A detailed study on Amazon Forest structure and mortality rates through LPJ-GUESS vegetation model

Evaluation of Amazon's tropical forest allometry and mortality through LPJ-GUESS dynamic global vegetation model in comparison with observation from TEAM NETWORK

Course NGEK01, 15 ECTS

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Bachelor degree thesis, 15 credits in Physical Geography and Ecosystem Analysis Department of Physical Geography and Ecosystem Science, Lund University

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Popular abstract

Competition between neighbouring trees has a big impact on their growth. Trees have different strategies to deal with competing neighbours. Some grow quickly and tall, overshadowing neighbouring trees, but die young (Georges K., 2015). Others grow more slowly, but outlive the fast growing ones and cast shade on them over a longer period. These interactions have a strong influence on the dynamics of forests and their functioning as ecosystems (Georges K., 2015).

In this study, I am going to analyze tropical tree structure in the Amazon forest through LPJ-GUESS dynamic vegetation model. The model has the capacity to simulate individual plants belonging to different species, or also called PFTs, plant functional types. The average of each across individuals within a cohort/age class in a patch is simulated on a number of patches that are representing the smallest spatial resolution. The simulations happen by considering a series of mathematical equations inserted in the model throughout algorithms which are representing daily and yearly plant processes of interaction within the ecosystem and environment. In my studies, in particular, I analyze which are the impacts of changes of allometric equations parameters by testing different model runs. What I am aiming for, in specific, is to see if particular changes in allometric equations parameters will drive a significant change in simulating tropical tree size, structure and biomass. Moreover, NPP and tree mortality have also been investigated to check if the simulated productivity (in terms of biomass) of each chosen site was affected more or less by those variables. Finally, a detailed exploration was given by comparing simulations with observations given by TEAM NETWORK to test how the model was reproducing tropical tree structure in the four selected countries in the Amazon (Peru', Ecuador, Suriname, Brazil).

Abstract

Nowadays it has become relevant for scientists to understand the impact of tropical forest structure on the Global Carbon Cycle. Dynamic vegetation models have been developed to pursue this issue, specifically by improving algorithms that could analyze the allometry, biomass content and mortality rate of each singular simulated plant individual and how this responds to climate change, management and rising CO_2 concentrations.

In these studies, I use and test the LPJ-GUESS vegetation model, which is an ecosystem framework for modelling the structure and dynamics of terrestrial ecosystems at landscape, regional and global scales (Smith. et al., 2001). It was used in order to simulate a better reproduction of structural tropical tree dynamics through the use of allometric equations for the scaling of the tropical tree growth in the Amazon forest. Specifically, in four locations from the Amazon forest, stand structure and developments were well reproduced by the model in comparison to observations of tropical forest structure available from the TEAM network, which provides observational information on the number of individual trees and their sizes on a range of plots across the tropics. Specifically, allometries were both investigated by adjusting standard settings in the model to reach better performances and assess how these settings impact size structure and observations. My results show that the model is not fitting the observation by not simulating accurately directly the size structure of the trees. Improper algorithms and the use of inappropriate parameter values were identified as possible explanations for the lack of agreement of the model with the TEAM network observations.

1. Introduction

Nowadays it is becoming more relevant for scientists to determine the paths through which CO_2 from the ocean and biosphere is returned to the atmosphere as well as the size of the net flux (NBP), its drivers, underpinning mechanisms, and distribution across the vegetated regions of the world. For this reason, anthropogenic and natural carbon sinks and sources have been evaluated in the past decades to get a deeper understanding of those natural processes. Under an IPCC scenario that has stated that global emissions increased by 40% from 278 ppm in 1750 to 390.5 ppm in 2011 and anthropogenic CO_2 emissions to the atmosphere were 555 ± 85 PgC (1 PgC = 1015 gC) between 1750 and 2011 (Govindasamy et al., 2013), what has certainly been put into light by scientists is the way terrestrial ecosystems mediate the exchange of carbon with the atmosphere; for instance to delineate if they represent a carbon source or sink. Understanding the factors controlling land C uptake by natural ecosystems is becoming very critical for reducing uncertainties in projections of future climate (Huntzinger et al., 2017, Friedlingstein et al., 2006; Scholze et al., 2006; Sitch et al., 2008; Booth et al., 2012; Arora et al., 2013; Ahlström et al., 2013).

It is known that tropical forests are the largest terrestrial component of the global carbon budget by accounting 50% of the carbon stored in the global vegetation (350–600 Gt C). This amount rivals the 750 Gt C found in the atmosphere (Brinck et al., 2017). In particular, the Amazon forest is the most extensive tropical forest on Earth by storing an estimated ~100 Pg C in aboveground woody biomass (Feldpausch et al., 2012) approximately 25% of the global aboveground forest carbon stock (Pan et al., 2011). It represents a huge sink of carbon fluxes to the atmosphere gaining 0.56 GtC per year and including around 410 billion individual trees within 7.8 million km_2 (Rödig et al., 2018). For this reason, in this study, productivity and mortality rate of the Amazon forest were first simulated by a computer model (LPJ-GUESS, dynamic global vegetation model) then compared to observations in order to deeply understand the capability of the model to simulate the Amazon carbon storage capacity over time. Computer models like LPJ-GUESS integrate theoretical and experimental results to project vegetation responses to changing CO_2 and climate (Kerns et al. 2014). Vegetation models have been created and improved in the past decades in order to represent forest structures dynamics and their responses for global ecosystems (Fisher et al., 2018). They simulate, within a developing climate change scenario, how a full range of climatic and other environmental conditions affect how plants (here forest trees) establish, grow, reproduce, and persist or die (Kerns, B. et al. 2014). Capturing forest structure by vegetation models does not only mean capturing the effect of biotic interactions and disturbances on plant species but also seeing their response to global climatic changes. There are many developed techniques used for depicting and simulating these changes of the environment with contemporary models often using a more sophisticated and explicit representation of structural dynamics compared with earlier models. For example, in the simplest formulations of vegetation dynamics (e.g. the IBIS model of Foley et al. 1996), individual and population growth are combined in an overall parameterization of the effects of resource competition on PFT abundances, while second-generation models, like LPJ-GUESS and POP, explicitly represent

the organisation hierarchy of regional ecosystems from landscape to patch (or stand), age class (cohort) and individual level, and this has been shown to result in more realistic structural dynamics compared to larger-area approaches (Wolf et al.2011; Haverd et al. 2014).

In my project, comparisons between observation data and model predictions for the same locations were done by adapting simulated parameters of allometric equations to a more suitable model run for both the simulation of number of trees and biomass values. In fact, the model was run two times, the first run was used to set the simulation and test its reliability based on comparisons with observations, the second run used adapted parameters to investigate whether this resulted in more accurate predictions. Specifically, my area of studies have been focusing on four regions, Brazil, Ecuador, Suriname and Peru', all covering parts of the Amazon Basin, and for the observation, number of trees and biomass dataset were taken from different plots of the same locations of 1 hectare each from data collected by the TEAM network. The model however was working with a smaller spatial resolution of 0.1 ha or also called patch and it was run in a specific cohort-population mode. Less advanced models usually use average individual-population modes that lack an explicit representation of age classes (and patches) and use instead a large-area parameterisation in which the distribution of height, biomass, density imply a set of tree carbon pools with no information on tree size or shape. The two types of models have many similar components such as PFTs - the subdivision of different plant species in plant functional types - , but differ in the way vegetation is represented internally (Smith et al., 2001). There are also differences in the way certain processes control vegetation dynamics, i.e. changes in the physical structure, composition and distribution of vegetation through time. Basically, using cohort mode instead of population mode allows the model to better simulate ecosystem natural processes of the tropical forest such as net primary production or soil hydrology.

Moreover, the latest models made use of more developed mathematical equations to predict and simulate forest structure, allocation and tissue turnover for example. Population growth within a singular patch is the balance of an annual rate of establishment of new saplings, influenced by current density, and mortality, which may increase under conditions of resource limitation, crowding or disturbance (Smith et al., 2011). Behind the calculation of each of those environmental conditions, one of the most widely used techniques is allometry, especially for summarizing biomass variation collected in forest inventories (Jenkins et al., 2004); for instance, by identifying, mathematically, how the relationship of both the diameters of the trees to the crown area (1) and to their heights (2) tells how much space a tree needs for a given stem size. In this study, specifically, the rule of those particular allometric equations was analyzed in order to correctly simulate the overall stand growth and mortality rates, which are closely linked to tree size and therefore forest structure. This facilitates better simulation of both biomass and its rate of change (either increasing or decreasing).

The aim of the project was to assess how faithfully the LPJ-GUESS vegetation model can capture the size structure of trees in South American tropical forest and whether the model results can be improved by updating parameters governing tree allometry in the model. An improved representation of size structure dynamics could be expected to impact tropical

forest functions such as NPP, different mortality components and tree biomass. These outputs from the model were therefore analysed and implications for the suitability of LPJ-GUESS for tropical forest carbon studies discussed.

1.1 Aim

The aims of the study are to:

1) Test LPJ-GUESS against observed stand structure data.
2) Test effect of updating the allometric equations on representation of stand structure.
3) Assess the influence of these changes on NPP and/or mortality rates.

Finally, in this thesis, I apply an updated version of the model that has to deal with a better representation of tree structure in tropical forests.

2. Methodology

2.1 Ecosystem model

I employed the LPJ-GUESS version 4.0, subversion revision 8877, dynamic vegetation model (Smith et al., 2014) as the main tool for my study. It is a process-based dynamic vegetation-ecosystem model designed for regional and global applications where the basic structural unit is an average individual plant and each compartment consists of a quantity of C biomass expressed on a ground area basis, per patch in units of kg C m^{-2}. The model is process-based, which in the case of LPJ-GUESS means specifically that it is run on patches that are aimed to represent the distribution of a singular individual within a landscape representative of a grid cell and each individual photosynthetic, respiratory, stomatal conductance, and phenological (leaves and fine roots) values are simulated on a daily time step.

To simulate tree growth resulting from the allocation of NPP (net primary production, i.e. carbon assimilated through photosynthesis and left over after plant metabolic costs in the form of autotrophic respiration are deducted), the model makes use of allometric equations such as the ones showing the relationships between diameter and crown areas and height and crown areas to define the growth of individual trees. Integrated across age classes, PFTs and patches, tree allometric development drives biomass accumulation at the grid cell level. Specifically, allometric equations taken from B. Smith et al.,2014 of stem height and diameter and from Shenkin et al., 2020 of stem radius correlated to crown areas have been taken into account in this study. The reason for this was to present an assumption based on mathematical formula (see formula 1 and 3) on how plant geometry and structure usually develop in a tropical environment and then, compare their trends with observation and model performed values for both tree biomass and diameter classes for all the four selected locations in the Amazon forest.

2.2 TEAM-NETWORK- The Tropical Ecology Assessment and Monitoring and observed data

The Tropical Ecology Assessment and Monitoring (TEAM) Network is a partnership between Conservation International, the Wildlife Conservation Society and the Smithsonian Institute with the goal of better understanding how tropical forests are responding to a changing climate and disturbed landscapes both on a local and international scale. They make use of the coordination of an integrated and systematic sampling program at multiple spatial and temporal scales (J. MacCarthy et al. 2011) and this particular network of sites is valuable for addressing the aims of my particular studies since they provide information on the number of individual trees and their sizes on a range of plots across the tropics.

