Response to Anonymous Referee #1

Thanks for your comments and suggestions. We will revise this manuscript according to your review comments. Below are our responses and plan for revision. Your comments are in italics, and our responses are in roman.

*The current paper aims to compare the predictions of biomass allocation within a vegetation demographic model (VDM) **with explicit competition versus a model without competition**, under elevated CO_2 across a nitrogen availability gradient. To this end, the authors use a derivation of an existing VDM, where the only process that varies is the biomass allocation. The authors then present comparisons between **the two model versions** at equilibrium for one site. The topic of predicting vegetation allocation pattern for different nutrient limitation states is an important one, and one that existing vegetation model often have trouble with. The approach of having one model with two different process representations is also very valuable as it can pinpoint model differences to the exact processes in question.*

However, the value of this study is largely obscured by the way the model is presented and discussed, making it very difficult for the reader to link between model assumptions, results and model implications.

Thanks for the comments. We will revise the manuscript following the comments and suggestions of all the three reviewers.

Major comments

*It is unclear to me if this analysis actually shows **a difference between a model with and one without competition or simply a difference between a model with fixed and one with flexible allocation**. As the authors themselves point out in the introduction, pool-based vegetation models often incorporate a flexible allocation scheme based on nutrient and water availability. It is currently unclear if a model with such a scheme would perform differently from the competition model included here.*

It is a model with one PFT (no competition) vs. multiple PFTs (with competition). We will clarify this and change the notations of the figures (from "fixed vs. comp." to "single vs. multiple").

*One of the key assumptions of the model **is the order of allocation** (l 245): first a fixed fraction allocated to the sapwood, then allocation to the leaves and roots, then if there is available C and N left, to sapwood and fruit. And, most importantly, any carbon left in excess because of N limitation is allocated to sapwood. This last step could have some interesting implications for light competition under N limitation, and can maybe explain the different wood allocation*

patterns observed for the competition models. This model assumption needs to be justified and discussed.

I agree with the reviewer that our description of allocation scheme is confusing, and leads to misunderstanding of the simulation experiments. We used four steps to describe the technical implementation of the ideas of the allocation model in the codes. It failed to convey the major principles of the allocation scheme itself.

The allocation scheme is robust and has been used in many Perfect Plasticity Approximation model-based studies. The carbon assimilated by leaves via photosynthesis enters into the non-structural carbon (NSC) pool first and then is used for respiration, growth, and reproduction. The nitrogen absorbed by roots enters into the non-structural nitrogen (NSN) pool and then is allocated to plant pools (*i.e.*, leaves, fine roots, seeds, and sapwood) following plant growth. The partitioning of carbon and nitrogen into the plant pools is constrained by allometric equations, targets of leaves and fine roots, and the target C:N ratios of these plant pools. The plant growth (and therefore allocation) is simulated at two steps: 1) calculating the amount of carbon and nitrogen that will be used for plant growth at this time step (which can be hourly, daily, weekly, etc.); 2) allocating the available carbon and nitrogen to leaves, fine roots, seeds, and sapwood following rules of first principles. We let the plant growth follow the rules below as they are in the first version (Weng et al. 2015, Biogeosciences. carbon only model) and second version of LM3-PPA (Weng et al. 2017, Global Change Biology. carbon and nitrogen):

1. Plants maintain their leaves and fine roots as close as possible to their targets as defined by allometry equations during the growing season (i.e., leaf and fine roots priority over stems)

2. The ratio of fine root area to leaf area is constant (pipe model) when there is no disturbance to abruptly change leaves and fine roots.

3. Plants must keep some carbon storage (i.e., NSC) for respiration (*i.e.*, they don't kill themselves by using up their NSC for tissue growth).

4. C:N ratios of plant tissues must be close to their target C:N ratios, though they can have daily variations due to numerical issues in matching carbon and nitrogen allocation in daily growth.

