***4.2.*** ***What is the effect of reduced precipitation on biogeochemical cycles for PFT and trait-based versions? Does the approach changes the result/matters?***

It has been argured that a PFT approach is not the best way to represent carbon cycle and its responses to climate change due to its limited representation on functional diversity (VAN BODEGOM; DOUMA; VERHEIJEN, 2014; VERHEIJEN et al., 2015; YANG et al., 2015)⁠. Besides, it is widely accepted that a more diverse ecosystem, including diversity in terms of functionality, is less sensible to the environmental change adverse effects, especially because it present a more diverse response to the changes and would, in theory, be able to recover from a disturbance through, for example, change on functional composition and structure that would compensate the possible loss of species and/or strategies (REFERENCIA).

As expected we observed a expressive reduction in carbon stock for both versions of the model given the degree of reduction on precipitation. The reduction on biomass Amazon forest due to reduced precipitation is in agreement with experimental (DA COSTA et al., 2010; NEPSTAD et al., 2007)⁠, observational (BRIENEN et al., 2015; ENQUIST; ENQUIST, 2011; PHILLIPS et al., 2009, 2010)⁠ and modelling studies (POWELL et al., 2013)⁠. In our model, This reduction is a result of the increased soil moisture stress that reduces the photosynthetic rates (see Equation XX and section XXX) and the net primary productivity, it means that the carbon avaiable to be invested in the plant compartments is globally reduced. However, some studies have being clained that the decrease in biomass due to drought is not necessarely linked to a decrease in carbon availability, but much more related to hydraulic failure (ROWLAND et al., 2015)⁠, however, to date, our model is not able to capture this type of mortality. In that sense, further studies using models to understand the impacts of drought, including CAETÊ should consider these factors and include hydraulic traits. The biomass reduction was more conspicuos on the naturally drier Amazon regions, especially on the fringes of Amazon basin that are characterized by a transition between the moist forest to a seasonal forest and a woody savannah-like type of vegetation, but also in country borders between Brazil, Venezuela and Colombia. This is expected because in these locations the vegetation is already under high physiological stress because of limited water resources, consequently, a drier condition may push them to a threshold condition (AGUIRRE-GUTIÉRREZ et al., 2019)⁠

potential explanation is that drier forests are already under

high ecophysiological stress because of limited water

resources, and therefore a drier environment would push them

closer to their climatic threshold (Allen et al. 2017). → Possí

We expected a more pronounced difference regarding the ability of storing carbon between the two approach. However the model operation, the chosen traits and the defined trade-offs may explain this result.

-our results is contrary to the ones found in (VERHEIJEN et al., 2015)⁠

-pls approach enabled the maintenance of biomass in some places where the PFT approach was not able, however in places where both were able to maintain some level of biomass the PFT presented a higher value of biomass. This is because the mechanism of biomass loss with reduced precipitation was different in the different approaches. Because in the trait-based approach is possible that the community to change their traits, composition and structure, we saw an increase in the investiment on fine roots ( for further discussion in terms of the traits and mechanisms responsible for that see next session), however it was to detriment of investiment in woody tissues. Because fine roots contribute in a lesser extent to total biomass when compared to woody tissues it may led to a relative lower biomass in places where the PFT was also able to maintain biomass. Entretanto, this change for more fine roots investiment allowed the trait-based approach to maintain biomass where PFT approach was not able.

If it at the first moment seems to confer more resilience for a trait based approach which enable an increase in fine roots investiments, in long term it can lead to uncertain and even oppose results. The predominance of strategies that invest less in woody tisues can lead to an ecosystem that store less carbon in total. If biomass is a measure of resilience, as many studies consider, it may turn in long term the ecosystem less resilient.

This result may be derived from the structure of the model and the chosen functional traits. In our model the only advantage associated to woody tissues is that 5% of the strategies that show higher biomass are able to capture 100% of the light. Besides that woody tissues only brind respiratory costs. In that sense, in a scenario of drought invest in fine roots seems much more advatangable event if the total biomass is prejudicada. In that sense, in future studies new relationships regarding to woody tissues may be necessary.