TEAM describes the spatial arrangement for tree and liana measurements, specifically individual tree and liana latitude and longitude Cartesian coordinates as well as latitude and longitude (Datum: WGS84) locations when possible. The latitude and longitude coordinates for the 1 ha plots at each TEAM Site are listed in Table 1 (J. MacCarthy, et al. 2011). For instance, the size of all trees above 10 cm diameter at breast height (DBH) are recorded during a single census. The data were preprocessed for me by the TreeMort project (http://more.bham.ac.uk/treemort) and this preprocessing included the use of allometric equations to estimate biomass of each tree from DBH.

Four different locations (with a total of 6 plots) were selected for closer analysis in my study and are respectively Peru', Suriname, Brazil and Ecuador (see Table 1 with geographical coordinates). Those data are assumed to be collectively representative for the range of climate, soil and thereby vegetation conditions across the Amazon rainforest. Then, size structure information, i.e. the number vs size and biomass vs size distributions in tonnes ha^{-1} values have been extracted as well for the four different locations and analyzed through Microsoft Excel and plotted with average values and then compared with modelled results.

Table 1. Selected locations coordinates with WGS-84 Coordinates system.

Country	Longitude	Latitude	Year*
Brazil	-51.25 (CAX) -71.25 (MAS)	-1.75 (CAX) -11.75 (MAS)	2003
Peru	-56.25 (COU) -75.25 (YAN)	4.75 (COU) -10.75 (YAN)	2011
Suriname	-59.75 (CSN)	-2.75 (CSN)	2013
Ecuador	-76.25 (YAS)	-0.75 (YAS)	2012

*The time when the measurements have been done was different, different years for different locations, specified above.

In order to show the selected locations, ArcMap has been used to make a map of the selected plots (Figure 3). A deeper study on the climatic conditions affecting the area has also been included (See Figure 4).
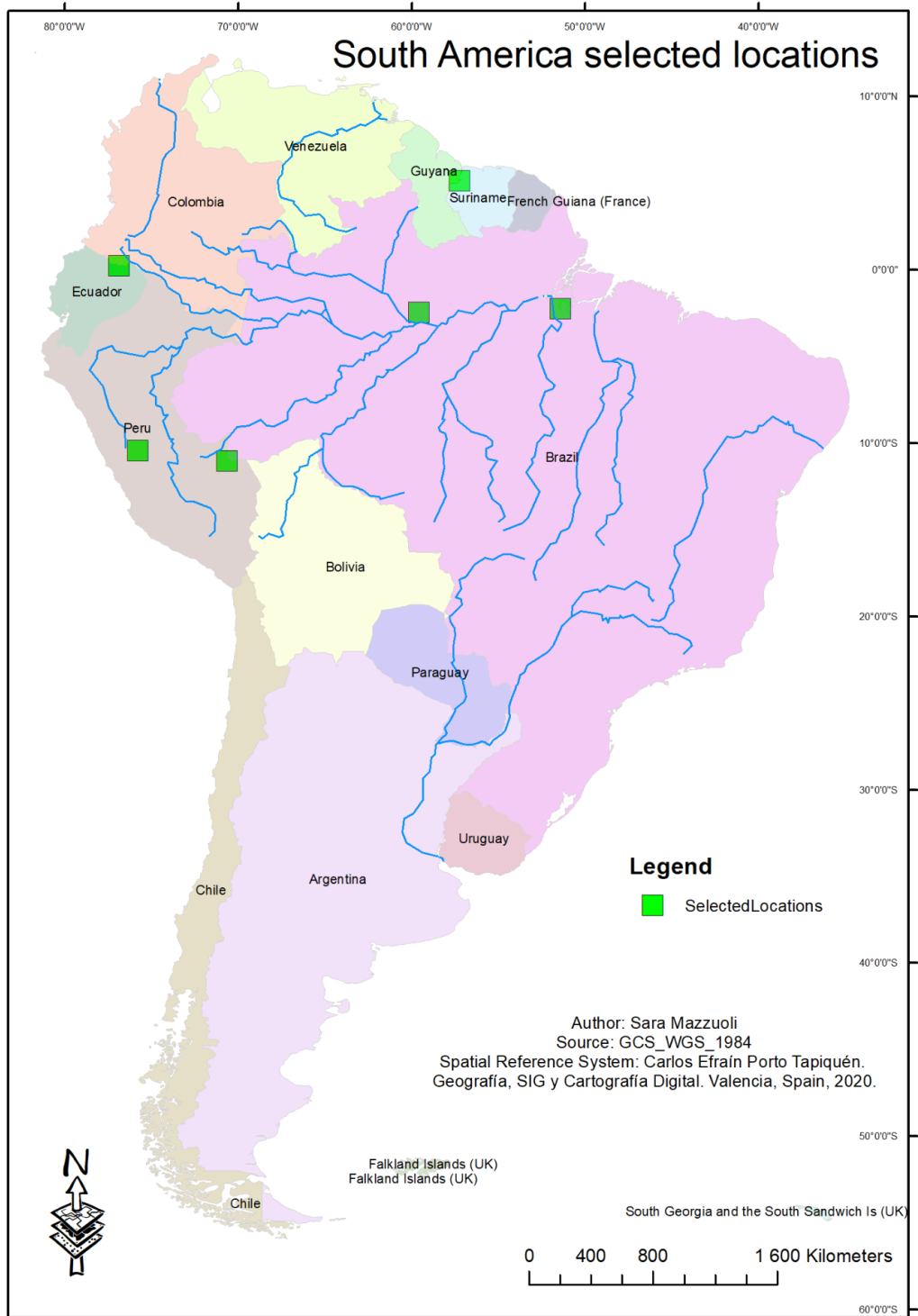
Figure 1. South America's political map showing the selected locations.
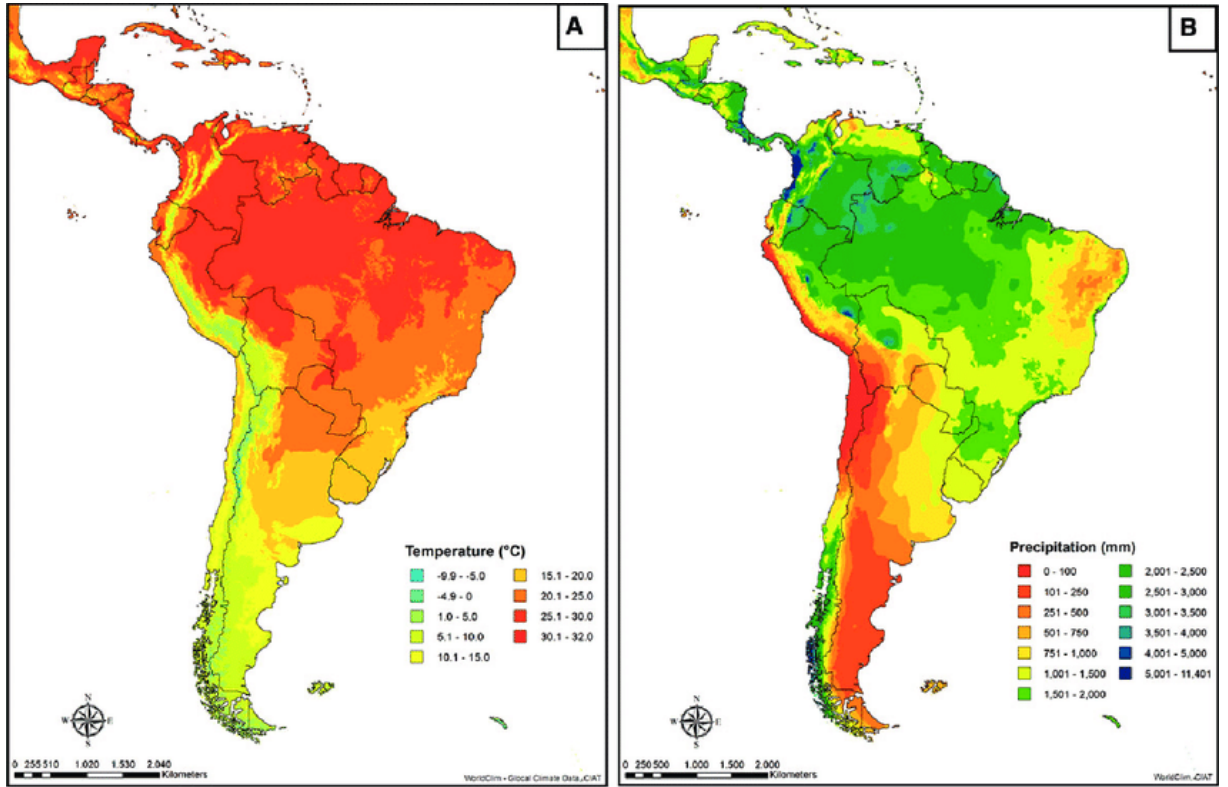
Figure 2. Average temperature (A) and precipitation (B; mm/yr) in South America. Historical data referring to the years from 1950 to 2000.

2.3 Allometric equations and simulation protocol

Allometric equations were used in the model for calculating the relationship between crown height, diameter and canopy area. Equations input coefficients were then changed in order to improve model simulations.

The used allometric equations as following:

$$H = k_2 D^{2/3}$$

(1)

where H is stem height (m), D is stem diameter (m) and k_2 is a PFT-specific constant (B. Smith, et al. 2014). In this equation, it is assumed that the height of the trees is correlated with its diameter. This governs the rate of increase in tree biomass content as trees grow.

Moreover, plants invest most of their nutrients in biomass growth (B. Smith, et al. 2014) and specifically, biomass allocation in leaves depends on how water taken up from the soil is mainly flowing within the roots and sapwood vessels inside the trunk before it can reach the crown area. Therefore, it is assumed that sapwood maintain a cross-section area in proportion

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to the total area of leaves (B. Smith, et al. 2014), and this assumption can be represented by the following equation:

$$LA = kla{:}sa\ SA$$

(2)

where LA is annual maximum individual leaf area (m^2), SA is sapwood cross-sectional area (m^2) and kla:sa is a PFT specific constant (B. Smith, et al. 2014).
This formula has not been directly used by these studies, however, it is relevant in terms of understanding the processes behind forest growth.

To determine how crown area is related to the diameter, and therefore, to tree structure, the following equation is used by the model (Smith et al., 2014):

$$CA = k_1 D^{1.6}$$

(3)

where CA is crown area (m^2 and k_1 is a PFT-specific constant (B. Smith, et al. 2014). As stated also previously, by analyzing the crown area it is possible to understand the correlation with the tree structure in the model outputs. This relationship is referred to as 'baseline' below.

Another equation has been the following:

$$Tropical\ forests\ crown\ (CA) = 10^{-0.251} \times rstem^{0.707}$$

(4)

where the tropical forest crown is defining the area of the crown, and rstem is the radius of the stem. Equation 4 was converted analytically to the form of Equation 3, allowing it to be applied in the model. The resulting allometric coefficient parameters k_1 and k.rp shown in Table 2.

Table 2. k_1 and k_2 values before and after derivation.

Original Shenkin et al. parameters	Updated Shenkin et al. parameters
k_1=250	k_1= 249.7
k.rp=1.6	k.rp= 1.414
k_2=60	k_2=60
Npatch = 100	Npatch = 100

The number of patches selected for running the model have been 100. A higher number has been chosen in order to average out stochastic variation in stand structure across a grid cell caused by different local times-since-last-disturbance, and individual establishment and mortality events which are drawn randomly from a prescribed distribution.