5. Plants are able to use available carbon and nitrogen in the most efficient way from the perspective of competition.

Following these rules, our model numerically calculates the amount of carbon and nitrogen that are available for growth (i.e., building new tissues) at a daily time step. Basically, the available NSC (G_C) is the summation of a small fraction (f_2) of the total NSC in an individual plant and the differences between the targets of leaf and fine roots and their current biomass capped by a larger fraction (f_1) of NSC (Eq. 1.1). The available NSN (G_N) is analogous to that of the NSC and meets approximately the stoichiometrical requirement of plant tissues (Eq. 1.2).

$$G_C = \min\left(f_1 NSC, f_2 NSC + L^* + FR^* - L - FR\right) \qquad \text{(Eq. 1.1)}$$

$$G_N = \min\left(f_3 NSN, f_4 NSN + N_L^* + N_{FR}^* - N_L - N_{FR}\right) \qquad \text{(Eq. 1.2)}$$

where L^* and FR^* are the targets of leaves and fine roots, respectively; L and FR are current leaf and fine roots biomass, respectively; N_L^* and N_{FR}^* are nitrogen of leaves and fine roots at their targets according to their default C:N ratios. The parameter f_1 gives the daily availability of NSC during periods of leaf flush at the beginning of a growing season and f_2 for normal growth of stems after plant leaves and fine roots approach their targets. Usually, parameter f_1 is much larger than f_2. We let $f_1 = 0.05$ and $f_2 = 1/(365\times3)$ in this study. The parameter f_2 is used to keep a certain amount of NSC. Likewise, the parameters f_3 and f_4 are defined the same way as f_1 and f_2. We let $f_3 = f_1$ and $f_4 = f_2$ for convenience in this study. Compared to carbon availability, nitrogen availability is relatively stable because SOM cannot vary wildly from day to day (thought temperature can). Plants thus always have a stable supply of nitrogen from these SOM. The mean nitrogen available for growth (G_N) is actually equal to mean daily mineralization rate. The parameters f_3 and f_4 are only used to smooth nitrogen supply and get proper seasonal patterns.

The allocation of the available NSC (G_C) to wood (G_W), leaves (G_L), fine roots (G_{FR}), and seeds (G_F) is following the equations below (Eqs. 2). This allocation scheme coordinates the supply of carbon and nitrogen for growth by adjusting the allocation between high-nitrogen tissues and low-nitrogen tissues to maximize leaves and fine roots growth (G_L and G_{FR}, respectively) to maximize nitrogen usage at given nitrogen supply (i.e., G_N) and keep the tissues at their default C:N ratios.

$$G_C = G_W + G_L + G_{FR} + G_F \qquad \text{(Eq. 2.1)}$$

$$G_L + G_{FR} = Min\begin{bmatrix}[L^* + FR^* - L - FR], \\ (1 - f_{W,min})\, G_C\end{bmatrix} \cdot r_{D/S} \qquad \text{(Eq. 2.2)}$$

$$G_F = v[G_C(t) \cdot r_{D/S} - (G_L + G_{FR})] \qquad \text{(Eq. 2.3)}$$

$$G_W = \left(1 - v \cdot r_{D/S}\right)G_C - (1 - v)(G_L + G_{FR}) \qquad \text{(Eq. 2.4)}$$

$$\frac{(FR+G_{FR})SRA}{(L+G_L)/LMA} = \varphi_{RL} \qquad \text{(Eq. 2.5)}$$

$$\frac{G_L}{CN_L} + \frac{G_{FR}}{CN_{FR}} + \frac{G_F}{CN_F} + \frac{G_W}{CN_W} \leq G_N \qquad \text{(Eq. 2.6)}$$

$$L + G_L \leq L^* \qquad \text{(Eq. 2.7)}$$

$$FR + G_{FR} \leq FR^* \qquad \text{(Eq. 2.8)}$$

where, $r_{D/S}$ is a nitrogen-limited allocation factor to be solved numerically each step; $f_{W,min}$ is the minimum fraction of G_C for stems (0.15 in this study); v is the fraction of carbon for seeds (0.1 in

this study); CN_L, CN_{FR}, CN_F, and CN_W are the default C:N ratios of leaves, fine roots, seeds, and wood (including sapwood), respectively. Parameter $r_{D/S}$ ranges from 0 (highest nitrogen limitation; no nitrogen for leaves, fine roots, and seeds at this step) to 1 (nitrogen is sufficient for all tissues).

