no. February. doi:} 10.1111/2041-210X.12753.$