Finally, figure 3 and 4 have been made in order to show respectively the proportion in between equations 1, 3 and 4.
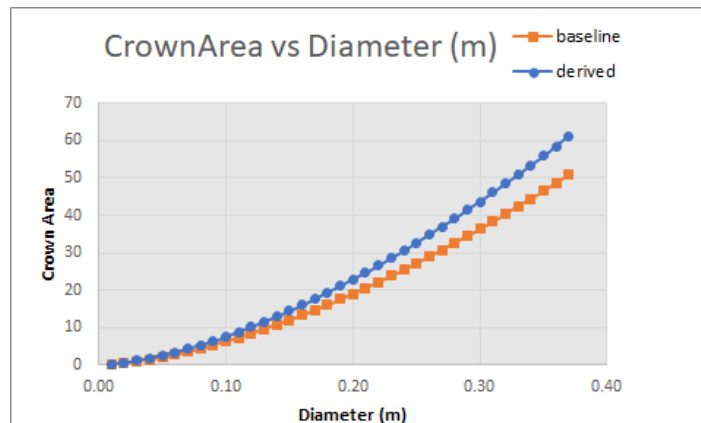

Figure 3. Crown area vs diameter (m) calculated with two different formulas (1 and 3). Crown area increases until its maximum value, set at 50 m^2 .

Figure 4. Height of the trees vs diameter (m) calculated.
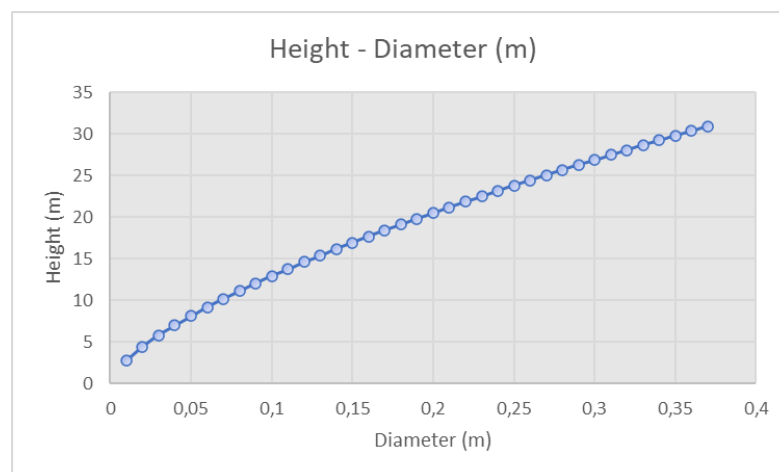
The line in Figure 4 is showing the relationship between the diameter of the tree and the height of the tree, which is also the visual representation of equation 1. As Figure 3, the crown area parameter stops at 50m^2 since it is capped by the model to that value. The line grows in a logarithmic way; contrary to the lines in Figure 3 that grows in an exponential way.

2.4 Mortality rates

Simulated mortality rates were also studied in order to interpret the age class diagrams, obtained by the study of productivity. Mortality can vary depending on canopy size, climate variability and changing levels of competition, therefore it has been useful to proceed with these analyses in order to understand their correlation with productivity values for the selected locations. By looking at the values obtained by the model output, specifically for carbon turnover flux which indicates the different mortality components, I could first analyze the mortality rates for each location during 106 year time period (from 1900 to 2015) and then compare them with productivity values to see if the model was depicting reality or was far away from observations.

The analyzed mortalities components where respectively:
- MgrowC -resource stress mortality- is usually high when the mortality of the trees is induced by unusual climatic conditions such as droughts or when individuals are succumbing to shading by taller neighbours. In case of droughts, it is more common for bigger trees to die since they can be affected by the lack of nutrients.
- MthinC -self-thinning mortality- within a cohort mortality happens when individuals within a cohort expand to cover, with their crown area, more than 100% of space. This results in mortality of suppressed individuals captured as a reduction in stem density until the integrated crown area is reduced to 100%, i.e. no overlap between tree crowns.
- MminC -background mortality- increases when trees approach their old age. This captures effects of senescence, reduced resilience to pathogens etc as trees grow old.
- MallocC -allometric mortality- arises when allometric constraints in the model cannot be met. This usually happens when there is a severe downturn in growth conditions from one year to the next, such as a drought.
- MortdC -background disturbance mortality- mortality due to disturbances such as windthrow, landslides.
- MfireC –mortality due to wildfire- is linked to weather and fuel availability.

Each of them is indicating a different type of mortality component and they are all expressed in terms of biomass loss in kgC m^{-2} $year^{-1}$. For my analysis, MallocC was added to MgrowC for representing the allocated and background mortalities because they represent different events in the model that are triggered by trees experiencing the same stress in the form of low resource availability that draws down productivity relative to tree size.

2.5 Conversion of biomass units

The units for biomass values were converted into the same, tonnes dry weight ha^{-1} for biomass and trees per hectare for the number of trees, for both observed and modelled data considering a proper arrangement into the graphs and further comparisons. Specifically, the unit for observed data was tons AGB ha^{-1}, where AGB is above-ground biomass. In order to

change the values into the right unit, AGB has been converted to dry weight biomass and a specific formula for tropical forests has been used by Saatchi et al. 2011, shown as following:

$$BGB = AGB + 0.489 AGB^{0.89}$$

<div align="right">(B1)</div>

where BGB is below ground biomass. For the case of modelled data, the unit for biomass obtained by the model was kg C m^{-2}, but those have been changed to tons dry weight^{-1} ha by multiplying the values by 20. This includes a conversion factor of 2 from carbon to biomass as recommended by the IPCC (M. Løyche Wilkie, al. 2008).

3. Results

3.1 Modelled and observed data in comparison

Average number of trees, biomass values and NPP rates for both observed and modelled data have been calculated and are shown in the Table below for each location. Modelled baseline (with original allometry) and modified (with observation-derived allometry) results are distinguished. Histograms have been made to represent each location's trees' size, tree number and biomass. Statistical analysis of observation against modelled and relatively calculated RMSE are also shown in scatter graphs as follows. All the data in the histograms have been subdivided into 8 specific diameter classes and each class has been separated by 5 cm or 10cm respectively. Differently for the higher diameter class (60 more), a unique class has been assigned.

Table 3. Six plots result for respectively the number of trees (trees ha^{-1}), biomass (tons dry weight ha^{-1}) and NPP $\left(\text{Kg C m}^{-2}\text{ yr}^{-1}\right)$ values.

	Total Number of trees Observed (trees ha^{-1})	Total Number of trees Modelled baseline (trees ha^{-1})	Total Number of trees modelled modified (trees ha^{-1})	Total Biomass observed (tons dry weight ha^{-1})	Total Biomass modelled baseline (tons dry weight ha^{-1})	Total Biomass modelled modified (tons dry weight ha^{-1})	Total NPP values modelled baseline (kg C m^{-2} yr^{-1})	Total NPP values modelled modified (kg C m^{-2} yr^{-1})
PlotCAX Brazil	589	440	352	209	137	332	1.121	1.064
PlotMAS Brazil	682	310	247	189	236	567	1.547	1.394
PlotCOU Peru'	565	337	326	193	198	373	1.395	1.377
PlotCSN Suriname	430	517	368	182	184	295	1.133	1.044
PlotYAN Peru'	697	551	283	219	217	560	1.385	1.454
PlotYAS Ecuador	664	222	365	174	261	505	1.303	1.327
Tot.	**3627**	**2377**	**1941**	**1166**	**1233**	**2668**	**7.88**	**7.66**

Table 3 shows the observed and modelled versions for the six different locations of biomass and diameter values. NPP values have been also added in order to express the productivity of the sites and therefore to see how the differences in total biomass in the different sites are depending on the productivity of the site itself. Quite high values are shown for the number of trees for observed data while less for the case of modelled baseline and modified. In the case of biomass, higher values were simulated with modelled modified parameters. Changes in values for NPP are not significant. Following, plots of diameter classes versus number of trees (Figure 5) or biomass values (Figure 6) for the three different studied cases, modelled baseline, modified and observed data:
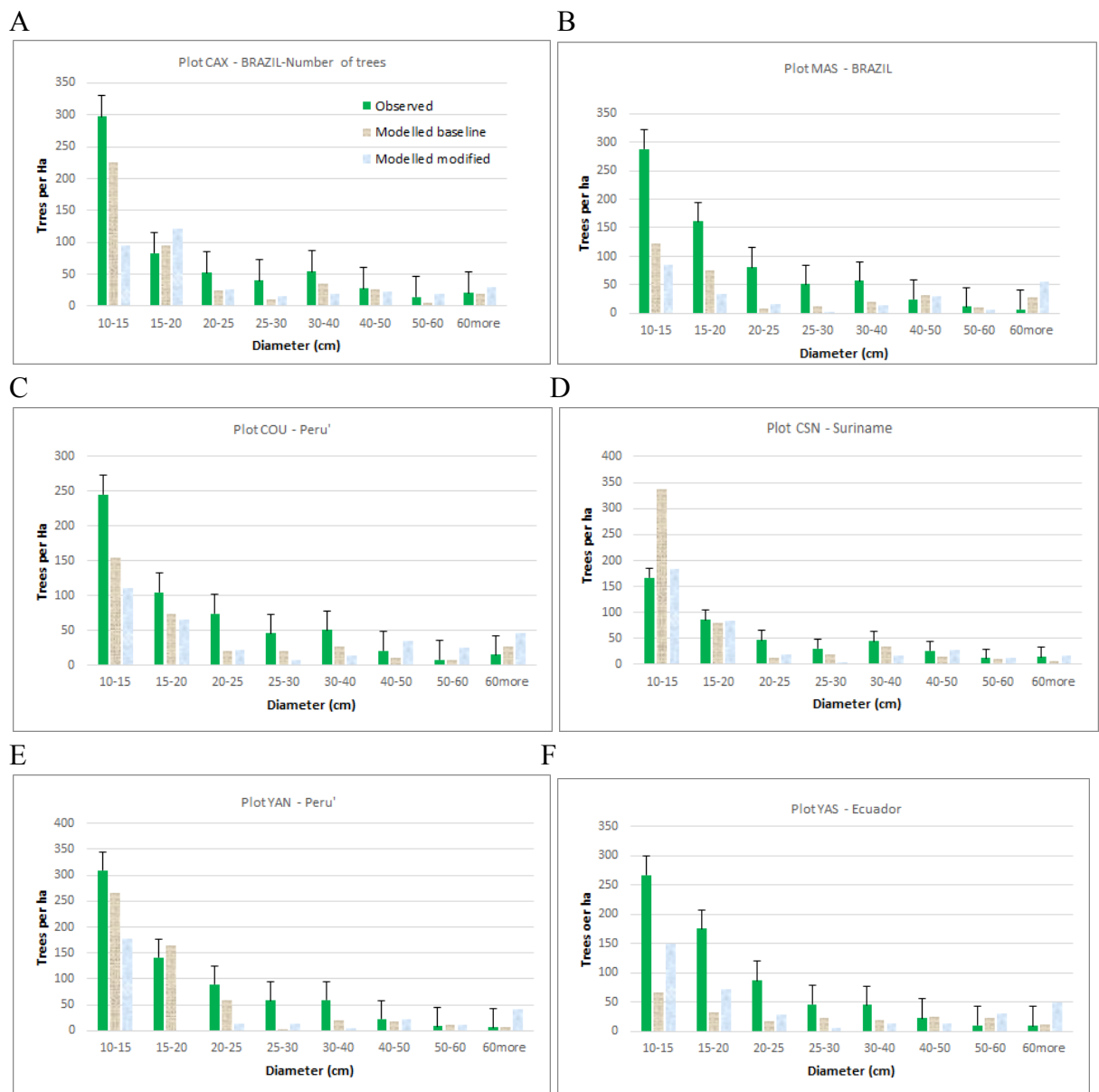
Figure 5. Observed, modelled baseline and modelled modified for all the plots (from panel A to F), for diameter vs number of trees per hectare with positive standard deviation error for observed data.