The allocation scheme itself is flexible and can generate variable allocation patterns even with one fixed scheme of allocation (i.e., fixed φ_{RL}) at different environments because of variable $r_{D/S}$. The key step in solving this set of equations is to solve $r_{D/S}$ in each growth step (daily in this model). This parameter changes with relative nitrogen availability. When there is no nitrogen limitation, $r_{D/S}$ equals to 1 and the allocation follows the conditions defined by Eqs. 2.1~2.5 (carbon only model). When $r_{D/S}$ equals to 0, G_N does not meet the nitrogen demand even if all the G_C is allocated to wood tissues and we have to return the excessive carbon to the NSC pool (this is a very rare case because of low carbon input long before $r_{D/S}$ approaches to 0 due to nitrogen limitation, though our codes must be able to deal with all possible cases.). When $r_{D/S}$ is in between (0< $r_{D/S}$<1), the leaves and fine roots cannot reach to their targets after this step of growth (i.e., plants maintain a low LAI in low nitrogen environments). At low nitrogen availability, the parameter $r_{D/S}$ keeps a low LAI, a relatively constant NPP/GPP ratio, and a stable NSC for each single PFT. The low LAI reduces carbon supply, and therefore reduces nitrogen demand for plant growth, making $r_{D/S}$ larger than zero.

Overall, this is a flexible allocation scheme and still follows the major assumptions in the previous versions of LM3-PPA (Weng, et al., 2015, 2017). It prioritizes the allocation to leaves and fine roots, maintains a minimum growth rate of stems, keeps the constant area ratio of fine roots to leaves, and optimizes resource usage by relocating carbon and nitrogen to wood tissues when nitrogen is not sufficient for full growth of leaves and fine roots. In normal growth, for each time step, leaves and fine roots get $(L^* + FR^* - L - FR)$, stems $(1-v)f_2$NSC, and seeds vf_2NSC. In the early days of a growing season when leaves are much lower than its target, leaves and fine roots get a large portion of G_C (maximum is 0.85 in this study, 1- $f_{W,min}$). When nitrogen is limited, leaves and fine roots are lower than their targets, reducing photosynthesis and carbon supply. So, this allocation scheme will not result in over-growth of stems because of the reduced leaves at nitrogen limitation.

Based on these allocation rules, the mean of allocations of carbon and nitrogen to leaves, fine roots, and wood over a growing season are governed by the targets for the leaf area per unit crown area (i.e., crown leaf area index, l^*) and fine root area per unit leaf area (φ_{RL}). Since the crown leaf area index, l^*, is fixed in this study, φ_{RL} is the key parameter determining the relative allocation of carbon to fine roots and stems. A high φ_{RL} means a high relative allocation to fine roots and therefore low relative allocation to stems, and *vice versa*.

The parameter $f_{W,min}$ is for maintaining a relatively stable growth rate of tree trunk in the highly variable years. Since allocation ratios to stems are around 0.4~0.7 in temperate forests, with a value of 0.15, it does not affect the overall allocation ratios of carbon among leaves, fine roots, and stems, and still keep trunk grow in bad years, though at a very low rate. If we let $f_{W,min}$

= 0 (i.e., completely leaf growth priority), trees would have unreasonably high variation of trunk growth because leaf and fine root growth would use all carbon for approaching to their targets and leave nothing for stems in bad years.

The parameter f_2 represents another strategy of growth: *conservative* vs. *progressive*. At a small f_2, trees keep a large NSC pool for bad years (conservative); at a big f_2, trees grow fast and take the whole site at a short period of time, but risks starvation in bad years. Since we don't explore this strategy in this study, we let it be constant for all PFTs.

We will add a section in discussion to justify these assumptions.

*While I understand that this is a theoretical study, and such studies are valuable and note **every study needs to show a comparison with data**, **there is a complete lack of model reality checking**. Especially when the two model versions show contrasting al- location patterns, there should be a way to determine what the reality is. There is a wealth of data from FACE experiments, N addition experiments, long-term measurements, soil N gradients etc. I believe it would be very interesting to have a section in the discussion comparing the current model predictions with general observed trends.*

We agree with this comment. We will synthesize the data from FACE and nitrogen fertilization experiments and add a section for reality checking of the model and discussing our simulation results.

As it is, the discussion mostly contains comparisons with previous models from the same model family, which while I think is probably relevant to the authors for model development purposes, is of little interest to the general audience.

We will add a section in discussion to compare with other model predictions.

Detailed comments

*L 52 I'm not sure there are any ESM's that just simulate the nitrogen cycle, this sentence might need rephrasing*

We will rephrase this sentence to "that simulate ecosystem biogeochemical cycles as lumped pools and fluxes …".

