Authors response to referee # 2

This manuscript attempts to show the importance of spatial redistribution of P from rivers to land, among sub-basins to maintain P cycles of lowland Amazonia. This is an interesting challenge to understand the P cycles from the view of functional roles of animals. Therefore, this manuscript would attract many readers' attention. The introduction section is generally well written and explains the characteristics of Amazonian ecosystems and the P cycles. However, as described below, there are several concerns to be addressed before recommendation can be made for publication in Bio-Geosciences.

We thank you for reviewing our manuscript and for recommending re-structuring the paper. We hope that by substantially re-writing large sections we addressed your concerns.

Main comments: In Introduction, the authors emphasize the dynamic nature of nutrient cycles in Amazon, particularly focusing on the lateral P transfer between different ecosystems or different sub-basins by terrestrial animals. For example, the authors mention that this study shows animals (herbivores and detritivores) redistribute P from flooded sub-basins to P-poor terra firme sub-basins (e.g., P4L20). However, it is unclear at least to me whether this manuscript actually explores the lateral P transfer. It seems that the authors examine how herbivory and detritivory, and the resultant P mineralization affect the amount of vegetation P within "each" sub-basin of three ecosystems that differ in P availability and precipitation (Fig.4 and 5). The mathematical model of this study seem to include only terrestrial piscivores as a vector causing lateral transport of P from river to land, and the results look very confirmatory. If my understanding is correct, I would like to recommend the authors to rewrite and reorganize the manuscript largely to clarify the rationale and the goal of this study.

This is a central point in our manuscript - indeed our aim with this simple model is to describe in a lumped way lateral P transfer within sub-basins. Two modes of transport are considered - both connecting lowlands and uplands and therefore representing 'lateral' transport. The first mode is by non-directional redistribution of P by herbivores and detritivores that respectively feed on vegetation and litter P in proportion to the amounts of P in those pools. By returning P to either lowlands or uplands in proportion to the areas of these ecosystems, they effectively redistribute P across the landscape, though not in a pre-specified direction. The direction of P flow, in fact, is emerging from the model-generated gradients in P across the landscape. The second mode of transport is the one mentioned by the reviewer: piscivores feeding in the rivers and excreting (or dying) on land. We assessed the role of both modes of P transfer in Figures 4-7. The new Figures 4-5 should provide a better illustration of the first P transfer mode compared to the previous version of the manuscript. The text has also been re-structured to clarify which mechanisms of P transport are considered in the model.

In addition, it would be necessary to reorganize Discussion section because most

of the sentences seem not relevant to the findings of this study. Please discuss the present results by referring to earlier studies on herbivory and detritivory rates as well as ecosystem properties associated with P cycles in Amazon and other ecosystems. To do this, some sentences could be brought from Introduction section.

The introduction, methods, results and discussion sections were re-structured to make clear that this paper aims to make a synthesis of the Amazon basin P cycle. Our study in particularly explores and provides insights about the importance of animal redistribution of P within and between seasonally flooded and non flooded ecosystems (within each sub-basin). Although the paper became more extensive, we hope this new structure makes it easier for readers to follow and interpret our results.

Minor comments:

Materials and Methods

P8L8(Fig.3): If P transport from flooded area to non-flooded area (terra firme) is not modeled in this study, it would be better to depict the two boxes representing herbivores or detritivores separately for each area.

We have modified the figure 1 to make clear that we consider herbivory and detritivory fluxes within the sub/basin (the first mode of P transport mentioned in a reply above); we have also corrected the names of some of the variable in figure 3 better specifying the in- and out-fluxes. We hope now it is clear that we are actually modelling the animal fluxes between seasonally flooded and terra firme ecosystems within the same sub-basin.

P8L15: Please explain the equation and each symbol more carefully here. What OoE stands for?

Thanks for pointing this out, we have now re-written the description of the parameters, and checked the consistency of the symbols, text, tables and in fig. 3.

P10L3: discussed

Changed

P10L10-16: These sentences have been described already in Introduction, and thus could be deleted.

This paragraph has been deleted

P10L17: It would be needed to explain about Rio Negro basin and its relation to the overall Amazon here.

We expanded the explanation to:

"Rio Negro is a sub-basin draining only the lowland of the Amazon basin and therefore the weathering rates measured can be taken as a good proxy for lowland amazonian weathering"

P10L21: I could not understand how the value 1895.84 molP per km2 per year was calculated. Please explain.