For the observed data, all the figures are showing higher numbers of trees for smaller diameter classes (10-15 cm of diameter). Figure D is showing a higher number for modelled baseline for the same diameter class.

At all sites, the observations are showing a secondary peak of trees belonging to the 30-40cm diameter class and relatively few bigger trees. Number of trees observed ranges between 309 (for smaller class, plot YAN) and 7 (for bigger class, plot MAS and YAN).

Modelled baseline trends are also performing quite similarly to the observations for all locations, so higher numbers of trees are registered for smaller diameter classes and 30-40cm

class is slightly above the neighbouring classes. Number of trees simulated ranges in between 338 (smaller class, plot CSN) and 4 (class 25-30cm, plot YAS).

A completely different situation can be depicted from modelled modified: it is possible in fact to observe quite high values for medium diameter classes (see Figure A, 10-15cm diameter class) or values completely disappearing from the simulation (see Figure E, same diameter class). Often, bigger classes (60more) are performing higher values than medium classes (see Figure 7, A, B, C, F, E).

For the medium classes, different values have been simulated depending on the location. Number of trees simulated ranges between 184 (smaller class, plot CSN) and 4 (diameter class 25-30 for plot MAS and 30-40 for plot YAS).
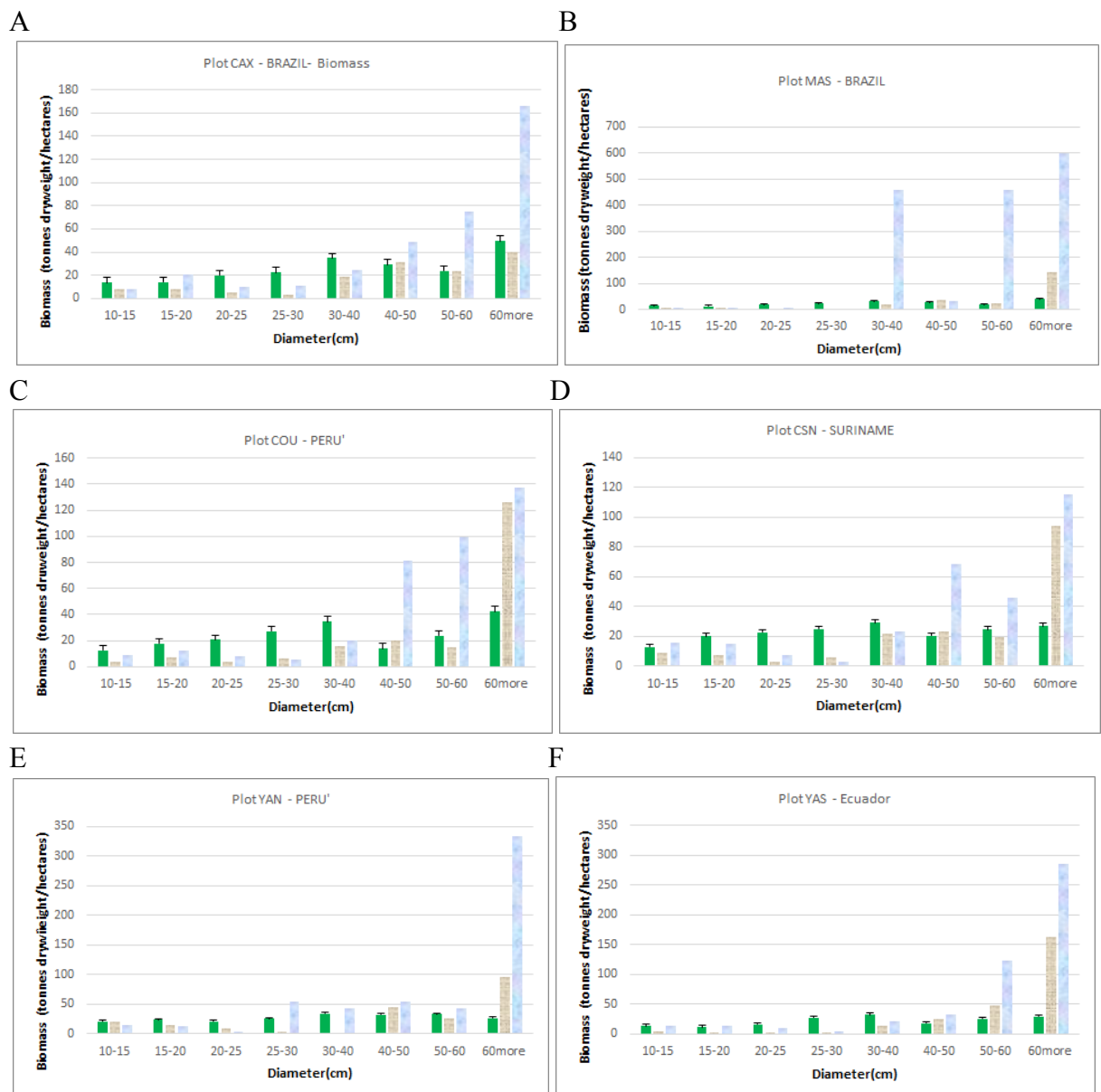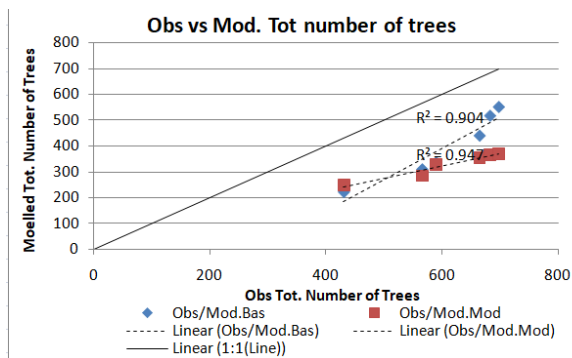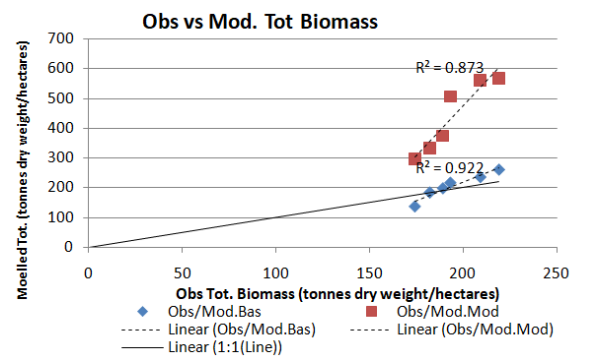

Figure 6. Observed, modelled baseline and modelled modified for all 6 plots, for diameter vs tree biomass (tonnes dry weight ha^{-1}).

Biomass values calculated in tons biomass ha^{-1} are increasing respectively with diameter classes. Quite large differences can be seen in between modelled baseline and modelled modified. For observation data, it is possible to see that higher biomass values are always registered for 30-40 diameter classes and 60more. Similar values are instead registered for the other diameter classes. Modelled baseline trends are always showing high values for the 60more diameter class and smaller for the other classes. For smaller classes, values tend to be very low and always below 50 biomass dry weight ha^{-1}. Same situation has been simulated for biomass for modelled modified: smaller diameter classes, respectively below 40-50cm, are showing values below 50 biomass dry weight ha^{-1}, apart from figure B and E where slightly higher values are respectively registered for classes 30-40 and 25-30 (457 and 54 biomass dry weight ha^{-1}). In modelled modified, the highest values are registered in plot B (Plot MAS) with around 600 biomass dry weight ha^{-1} for higher diameter class. Other simulated baseline values, for 60more diameter class, are ranging in between 164 for plot YAS and 40 for plot CAX; while in between 600 (plot MAS) and 115 for plot CSN, the same unit as stated above for modelled modified. Plot MAS seems the one with highest biomass modified simulated values for higher diameter classes.
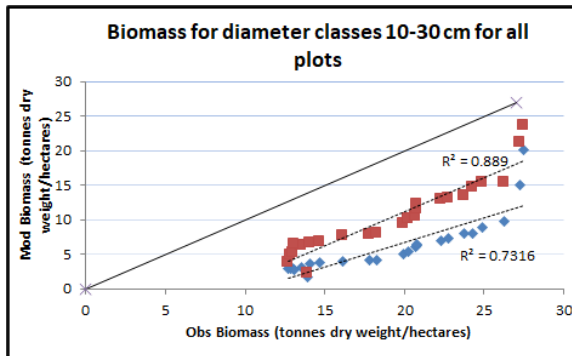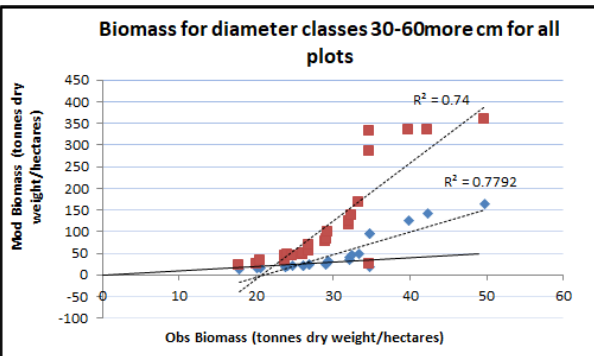
A

B

C

D

E

Obser/Modell for 10-30 diameter classes number of trees

F

Obser/Modell for 30-60more diameter classes number of trees

G

Mod. baseline and Mod. modified NPP
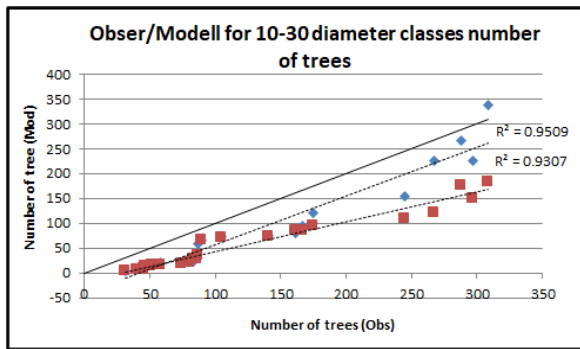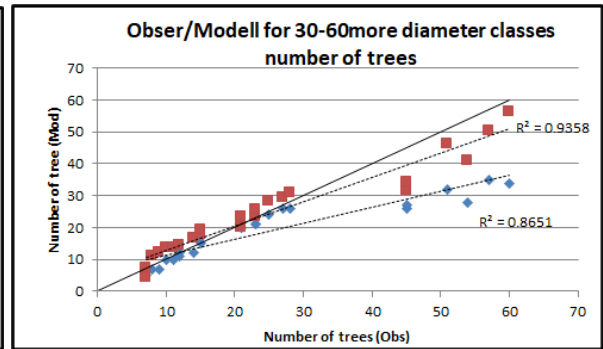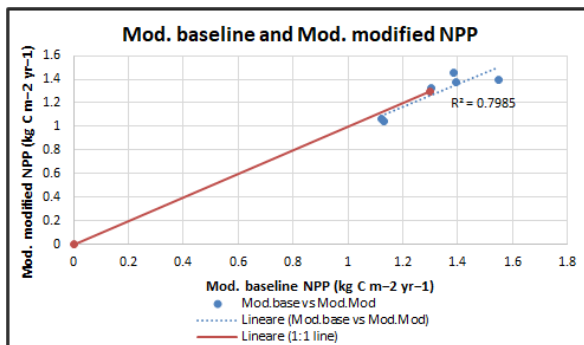
Figure 7. Modelled versus observation data in scattered plots for both number of trees and biomass values and relative RMSE.