L85 the last sentence in this paragraph ("Competitively-optimal...") does not follow directly from the rest of the paragraph, there seems to be a logic jump. What is competitively-optimal? How does such a model result in allocation strategies?

We will add a paragraph to explain "competitively optimal" and allocation strategies.

L99 There is a lot of information packed into this equation which is not appropriately explained. Also I am not sure if this equation is relevant to the rest of the paper.

We will remove this equation and add a figure to show the idea of three levels of model processes in this model.
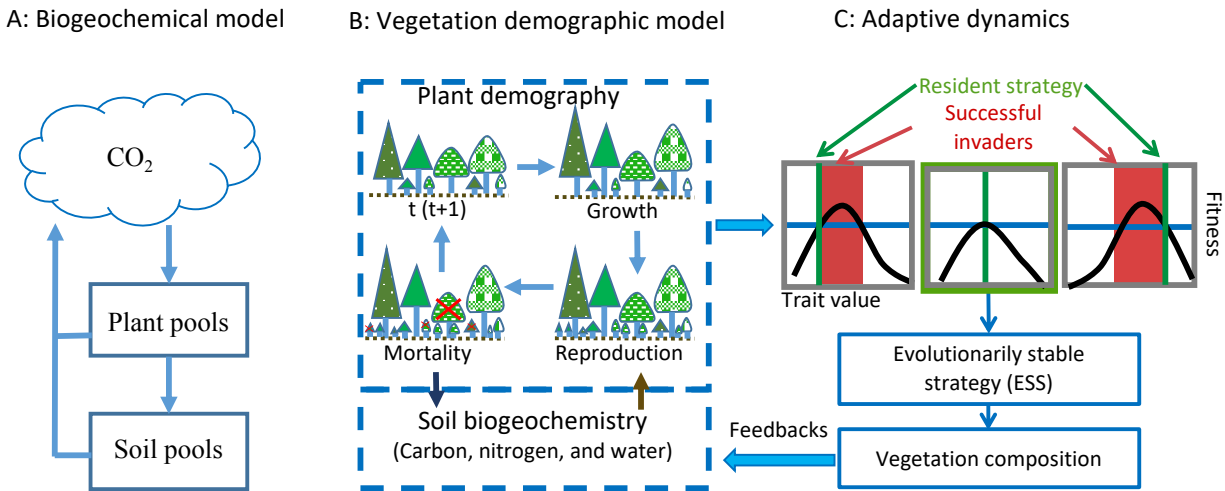
L111 The turnover of vegetation carbon pools is generally not only driven by mortality but also tissue senescence

We will rephrase this sentence to include senescence of leaves and turnover of fine roots.

L 207 Are the C:N ratios of all pools considered fixed?

Only leaves and fine roots are strictly fixed. Wood C:N can be variable in numerically solving the allocation patterns for convenience, but the allocation scheme makes it only variate in a very small range.

L238, eq. 7 It would help here if the first term and the second term in the minimum function were explained in words - I think it is start of growing season available NSC and during growing season available NSC?

We explained it within the new description of the allocation scheme (Eq. 1 in the response to allocation description).

L245 I'm not sure I understand why step 1 is needed given eq 6c

We explained it within the new description of the allocation scheme. It is a minimum growth ($f_{W,min}$). In Eq. 6, we only define the target sapwood cross sectional area.

L254 Does step 4 here imply that the sapwood has variable C:N? Can this increase indefinitely under N limitation?

Yes, sapwood has variable C:N ratio during the numerical iteration. However, it does not lead to indefinite increase in wood C:N because of reduced GPP and relatively stable supply of mineral nitrogen.

L279 Is there a justification for the range of soil N availability?

AU: We set these levels according to Harvard Forest soil nitrogen content. We will update the manuscript with description of soil nitrogen and references.

L355 Generally, I would say 'hump-shaped' is a curve that goes up then down, which is not the case here.

We will rephrase this sentence.

L445 Are there no observational studies showing this behaviour?

This study is experimental. We will look for other empirical studies.

L482 Are there no measurements in the literature of fine root C:N ratios?

There are many measurements of root C:N. However, here, we are talking about its ESS responses to ecosystem nitrogen. We will rephrase this sentence and clarify it.