* 1. The mechanism ossaf biomass loss é diferente em cada uma das versões. É por isso que na média a perda de biomassa pelo de pft é “menor”, porque eles preservam a biomassa de troncos, que proporcionalmente conta mais para biomassa total
  2. Apesar da vantagem trazida pelo aumento das raízes finas por aumentar a absroção de água, acontece uma diminuição relativa da biomassa total, já que raízes finas são tecidos de mais curta duração e porque tecidos lenhosos são os que mais contribuem para biomassa total. Tal diferença de investimento em tecido de curta ou alta duração pode ter enviesado nossos resultados de maneira a observamos uma redução na biomassa total maior do que a esperada.
  3. Apesar de ter previnido a perda total de biomassa em regiões onde o de PFT isso pode levar a uma diminuição no estoque total de carbono.
  4. a perda mais gradual pode mostrar certa resiliência
  5. a abruptidão na perda dos pft é porque não consegue mudar e investir em raízes quando necessário
  6. tradeoffs raízes finas e investimento em tecidos lenhosos (PCA?)

-Aqui é o lugar certo para falar de resiliência. -porém é preciso pensar nessa modificação a longo prazo

- It is important to highlight that we did not consider the CO2 fertilization effect, that can be a source of “resilience” against reduced precipitation and higher temperatures (LAPOLA; OYAMA; NOBRE, 2009; RAMMIG et al., 2010) ⁠

***4.3. What is the effect of reduced precipation on functional diversity and its implications to Amazon carbon stock?***

Climate change, as reduced precipitation, is already changing biodiversity all over the world by eliminating species or changing the communities composition (REFERENCIA). However, much less is known about the effects on functional composition, structure and, ultimately, on functional diversity .

Our results show that the applied scenario of reduced precipitation has led to a significant functional reorganization of Amazon forest. This is seen through the indices resulted from our analysis that compare, before and after the disturbance, the dissimilarity between the curves (in the case of the single-trait analysis; Table XXXX) and the similarity between the hypervolumes (in the case of multi-trait analysis; Jaccard index equal to 0.036). The reorganization of the community was due to the alteration on the environmental filtering, in other words, the drier condition selected strategies that coped better with the moisture stress, changing, in that manner, the functional composition. This selection was in the direction of strategies with higher values towards fine roots allocation and residence time to the detriment of allocation in other compartments (these results can be seen in the PCA (Fig XXX) and in the trends of the values distribution (Fig XXX and Table XXXX)). These results are in agreement with previous theoretical, observational and experimental studies that argue that a change in moisture stress, and environmental change as whole, is able to drive functional composition shifts (AGUIRRE-GUTIÉRREZ et al., 2019; ENQUIST; ENQUIST, 2011; ESQUIVEL-MUELBERT et al., 2018; NEPSTAD et al., 2007; PHILLIPS et al., 2010; SAKSCHEWSKI et al., 2016)⁠. The observed change on functional composition had two consequences: first, because in our model higher values of fine roots biomass (determined by carbon allocation and residence time) is linked to higher capacity of water uptake, we can infer that the imposed drought led to a change in functional composition towards more dry-affiliated strategies. The same type of shift in functional composition was observed in Amazon (ESQUIVEL-MUELBERT et al., 2018; MADANI et al., 2018; PHILLIPS et al., 2010)⁠ and other tropical forests(ENQUIST; ENQUIST, 2011; FAUSET et al., 2012; FEELEY et al., 2011)⁠.

Second, the observed increase in fine roots biomass was at the expense of investiment especially in woody tissues. This is a product of the trade offs *a priori* defined (for example, the allocation to one compartments always restrics the allocation to another; Table XXX) and of the trade-offs that emerge from the model itself. The most proeminent emergent trade-off was the one observed between fine roots and aboveground woody tissues traits (Figure PCA XXX). The trade-off between root and aboveground woody tissues was also found in observational studies in Amazon (MALHI; DOUGHTY; GALBRAITH, 2011)⁠ and other forests around the world (WOLF; FIELD; BERRY, 2011)⁠. Despite the advantages confered by the increase in fine roots biomass against the drier climate, it can result in relative lower values of total plant biomass and, consequently, to a smaller capacity of ecosystem to store carbon. This is because fine roots are plant tissues of short duration and contribute much less to the total plant biomass when compared to aboveground woody tissues. Because of this, the functional composition shift may have biased our results concerned to the imapcts of reduced precipitation on the Amazon ability to store carbon (see section XXX). In that sense, future studies using CAETÊ to understand the impacts of climate change, should use traits and trade-offs that are more mechanistically related to the role of woody tissues in determine the ecosystem resistance to disturbance (e.g. woody density, cavitation vulnerability and adult plant height; PHILLIPS et al., 2010; ROWLAND et al., 2015⁠).