Scatter plots show how much modelled data for biomass and number of trees values are fitting into the observation and vice versa. Both of them were subdivided into 2 main groups and separated at the 30cm diameter class in order to guarantee a better statistical analysis of the selected locations. Plots for total biomass and number of tree values (for observation and simulations) have also been made (Figure 7, panel A,B). NPP baseline and modified were studied and RMSE calculated (see Table 4).

Table 4. RMSE values and respectively correlation coefficients for both biomass and number of trees. (Mod.Base = modelled baseline, Mod.Mod = modelled modified).

	RMSE (Obs vs Mod.Base)	RMSE (Obs vs Mod.Mod)	R^2(Obs. vs Mod.Base)	R^2(Obs. vs Mod.Mod)
Tot. Obs vs Mod. Number of trees	135.15	102.58	0.904	0.947
Tot. Obs vs Mod. Biomass (TonnesDryweight ha^{-1})	69.87	75.43	0.922	0.873
10/30cm Obs vs Mod. Number of trees	49.59	70.56	0.732	0.889
30/60cm Obs vs Mod. Number of trees	11.7	5.3	0.779	0.741
10/30cm Obs vs Mod. Base Biomass (TonnesDryweight ha^{-1})	18.7	26.56	0.951	0.931
30/60cm Obs vs Mod. Base Biomass (TonnesDryweight ha^{-1})	40.15	134.5	0.865	0.935

3.2 Mortality rates

In this section, mortality components for both modelled modified and baseline have been analyzed over the long-time period of 1901-2015. This time period was chosen in order to depict long term mortality effects on the Amazon forest structure as it develops, through time, by the establishment and death of new or old individuals.

The mortalities components were represented with different colours defined by the legend in the first graph (Figure 8, panel A).

A   B

C

Plot MAS - Brazil - Baseline

D

Plot MAS - Brazil - Modified

E

Plot COU - Peru' - Baseline

F

Plot COU - Peru' - Modified

G

Plot CSN - Suriname - Baseline

H

Plot CSN - Suriname - Modified

I

Plot YAN - Peru' - Baseline

L

Plot YAN - Peru' - Modified
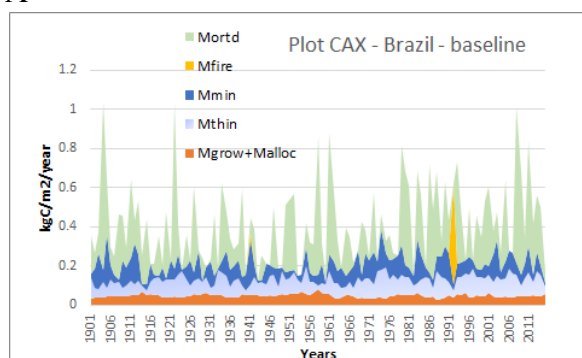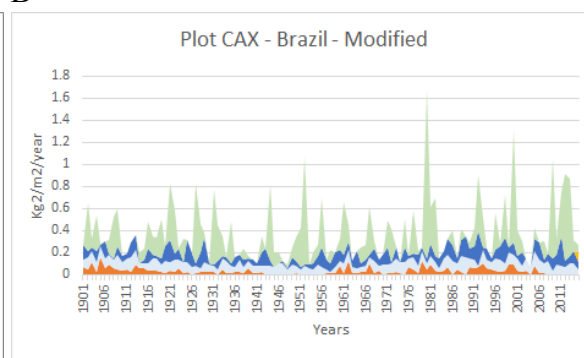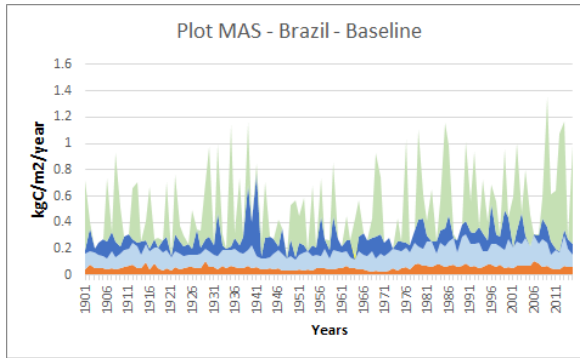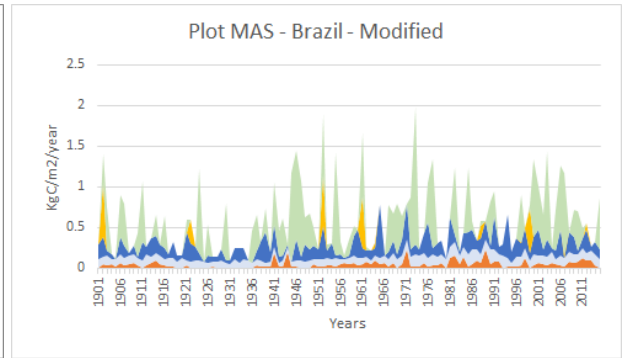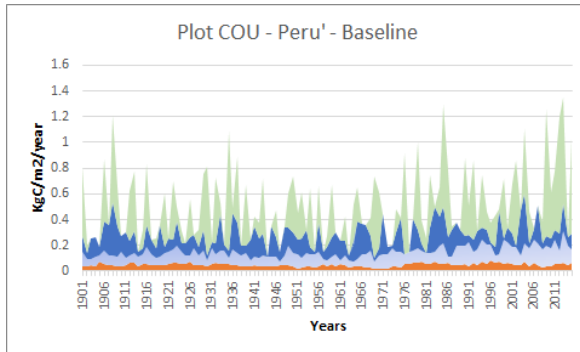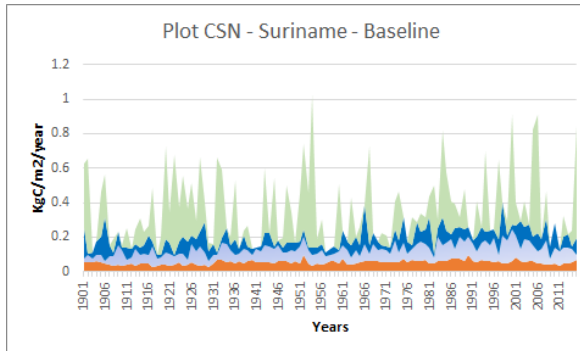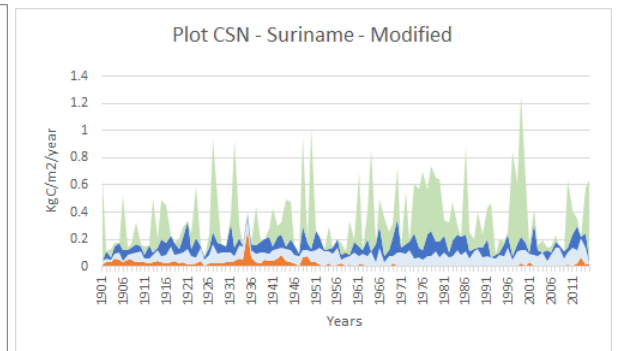
M

N
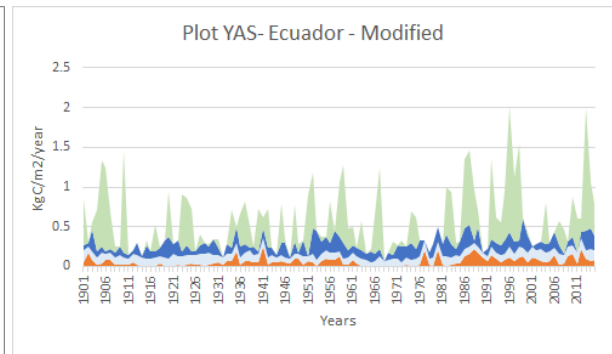
Figure 8. Mortality rates for different components for both modelled baseline and modified. Legend is shown in panel A.

Higher values of mortality are ways registered by background disturbance mortality, followed by background mortality, self-thinning mortality, and resource stress and allometry mortalities. It can be seen in panels A, D, I and L. It is hard to depict correlation in between the values registered for the same location for mortality baseline and modified; sometimes it shows higher values for the different components for the modified (panels I and L, for instance) sometimes they are quite similar (panels E and F).

4. Discussion

4.1 Observed vs Modelled baseline data, a first comparison

Observation data collected by TEAM network for the six selected locations have been carefully recorded by considering the size of all trees above 10 cm of diameter at breast height (DBH) and the location of the plot. However measurement errors in field data collection are quite ubiquitous and usually variation in the height of the measuring tape or caliper on the stem and variation in the hydration status of the stem can introduce random errors into stem diameter measurements. Moreover, further error in positioning the measuring tape to be perpendicular to the long axis of the stem can induce systematic overes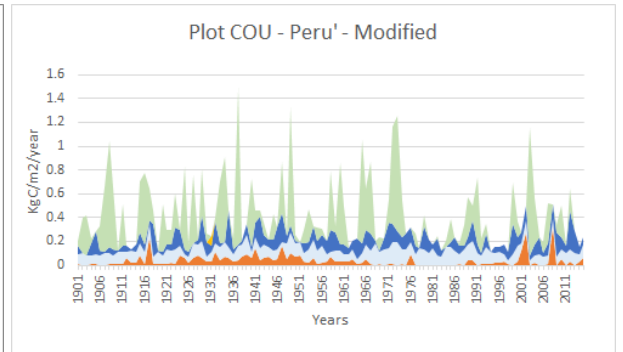timation of diameter (Muller et al., 2014). All of this must be taken into account while analyzing observed data therefore standard deviations have been introduced in the figures indicating tree diameters (Figure 5) and biomass values (Figure 6) in order to consider the above stated human uncertainties. Observations for the numbers of trees for all plots have shown quite high significant values for smaller diameter classes (10-15cm); while smaller values for higher diameter classes (60more cm) (see Figure 5). This mi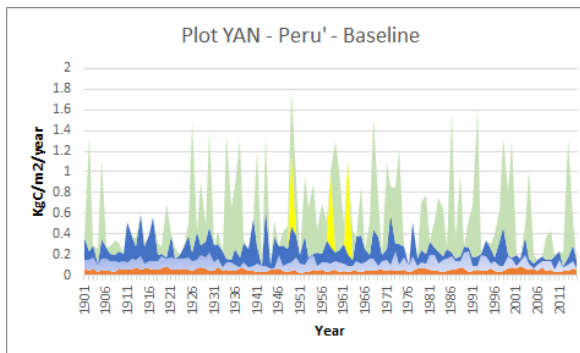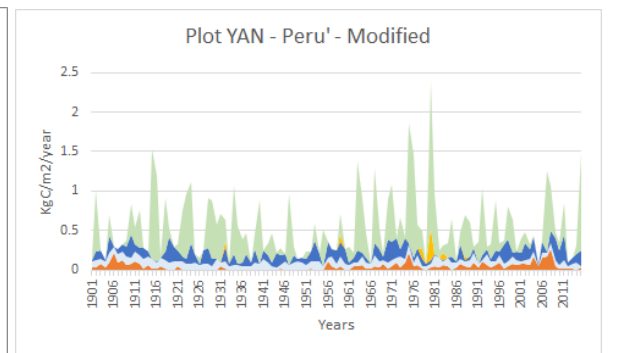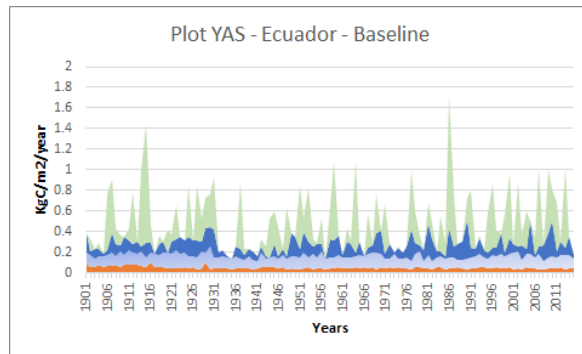ght be due to the facilitation of measurements for trees with a smaller diameter. On the other hand, observations for biomass values have been showing a different trend: slightly higher values for higher diameter classes and smaller for small trees. Middle classes show most of the time smaller, other times higher values than the ones registered for the 60cm diameter class (see Figure 5). Competition of tree species or high mortality rates for smaller and younger individuals might be the reason for this specific tree structure allocations, however, more detailed considerations will be given below.