More explanation was added to the MS "Redistributing all the P that is weathered in the Andes to the whole Amazon basin results in 246 molP in XX per km2 (of whole Amazon basin) per year, the area where this comes occupies only 13% of the total area. We divide the previous number by 0.13 to get the in-situ weathering, getting then 1895.84 molP per km2 (Andean part) per year. All chemical weathering does not occur *in-situ*, but also during the transport and after the deposition in the river and seasonally flooded areas".

P11L3: A reference should be needed here.

We added some more information to explain why the sensitivities
For the animal P flux from rivers to the flooded areas, simulations with three different P inputs were run, with values of 0, 72 and 242 g P ha^{-1} a^{-1}. The first one simulates a scenario with no animals, the second simulates a

270 scenario in which P transfer is like the one is Suriname due to giant otter (*Pteronura brasiliensis*), with an associated P flux of 72 g P ha^{-1} a^{-1} as it was estimated in the introduction, and the last one simulates a scenario in which otters and other animals contribute, since this contribution is totally unknown, the limit for the sensitivity analysis was set to a value between 3 to 4 times of the previous one, 242 g P $ha^{-1}a^{-1}$.

P11L4-11: These sentences seem to have been explained already, and thus redun-Dant.

The sentence was removed.

Results

P12L6: What 4 vs.5 stands for?

We have corrected this issue.

P12L16: From where is P transported to terra firme ecosystem? If it comes from terra firme vegetation itself, the expression "transport" should be misleading.
The model redistributes the P transport from one part of the ecosystem to others and also between ecosystems.

We have added a new figure, now figure 4, in which the net animal fluxes to terra firme ecosystems are simulated in relation to herbivory and detritivory.

P13 Figure.4: Please change the order of the panels so as to match the order of site

explanations in text (1, Rio Negro, 2, Caqueta-Japura, 3 Cerrado). And, add (%) to the x axis label as in Figure 6.

We changed the scale to % and change the order given in the explanation, now we are also referring to Xingu sub-basin instead of Cerrado to be more consiste with language and avoid confusion.

P13L3: delete "we"

Changed

P14L5: What does "s<0.4" mean?

Given our model parametrization dry ecosystems are those that have a relative volumetric soil moisture content (denoted by "s") less than 0.4. We erased the value in parenthesis to avoid confusion.

Discussion
P15L8: Starting new paragraph here should not be necessary.

Changed

P15L9: different results between what?

The phrase was changed to: Second, animal driven redistribution leads to contrasting P in vegetation depending on herbivore grazing pressure

P17L2: redistribution, for example, ...
The phrase was changed to:
It would be interesting to assess if other models of nutrient redistribution exhibit a similar transition from positive to negative effects (for example, in the case of mega-herbivores before the megafauna extinction, see \citet{Doughty:2013})

P17L16: Again, it is unclear from where the animals transport P into terra firme ecosystems. Please explain.

P redistribution by animals represents a net P flux from seasonally flooded to terra firme ecosystems. The text has also been modified to: This is consistent with our model finding that redistribution is key to the P budget of the \emph{terra firme} ecosystems and that detritivores are particularly important in this process (fig. \ref{fluxes} and \ref{states})

P17L17-18:This sentence could be deleted.

Deleted

P17L19-P18L6: These sentences could be deleted, because they are not directly relevant to the present results, and seem very speculative.

Now the manuscript has been re-structured to differentiate between a specific discussion of model results and a more general discussion synthesizing the P cycling of the Amazon basin as a whole. Subsections in the introduction as well as in the discussion section have been included to make this distinction clearer .

P18L6-7: The sentence seems lack of scientific basis.

It is widely recognized (also in the scientific community) that traditional knowledge is highly valuable (make reference to IPBES or Aichi targets of the CBD). In this case, we would like to emphasize that complex food-webs well-known to local people but perhaps less understood or studied by the scientific community can play a major and possibly under-appreciated role in driving P cycling.

P18L14-P19L17: These sentences concerning human impacts and megafauna should not be the main topics of this manuscript, and therefore could be deleted

Even though these topics are not the main objective of the paper, we consider them important to mention, especially in the context of a broader and more holistic discussion about Amazon P cycling, which is now explicit in the discussion section. We argue that even without the action of megaherbivores (Doughty et al. 2013), P can effectively redistributed across Amazon landscapes. Even more, , during pre-colombian times humans have invented management strategies that modified the P biogeochemical cycle of the Amazon, also in part against the physical flow gradient e.g. P-enriched terra preta soils in terra firme ecosystems limiting P leaching. In the context of future applications of our model, it may be worth mentioning these points .