Besides the modification on functional composition the modified environmental filtering also affected the abundance of strategies and, consequently, the frequency distribution of trait values, what, ultimately, change the dominance relationship between strategies (Figure XXXX; ENQUIST; ENQUIST, 2011; ESQUIVEL-MUELBERT et al., 2018)⁠. Some observational studies show that Amazon forest presents a hyperdominance of few species and also that this dominance relationship can change with climate changes (FAUSET et al., 2015; TER STEEGE et al., 2013)⁠. Our results show that model CAETÊ is able to reproduce this hyperdominance in regular climate conditions: figure XXX show it through the high curves skeweness and positive kurtosis (ENQUIST et al., 2017)⁠ and through the concentration of higher frequency values around a small range of trait values. However, when the precipitation is reduced the frequency distribution in the traits values is modified towards a reduction in the hyperdominance: lower skweness and more negative kurtosis in the single-trait curves (Figure XXX) besides a spread in the occupance of the functional space in the hypervolume (Figure XXX). This is in agreement with the theory that a change in climate can cause a change in domincance thourgh a compensatory dynamic in communities: when the composition of an ecosystem adjust to the new conditions enabling types of plants that previsouly exerted a lesser functional role turn into a functional dominant strategy and vice-versa (GONZALEZ; LOREAU, 2009; SAKSCHEWSKI et al., 2016)⁠. In that sense, we observed that the compensatory dynamics in Amazon forest with the decrease in dominance allowed the emergence of new strategies and/or trait values that dealt better with the new climatic condition. This compensatory dynamics with shift in functional composition and in dominance was found in another modelling study for Amazon basin (SAKSCHEWSKI et al., 2016)⁠ and also in observational or experimental studies in tropical forests (ENQUIST et al., 2017; ENQUIST; ENQUIST, 2011; ESQUIVEL-MUELBERT et al., 2018).⁠

Together, the change in functional composition and in dominance provoked a change in all the components of functional diversity (Table/Figure XXX). To date, this is the first modelling study to address the modification in all the functional diversity facets for Amazon forest. The studies concerned to understand the impacts of climate change on functional diversity mainly focused on the impacts for functional composition, however functional diversity has different facets that express different ecological meaning (CARMONA et al., 2016; MASON et al., 2005; MOUCHET et al., 2010)⁠. Regarding to functional richness, we found for all the traits an unexpected and significant increase in this functional component derived from a higher occupancy of the functional space (FigXXX and Table XX) what, in its turn, led to an increase in the hypervolume occupied by all the strategies (Fig XXXX do aumento do hypervolume). This is contrary to the hypothesis that a more severe environment would decrease functional richness by selecting for a narrow range of strategies (CORNWELL et al., 2006; FUNK et al., 2017; PERRONNE; GABA, 2017)⁠. However the above cited compensatory dynamics is a possible explanation for the increase in the functional space occupation.

The evennes (i.e. the abundance regularity in the frequency distribution of the trait values in a trait space) has also showed an increase for all the six functional traits (Table XXX and Figure XXX) what means that the reduced precipitation made that the distribution of trait values in the trait space became more regular, another indication of the dominance decrease. Evenness is also an evidence of the effectivenness in using the functional niche space, it means that low functional evenness indicates that some parts of the functional niche space, although occupied, is under-utilised (DE LA RIVA et al., 2017; MASON et al., 2005)⁠. Then, our results indicates that a change in the environment can force the community to better occupy the functional niche space. However, a clear ecological role of evennes on the ecosystem functioning is still missing, and future studies could focus on understanding it.