The model itself performs productivity in terms of biomass and numbers of individuals and mortality rates for a determined location within a number of grid-cells where each tree photosynthetic, respiratory, stomatal conductance, and phenological (leaves and fine roots) values are simulated on a daily time step (Smith et al., 2014).

The model also accounts for climatic variabilities such as droughts or changes in precipitations or temperatures. All of that information helped me understand and interpret the flow of data in the biomass and number of tree plots.

As it can be seen in Figure 5, the number of trees was simulated to be higher for smaller diameter classes and less for bigger diameter classes, such as is happening in the observation.

However, in all graphs (see Figure 5, all plots) middle trees (30-40cm) are stimulated to be slightly more in number than their neighbor 40-50cm diameter class. This can happen when usually some bigger trees die and leave a gap for smaller trees to establish in. Specifically, when a disturbance in the past has resulted in a pulse of trees or a sub-canopy layer of trees being established. This effect, through time, is usually depicted by the model with a peak in medium classes such as in this particular case.

On the other hand, biomass values for modelled baselines are behaving in the same way as the observation. Simulated values are higher for medium and bigger classes and smaller for smaller ones. This is because the model is counting on the fact that biomass accumulates much quicker in tall and older trees because of the scale or power effect - for a certain increase in height (or stem diameter), the increase in volume is the cube of that increase- (see formula 1), and for the fact that a bigger canopy can capture more light, and rob shorter trees of that same light. Thus taller trees grow faster in volume (and therefore biomass), due to the scale effect, (light competition effect). Even for modeled baseline biomass values, in most of the plots (see Figure 6, panels A, B, C, D, E), it is possible to see higher values of medium/bigger diameter classes (40-50cm). This might be due to regeneration events, which is reflected by the peak of a specific diameter class in the graphs rather than others; and usually happens when a tree class has survived mortality events or there are canopies gaps created by small disturbances caused by a windthrow of one or a neighbourhood of tall trees. This process is captured by the 'patch destroying disturbances' feature of LPJ-GUESS. So, basically, how smooth or not these size structure plots are likely related to the frequency of death of large trees. In this case, when large trees are dying more infrequently (i.e. their mortality rate is lower) then gaps are created less regularly, leading to a more irregular size distribution. In contrast, where the larger trees are dying regularly, there will be regular gap creation and so regular cohort establishment, leading to a smoother size distribution.

Basically what has to be considered is that detecting influences of global change on forest biomass is complicated by the fact that biomass is always changing on small spatial scales even in old growth forests. This is happening because biomass is the result of several different processes that add and remove biomass, and the net effect is an integral over many individual adjustments across time (years) and space (patches), so that there is a potential for small systematic errors in individual processes to add up to big biases in biomass. Moreover, in old-growth forests, gap-phase dynamics mean that forests in most areas and at most times are increasing modestly in biomass as trees grow, while a few are experiencing large decreases in

biomass where one or more large trees have died ('slow in, rapid out', in the words of Korner 2003).

4.2 Observation and modelled modified, a further consideration about the simulated productivity in the selected locations

The second time the model was run was aimed to show how the numbers of trees and biomass values are impacted by a change of allometric equations parameters, potentially more representative for observations on tropical trees (see Formula 4; Shenkin et al. 2020).
As for observations, the number of trees is higher for smaller diameter classes and smaller for higher diameter classes. However, contrary to modelled baseline and observations, the number of trees tends to decrease in the middle classes of 25-30cm (for instance, see Figure 5 plot A). This might be due to the cause of regeneration and mortality events that affected the latter class letting the smaller one grow faster in the open spaces left by the older dead trees. Moreover, under ideal resource conditions (i.e. no resource limitation) small trees grow faster than tall ones (B. Smith, at. al 2014) because they have less maintenance costs to meet. In particular, in the model these costs are respiration and replacement costs of sapwood.

In the case of biomass simulation, from figure 6, instead, it is possible to see that the model has simulated high productivity values for higher diameter classes. In some plots, it is possible to notice that biomass for higher diameter classes reached very high values compared to the others (see Figure 6, caption B). Values are respectively 460 biomass dry weight ha^{-1} for 30-40 and 50-60 cm diameter classes and 600, same unit, for 60more class; while usually values are ranging in between 30 and 330 biomass dry weight ha^{-1} for higher diameter classes for other plots (see same Figure). The reason for this might be due to bigger trees shading smaller ones or a series of regeneration and mortality events happening consequently. It is important to remember that the model is simulating PFTs, not species, and the PFTs are assumed to be representative for a wide range of species with similar phenology (evergreen or drought deciduous) and shade-tolerance class and that it is assumed to have new trees established every 5 years, in normal conditions. The model itself does not simulate pathogen or herbivore attacks, but they are implicit in the background and stress mortality components. Finally, in many cases, modelled modified values show even larger discrepancies in the modelled distribution of tree number and biomass compared to the observations, such as in figures 6 plots E and F, where the values are completely disappearing for the trees belonging to the middle diameter classes; this is because the processes that govern stand structure (biomass allocation, allometry and different components of mortality) are down the chain of causality from NPP, which it better constrained by observations, and easier to link to quantitative data on sensitivity to environment (e.g. photosynthesis dependency on temperature, CO2 and soil water). In the case of the observations, the most obvious issue is whether the specific plots that were inventoried are representative for the wider ecosystem.

Studies show that crown scaling (relationship between crown area and diameter) does not change significantly across regions, but does change across ecosystem types (Shenkin. al, 2020). Moreover, in the tree-height game, each tree is assumed to choose a height given its

crown shape and that the asymmetry of competition is important, because higher leaves shade lower leaves but the lower don't shade the higher (Y. Iwasa, 1985). Specifically, in this study, the two used allometric formulas are explaining the relationship between height and diameter and diameter and crown area in a tropical environment. I am also not really considering how the crown areas' growth varies in between different tropical tree species in time and depth. Moreover, light capturing and competition are both very essential variables related to tree size structure and therefore crown areas; and in the model, are both expressed by mathematical allometric equations. Usually, the tall trees benefit from being close to the light, both for their own light capture (higher) and by shading shorter trees which thereby suffer in competition with the taller trees.

4.3 Mortality rates causes, NPP and climatic variables

In this study different mortality factors were considered. Mortality, usually, in a tropical tree environment, increases with a shading effect. The presence of different tree species, for instance the existence of shade-tolerant and non-shade-tolerant individuals or different PFTs -plant functional type- is a factor as well (B.Smith, at. al. 2014). Other causes of mortality, in this study, could have been due to senescence or the exposure to certain diseases or infections. Pathogens and other stressors such as insects or herbivores could be considered to be implicit in stress mortality based on low growth efficiency, which is included in the model and would have certainly influenced the results. The model is also considering climatic variations as main contributors of changes in photosynthesis and respiration rates therefore mortality rates. Although allometric relationships are stable to variations in growth (and therefore temperature and precipitation), deviations might occur during extremes such as a prolonged period of strong drought (which is represented by some of the mortality components).

In my studies, I decided to analyze mortality events happening within a century time set to understand how much each of the singular accidents would have affected the tree's productivity in the selected years. As it can be seen from most of the graphs (see Figure 8), background disturbance mortality is the one assuming the larger values in all locations for both modelled modified and modelled baseline, followed by background and self-thinning mortalities and then by the sum of stress and allometric mortalities. Fire mortality is the one which is less appearing since it is simulated to affect the tree's growth within one or twice per century. This is the mortality due to fuel availability or extreme weather conditions. Background disturbance mortality is the component that takes into account the mortality due to disturbances such as windthrow or landslides. However in my studies, I suggest that the main cause of decrease in biomass in different diameter classes is more due to the crown-area shade effects of bigger trees on smaller trees which is also seen as background mortality and self-thinning mortality. Values for all the mortality components are ranging in between 0 and 2,6 kg C m^{-2} yr^{-1} and are calculated by the model in order to consider the effects of different climatic variables on the tropical environment. Peaks and depressions are clearly visible from the graphs and depending on the year, values are changing more or less severely.

For the selected years, background and self-thinning mortalities are respectively ranging in between 0.002 and 0.625 kg C m^{-2} yr^{-1} considering all the plots for modelled baseline and in between 0.001 and 0.647 kg C m^{-2} yr^{-1} considering all the plots for modelled modified. The

values are not differing too much, just displaying differently depending on the year. For instance, values for plot MAS for background mortality for 2003 is 0.114 kg C m^{-2} yr^{-1}, while for self-thinning one is 0.038 kg C m^{-2} yr^{-1} for modelled baseline. Similar comparison can be done with modelled modified and by considering the different mortality component for the selected years and locations. This change in mortality rates can be linked to simulated locations' productivity parameters, as stated above, determined by the model as net primary productivity NPP, Table 2 is clearly showing. Higher productivities values have been simulated for plots MAS for baseline and YAN for modified, with respectively 1.547 and 1.454 kg C m^{-2} yr^{-1} , while smaller values are calculated for pot CAX for baseline and also for modified (respectively, 1.121 and 1.064 kg C m^{-2} yr^{-1}). Other plots are showing middle parameters and are therefore not far away in productivity compared to the neighbouring ones. Moreover, as it can be seen, simulated mortality rates are usually much less than half of NPP simulated values, which means that biomass productivity is much higher compared to the tree's mortality, which also means that biomass turnover cannot exceed biomass production.

In fact, in calculating individual tree competition indices or productivity of a site, a number of much more simplified assumptions are typically made by the model, for instance, by including that all species are equivalent competitors or that competitive strength changes linearly with distance and the diameter of the competitor - see Formula 1- (Stadt et al. 2007), therefore productivity of a site is much affected by those phenomena that others. Different way of proceeding for analyzing NPP -Net Primary Productivity- of each site was instead chosen. NPP was in fact simulated for the year where the measurements were taking place, which means that it has not been analyzed for long-term predictions.

The next step was to try to connect the productivity and mortality of a site with the climatic conditions present in the same locations. For this matter, precipitation and temperature values were analyzed and figure 2 is showing the average of those two variables for the selected locations and years. Precipitation is almost the same in between 51.25 and 76.26 longitude (kg m^{-2}yr^{-1}) where the Amazon forest is located, but with a slight difference between eastern and western locations. On the western side, where there are higher altitudes and mountain ranges extend, registered precipitation is averaging in between 40 and 50 rainfall (kg m^{-2} mth^{-1}); while on the eastern locations, where the Amazon forest is spreading, the altitude is lower and the climate is more tropical than mountainous, precipitation are averaging in between 50 and 60 (kg m^{-2} yr^{-1}). On the other hand, temperature trends for the same years and locations showed similar values; slightly lower values for western locations and higher for the eastern ones. Average temperatures of approximately 20-25 °C have been registered in the mountainous areas, such as Peru' and Ecuador, while 30-35 °C temperatures have been registered for eastern locations which are corresponding to Brazil and Suriname. After all, it seems that locations with a slightly lower values in precipitation but an higher value in temperature which are also corresponding to the one located closer to the equator (Suriname) or the ones in the Amazon forest are the areas that are more affected by drought, therefore are the ones which has been observed to induce higher mortality (see Figures 8) in the real ecosystem, even if they show quite similar NPP values.

4.4 Statistical Analysis

In order to estimate the correlation in between observation and modelled baseline biomass and number of trees, scatter plots have been made and results are showing that, the model seems to underestimate the parameters compared to observations for number of trees and biomass values for 10-30 cm class, while for 30-60more classes, the model overestimates simulated parameters compared to observation (see Figure 7, panels C, D, E, F and Table 4). The same is happening for observation and modelled modified parameters. Their relationship does not seem moderately strong, contrary, it appears not qualitatively robust and with more outliers than points that could fit into the 1:1 line. For total biomass values, instead, a quite balanced correlation can be seen between the two lines (see Figure 7, panel A, B). For NPP values, the same is happening (Figure 7, panel G). It seems the model changes in parameters in the allometric equations for the second run is not really giving a difference, however, from the sum of them, a better correlation is still more visible (see r² values in Table 4). This can also be seen from the RMSE values, which is giving the confidence interval on the average discrepancy between model and observation, which were also calculated: especially for biomass values for higher diameter classes, quite high numbers were calculated compared to the ones for smaller diameter classes; from the number of trees, the situation is reversing as described also from the analysis in the above sections (See Figure 5 and 6).

5. Conclusion

5.1 What was expected to be - Observed vs Modelled baseline
 Shade-tolerance and light or asymmetric competitions as well as background disturbance mortality have been seen to be the main contributors for biomass changes detections in the selected locations for modelled baseline predictions. While for observations, measurement uncertainties have been seen as the main cause of standard deviations errors which have been added into the plots in order to represent possible measurement errors in field data collection. The modelled baseline trends match the observation quite well.

5.2 How it turns out to be - Observed vs Modelled modified
 Modelled modified values were expected to be similar to the observations and more clearly represent the reality but in my studies, the results are showing a different picture. First of all, the values appearing in the plots and simulated by the model in a second run with changed allometric parameters are not close to both the baseline predictions and TEAM collected data for number of trees, diameter, heights and biomass. This result was not expected to happen, however, the model changed allometric parameters might have not considered further ecosystem or climatic variabilities such as changes in tree species or mortality rates derived by allometric equations. Usually observation cannot depict smaller ecosystem changes, while the model is more prone to depict this kind of variant due to the fact that each individuals is occupying a singular grid-cell and therefore by running the model it is possible to make predictions of productivity and mortality changes within a single tree. Moreover, I had to consider that the model was tuned based on the original allometry, so it might have happened that when I had to change to a different allometry, the performance change was negative. With

minor adjustments, the allometry parameters I used in this study came from the large-area parameterisation of LPJ, therefore, they were never tuned to achieve a realistic stand structure, since LPJ does not represent stand structure.

5.3 Further considerations

Overall, I conclude that biomass and productivity variabilities due to changes in parameters or coefficients in the model run have had a substantial impact on forest structure simulation changes for both biomass and number of trees compared to observations. This is possible to say also thanks to the pursued statistical analysis in scatter plots which is showing the not robust qualitative agreement between modelled data and observations. As I could also see, simulated biomass parameters for bigger trees are quite high for the all selected locations, this due to the fact that the model is calculating biomass considering the relationship between crown area and diameter. NPP and mortality values are also a huge source of notions for understanding the productivity of a site; and in my case, quite high values for NPP have been registered for the studied years, which also confirmed the high values of biomass calculated for higher diameter classes. The model also suggests that most of the changes in biomass are due to morphological factors, such as competition in light above ground, as well as physiological ones such as competition for nutrients below ground. Specifically, for the tropics, nitrogen availability usually exceeds demand. However, the lack of studies or literature that can prove this assessment are not present yet, therefore the need for more research is still needed in order to improve model structure. In conclusion, the model itself was too sensitive to the changes of allometric parameters, and more investigation is also required in order to better finalize the most appropriate parameter values and to ensure that the results are being attained for the right reasons.

6. References

In English:

Aber, J. D., Melillo, J. M., Nadelhoffer, K. J., McClaugherty, C. A., & Pastor, J. 1985. Fine root turnover in forest ecosystems in relation to quantity and form of nitrogen availability: a comparison of two methods. Oecologia, 66(3), 317-321.

Ciais, P., Sabine, C., Bala, G., Bopp, L., Brovkin, V., Canadell, J., ... & Thornton, P. 2013. Carbon and other biogeochemical cycles. Climate change 2013: the physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Comput. Geom, 18, 95-123.

Esquivel-Muelbert, A., Phillips, O. L., Brienen, R. J., Fauset, S., Sullivan, M. J., Baker, T. R., ... & Galbraith, D. 2020. Tree mode of death and mortality risk factors across Amazon forests. Nature communications, 11(1), 1-11.

Fauset, S., Gloor, M., Fyllas, N. M., Phillips, O. L., Asner, G. P., Baker, T. R., ... & Malhi, Y. 2019. Individual-based modeling of Amazon forests suggests that climate controls productivity while traits control demography. Frontiers in Earth Science, 7, 83.

Fisher, R. A., Koven, C. D., Anderegg, W. R., Christoffersen, B. O., Dietze, M. C., Farrior, C. E., ... & Moorcroft, P. R. 2018. Vegetation demographics in Earth System Models: A review of progress and priorities. Global change biology, 24(1), 35-54.

Fourcaud, T., Zhang, X., Stokes, A., Lambers, H., & Körner, C. 2008. Plant growth modelling and applications: the increasing importance of plant architecture in growth models. Annals of Botany, 101(8), 1053-1063.

Friedlingstein, P., Cox, P., Betts, R., Bopp, L., von Bloh, W., Brovkin, V., ... & Zeng, N. 2006. Climate–carbon cycle feedback analysis: results from the C4MIP model intercomparison. Journal of climate, 19(14), 3337-3353.

Hickler, T., Smith, B., Prentice, I. C., Mjöfors, K., Miller, P., Arneth, A., & Sykes, M. T. 2008. CO2 fertilization in temperate FACE experiments not representative of boreal and tropical forests. Global Change Biology, 14(7), 1531-1542.

Iwasa, Y. O. H., Cohen, D. A. N., & Leon, J. A. 1985. Tree height and crown shape, as results of competitive games. Journal of theoretical Biology, 112(2), 279-297.

Macduff, J. H., Humphreys, M. O., & Thomas, H. 2002. Effects of a stay‑green mutation on plant nitrogen relations in Lolium perenne during N starvation and after defoliation. Annals of botany, 89(1), 11-21.

Canadell, J. G., Pataki, D. E., Gifford, R., Houghton, R. A., Luo, Y., Raupach, M. R., ... & Steffen, W. 2007. Saturation of the terrestrial carbon sink. In Terrestrial ecosystems in a changing world (pp. 59-78). Springer, Berlin, Heidelberg.

Kunstler, G., Falster, D., Coomes, D. A., Hui, F., Kooyman, R. M., Laughlin, D. C., ... & Westoby, M. 2016. Plant functional traits have globally consistent effects on competition. Nature, 529(7585), 204-207.

McGuire, A. D., Sitch, S., Clein, J. S., Dargaville, R., Esser, G., Foley, J., ... & Wittenberg, U. 2001. Carbon balance of the terrestrial biosphere in the twentieth century: Analyses of CO2, climate and land use effects with four process‑based ecosystem models. Global biogeochemical cycles, 15(1), 183-206.

Thonicke, K., Venevsky, S., Sitch, S., & Cramer, W. 2001. The role of fire disturbance for global vegetation dynamics: coupling fire into a Dynamic Global Vegetation Model. Global Ecology and Biogeography, 10(6), 661-677.

Sapijanskas, J., Paquette, A., Potvin, C., Kunert, N., & Loreau, M. 2014. Tropical tree diversity enhances light capture through crown plasticity and spatial and temporal niche differences. Ecology, 95(9), 2479-2492.

Shenkin, A., Bentley, L. P., Oliveras, I., Salinas, N., Adu-Bredu, S., Marimon, B. H., ... & Malhi, Y. 2019. The Influence of Ecosystem and Phylogeny on Tropical Tree Crown Size and Shape. BioRxiv, 789255.

Simões-Gomes, F. C., Cardoso, D. C., & Cristiano, M. P. 2017. Geographical distribution patterns and niche modeling of the iconic leafcutter ant Acromyrmex striatus (Hymenoptera: Formicidae). Journal of Insect Science, 17(2).

Sitch, S., Smith, B., Prentice, I. C., Arneth, A., Bondeau, A., Cramer, W., ... & Venevsky, S. 2003. Evaluation of ecosystem dynamics, plant geography and terrestrial carbon cycling in the LPJ dynamic global vegetation model. Global change biology, 9(2), 161-185.

Smith, B., Wårlind, D., Arneth, A., Hickler, T., Leadley, P., Siltberg, J., & Zaehle, S. 2014. Implications of incorporating N cycling and N limitations on primary production in an individual-based dynamic vegetation model. Biogeosciences, 11(7), 2027-2054.

Stadt, K. J., Huston, C., Coates, K. D., Feng, Z., Dale, M. R., & Lieffers, V. J. 2007. Evaluation of competition and light estimation indices for predicting diameter growth in mature boreal mixed forests. Annals of Forest Science, 64(5), 477-490.

Piao, S., Wang, X., Wang, K., Li, X., Bastos, A., Canadell, J. G., ... & Sitch, S. 2020. Interannual variation of terrestrial carbon cycle: Issues and perspectives. Global change biology, 26(1), 300-318.

Verbeeck, H., Bauters, M., Jackson, T., Shenkin, A., Disney, M., & Calders, K. 2019. Time for a plant structural economics spectrum. Frontiers in Forests and Global Change, 2, 43.

Wolf, A., Ciais, P., Bellassen, V., Delbart, N., Field, C. B., & Berry, J. A. 2011. Forest biomass allometry in global land surface models. Global Biogeochemical Cycles, 25(3).

Appendix I
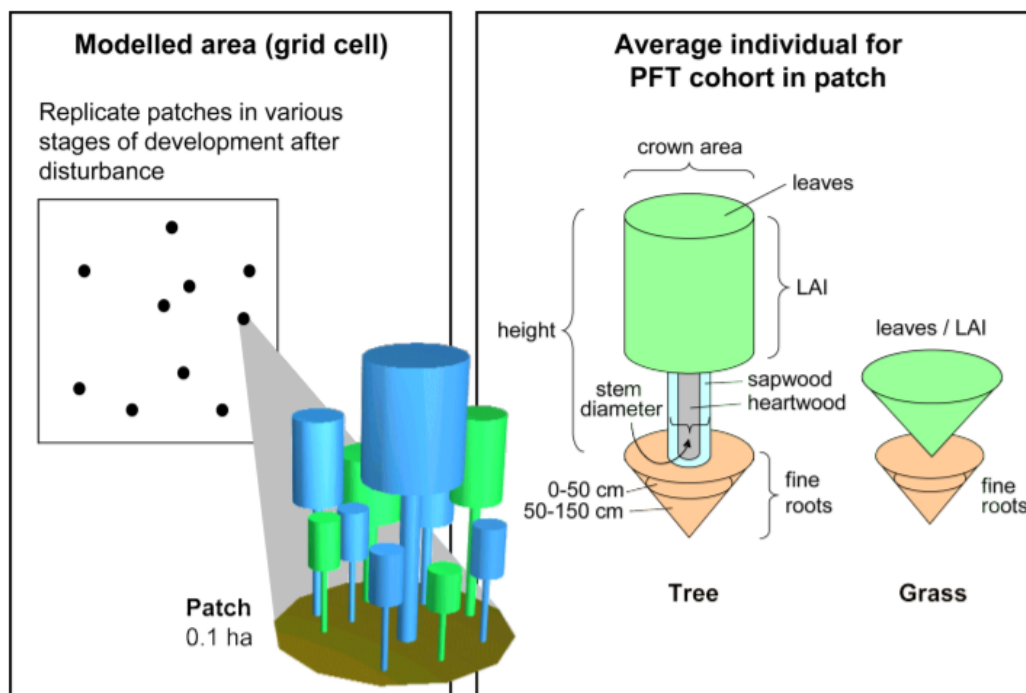
Figure 1A. Vegetation representation in LPJ-GUESS cohort mode.