The divergence (i.e. the degree to which the frequency of trait values occurs at the extremities of the functional space) has increased for all the traits except for leaf and wood tissues residence time, which showed a decrease in this variable although in a low degree (5.0 and 4.7% decrease for leaf and woody tissues carbon residence time, respectively; Table XXX and Figure XX)).The increase in divergence means that, regarding to a specific trait, the values distribution is no longer concentrated in only one extremity of the functional space, but other trait values that were not that important before becomes significant for the community and for the ecosystem functioning with the environmental change. Divergence is also a manner to understand if the frequency distribution of trait values in the functional niche space maximises the total community variation in functional characters (MASON et al., 2005)⁠. In that sense, high divergence could be a result of different, or even contrasting, strategies being able to deal with stress (FUNK et al., 2017)⁠. It agree with our results in which the reduced precipitation as a stress resulted in ….. The divergence decrease observed for the carbon residence time on leaves and woody tissues may be explained by the accounted trade-offs and by the model functioning. We observed a decrease on carbon allocation for these two plant compartments, so in order to maintain a biomass values these two traits needed to keep their values high or do not change the frequency around the values before the disturbance.

In summary our results suggest that changes in precipitation are important in structuring communities, that in its turn can rearrange through compensatory dynamics and minimize the adverse effects of those changes on ecosystem functioning such as carbon storage (FAUSET et al., 2012)⁠. However, the long-term effects of these rearrangements may have negative or uncertain consequences. For example, our study show that a drier climate tends to select towards strategies with higher investiment in fine roots to the costs of investiment on tissues that store relatively more carbon such as woody tissues. This may lead to a decrease in the carbon storage capacity of ecosystems in the long term and consequently impacts global carbon cyle. Also, other important ecosystem functions, like evapotranspiration rate, may be modified with the new functional composition and structure, generating prejudicial feedbacks on the water cycle. In that sense, many of the issues regarding to the climate changes impacts on functional diversity and its consequences for ecosystem functioning remain unanswered.

Despite the interesting and innovative results found in this study some considerations need to be done. First, the model was run two times with different climate conditions what prevented us to see how the community changes happen ao longo do tempo e consequentemente pode ter nos impedido de ver mudanças mais ustis na comunidade analisada, this is because the fact that the version of CAETÊ used here is stationary (see section XXX). Second, in order to analyse the different functional diversity facets, structure and composition, we have considered the whole Amazon basin as a unique community; however Amazon presents a high ecosystem heterogeneity caused by many abiotcs factors such as edaphics, altitude, dry season lenght e temperature that impacts the dynamics of the communities depending on the region (LEVINE et al., 2016)⁠. The lack of regionality distinction may have led to an overestimation of the functional diversity, especially regarding to the diversity of trait values. Further studies should, in that sense, consider the different regions of Amazon in order to understand if different regions respond differently to changes in environmental conditions and how the different responses affects Amazon basin as a whole. Another problem that may have impacted our results is the fact that we use the CWM approach to determine the trait value that will represent certain grid-cell. This type of integration end up desconsidering the diversity present within the grid-cell. One manner to overcome this problem would be to use the scale aggregation approach proposed by Carmona et al. (2016) that is able to sum the different traits distribution as the scale increases. Lastly, other traits more directly linked to the response to drought such as hydraulic traits (QUAIS?)

* Talvez se tivéssemos usado hydraulic traits a mudança na diversidade funcional não seria tão brusca?
* Talvez considerar traits hidráulicos seja de suma importância nesse sentido já que temperaturas altas e secas mais prolongadas afetam fortemente árvores de grande porte por falha hidráulica (PHILLIPS et al., 2010; ROWLAND et al., 2015)⁠, que poderia abrir “caminho para novas estratégias emergirem e levar a mudança na composição comprometend o estoque de carbono.

In further studies may be necessary to implement traits and trade-offs lineked to woody tissues (such as wood density and XXXXX traits de madeira relacionado ao stress hídrico) in order to capture more advantagens to woody investment (resistencia ao vento??) and turn the distribution more equilibrated.

⁠