Table 1A. Shapefiles description for South America map.

Figure 3.	Type of file	Reference System	Source
Country borders	polygon shape file	GCS-WGS-1984	https://tapiquen-sig.jimdofree.com
Water courses	line shape file	GCS-WGS-1984	https://tapiquen-sig.jimdofree.com

Table 3A. TEAM NETWORK description of locations

Caxiuanã TEAM Site					
Name	1ha Plot Coordinate	Longitude	Latitude	CollectionDate	
VG-CAX-3	0,0	-51.51098	-1.73408	2011-05-27	
VG-CAX-1	0,0	-51.45916	-1.70781	2011-05-27	

VG-CAX-2	0,0	-51.48499	-1.72963	2011-05-27	
VG-CAX-4	0,0	-51.52048	-1.75391	2011-05-27	
VG-CAX-5	0,0	-51.59084	-1.78128	2011-05-27	
VG-CAX-6	0,0	-51.4309	-1.72358	2011-05-27	
Central Suriname Nature Reserve TEAM Site					
Name	**1ha Plot Coordinate**	**Longitude**	**Latitude**	**CollectionDate**	
VG-CSN-6	0,0	-56.17737	4.83352	2014-02-26	
VG-CSN-4	0,0	-56.23012	4.76568	2014-02-18	
VG-CSN-3	0,0	-56.11807	4.81202	2013-11-28	
VG-CSN-5	0,0	-56.20585	4.811927	2013-12-05	
VG-CSN-2	0,0	-56.18646	4.697949	2013-12-03	
VG-CSN-1	0,0	-56.188459	4.737631	2013-12-05	
Cocha Cashu - Manu National Park TEAM Site					

Name	**1ha Plot Coordinate**	**Longitude**	**Latitude**	**CollectionDate**
VG-COU-1	0,0	-71.3978222	-11.8870005	2011-09-13
VG-COU-2	0,0	-71.4249016	-11.8993577	2011-09-13
VG-COU-3	0,0	-71.2813285	-11.9371996	2011-09-13
VG-COU-4	0,0	-71.4024744	-11.904708	2011-09-13
VG-COU-5	0,0	-71.4086283	-11.8784896	2011-09-13
VG-COU-6	0,0	-71.2692159	-11.965529	2011-09-13

Yanachaga Chimillén National Park TEAM Site					
Name	**1ha Plot Coordinate**	**Longitude**	**Latitude**	**CollectionDate**	
VG-YAN-6	0,0	-75.31577971	-10.42219729	2011-05-17	
VG-YAN-4	0,0	-75.29446998	-10.37508504	2011-07-13	
VG-YAN-5	0,0	-75.32989584	-10.40999508	2011-09-29	
VG-YAN-1	0,0	-75.2503069	-10.35049162	2011-08-29	
VG-YAN-2	0,0	-75.25653021	-10.3806513	2011-07-22	
VG-YAN-3	0,0	-75.28502173	-10.35418209	2011-08-24	
Yasuni TEAM Site					
Name	**1ha Plot Coordinate**	**Longitude**	**Latitude**	**CollectionDate**	
VG-YAS-1	0,0	-76.38311	-0.68029	2011-05-12	
VG-YAS-2	0,0	-76.41151	-0.69026	2011-05-21	
VG-YAS-3	0,0	-76.43198	-0.70051	2011-05-24	
VG-YAS-4	0,0	-76.44879	-0.65809	2011-05-18	
VG-YAS-5	0,0	-76.44434	-0.67545	2011-05-15	
VG-YAS-6	0,0	-76.47849	-0.68166	2011-05-27	

Temporal Coverage

The temporal period for the TEAM Network Vegetation - Trees & Lianas Data Set is described below. This is the maximum temporal range. TEAM Site specific temporal ranges can be determined directly from the data.

Begin	2002-11-13
End	2017-11-03

Methods Information

One (1) ha plots The one (1) ha plot, a 100m by 100m square lot, is a permanent long-term monitoring vegetation plot. The one ha plots are part of the TEAM standardized protocol and serve to monitor aboveground biomass, forest growth and dynamics, forest structure and composition. A summarized description of the steps followed to study vegetation in the 1 ha plots are: 1. Randomly locate the 1 ha plot within the designated research areas. 2. Establishment of the 1 ha plot. 3. First census of all trees 10cm or greater and lianas within the 1 ha plots. 4. Collection of voucher specimens. 5. Re-census of the 1 ha plot (calibrate the diameter measurer and add the new recruits). A detailed methodology is described in the Vegetation Monitoring Protocol that can be found at: http://www.teamnetwork.org/protocols/bio/vegetation.

DATA RECORDING
The following forms have been designed to collect field data: 1. First census 2. New recruits 3. Re-census 4. Moving the POM The forms can be found at the TEAM Network site: http://www.teamnetwork.org. Field station herbaria are used as repository for voucher specimens from the TEAM protocol plots.

The complete TEAM Monitoring Vegetation - Trees & Lianas Protocol document can be found at: http://www.teamnetwork.org/protocols/bio/vegetation.

DATA MANAGEMENT

Refer to the "Data Management Protocol" and the "TEAM Monitoring Vegetation - Trees & Lianas Protocol" for data management topics related to the TEAM Vegetation - Trees & Lianas Protocol.

Vegetation - Trees & Lianas Data Attribute Information

Attribute Value	Definition	Data Type	Example
ID	Unique number to identify each data record in the database. This number provides a unique identifier for each record but is not necessarily sequential and should not be used for maintaining records across database versions.	numeric	55
Observation Date	Date of tree and liana observation. {YYYY-MM DD}	date	2002-11-13
Family	Tree systematics.	string	Annon
Genus	Tree systematics.	string	Bocageopsis
Species	Tree systematics.	string	NA
Names of Collectors	Name of the person who collected	string	S de Almeida
Diameter	Tree diameter measurement. {cm} **Data collected in Vegetation Protocol Version 1.3 do not meet these standards.**	numeric	11.5
POM Height	Height at which the Diameter measurement was taken. {m} **Data collected in Vegetation Protocol Version 1.3 do not meet these standards.**	numeric	1.3
New Diameter	The new DBH associated with a new POM Height {cm} **Data collected in Vegetation Protocol Version 1.3 do not meet these standards.**	numeric	10.85

New POM Height	A new POM Height is needed if the POM the previous census is no longer appropriate. {m} **Data collected in Vegetation Protocol Version 1.3 do not meet these standards.**	numeric	1.85

Condition Codes Codes describing the tree and measurement observation:

B:	Buttresses
C:	Stilt Roots
D:	Damaged or Deformed
E:	Estimated Diameter
F:	Fluted
G:	Prostrate
H:	Branched Trunk
I:	Uprooted
J:	Inclined
K:	Dead
L:	Ladder Used
N:	Trunk with Regrowth
O:	Broken at the Base
P:	Broken at the Trunk
R:	Partial Crown Loss
S:	Missing Bark
T:	Tree Dying
U:	Tree re-measured

string J,B

V:	Current Measurement Less Than Last Year

**Data collected in Vegetation Protocol Version 1.3
do not meet these standards.**

Sampling Period	There is 1 Sampling Periods in a calendar year for the Tree/Liana Protocol. The Sampling Periods are the year sampling occurred plus the number of the sampling period. For the first Sampling Period in 2007 the Sampling Period is "2007.01".	numeric	2007.01
Comments	Any comments on the observation or identification.	string	Parts of tree collected for identification
Data Level	Data Levels are currently being established for each TEAM Network product. Current datasets being distributed are Level 0 which implies that all data being distributed meet the minimum data standards defined in this metadata document as well as additional QA/ QC rules applied to incoming data. We will expand the Data Levels and corresponding definitions as more synthetic products are developed and additional data curation occur.	string	Level 0
Sampling Unit Name	Unique code to identify the tree or liana point(Protocol-Site-Block-TreeNumber or Protocol Site-Block-LianaNumber). Note that Sampling Unit Names with a two digit decimal denote trees that have multiple stems. (e.g. VT-CX-1-3.01, VT-CX-1-3.02, etc).	string	VT-CX-6-001
Latitude	Latitude of the tree or Liana Point in decimal degrees.	numeric	1.78459044
Longitude	Longitude of the tree or Liana Point in decimal degrees.	numeric	-51.58924692
Spatial Method	Indicates whether the latitude and Longitude were collected via GPS (Collected) or were derived (Derived) analytically from the Block corner coordinates. {Collected, Derived}	numeric	Derived
Subplot Number	Number of the subplot.	numeric	10
1ha Plot X Coordinate	Point of intersection {in the X axis} where the tree was observed in the 1ha plot. {m}	numeric	2.95
1ha Plot Y Coordinate	Point of intersection {in the Y axis} where the tree was observed in the 1ha plot. {m}	numeric	2.81

Tree Number	Unique tree identification number.	numeric	1
Site Name	Name of TEAM Site.	string	Volcan Barva
1ha Plot Number	Number of the 1 ha plot.	numeric	6
Protocol Version	Name and number of the protocol used during the observation.	string	Vegetation Protocol 3.1
Data Set Creator Institution	Institution that produced the Data Set.	string	Museu Paraense Emilio Goeldi
Data Set Creator Scientist	Individual that produced the Data Set.	string	Samuel de Almeida

Data Set Contact The primary contact for the Data Set. The Data Set Contacts email and other contact information
string Museu Paraense Emilio Goeldi

GLOBAL INS PARAMETERS IN LPJ GUESS MODEL:
Connected to table 3.

```
group "tree" (

        ! Parameters common to all trees

        common
        lifeform "tree"
        crownarea_max 50
        ltor_max 1
        turnover_root 0.7
        rootdist 0.12 0.12 0.12 0.12 0.12 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04
        root_beta 0.982
        k_allom2 60
        k_allom3 0.67
        k_rp 1.6
        wooddens 200
        cton_root 29
        cton_sap 330
        nuptoroot 0.0028
        km_volume 0.000001477
        pathway "c3"
        respcoeff 1.0
        kest_repr 200
        kest_bg 0.1
        kest_pres 1
        k_chilla 0
        k_chillb 100
        k_chillk 0.05
        litterme 0.3

        harv_eff 0.95
        res_outtake 0.75
```

```
        turnover_harv_prod 0.04 ! Turnover rate for long-lived harvested products (wood) : 0.04 corresponds to a
25-year turnover time (as in Bondeau 2007)
        harvest_slow_frac 0.33        ! Bondeau 0.33


group "broadleaved" (

        ! Parameters common to all broadleaved trees

        leafphysiognomy "broadleaf"
        !cton_leaf_min 16
        k_allom1 250
        k_latosa 6000
        gmin 0.5
        intc 0.02
        ga 0.040
```