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Biogeosciences
Discussions

Interactive comment on "The influence of reservoir traits on carbon dioxide emissions in the Belo Monte hydropower complex, Xingu River, Amazon – Brazil" *by* Kleiton R. Araújo et al.

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Dear referee 2, We would like to thank you for the enlightening comments and suggestions. Please find our answers bellow after each referee comment.

Referee 2: Review of Araujo et al. This manuscript describes the results from a 2-yr study during high and low water seasons on the Belo Monte hydropower complex that consists of two main reservoirs, one of which is defined as a run-of-river and the other as storage. The authors aimed to contrast the impact of these two reservoir types on the CO2 dynamics of the entire complex. Additionally, they contrasted CO2 dynamics across various flooded environments within the complex. The manuscript has some

nice data but is predominantly descriptive. Regardless, data in tropical reservoirs is currently necessary and it is interesting to contrast these two types of system. Not to mention the huge dispute over this massive Amazonian project. I have many suggestions for how to improve this manuscript before this paper is ready for publication.

Response: We appreciate your suggestions, which have greatly enhanced the manuscript and its potential impact.

General comments 1. Be careful with the word 'traits' in the title. It implies features that do not vary in time. Is that the focus here? Do you mean ROR vs storage, plus flooded landscapes? That would be okay then. But if that was the case then I did not get the impression enough from your discussion that that was your focus. You need to bring out your main points much more. Try focusing the research questions or objectives more narrowly. This will help you throughout the entire publication.

Response:Thank you and that was the point. Basically our goal was to define the group of characteristics that classify each reservoir as 'ROR' or 'storage'. However flooded areas are defined as one of the environments that compose the reservoirs. Therefore, our point was to relate 'trait' only with reservoir type. We agreed with your suggestions related to text structure and they were taken into account to better describe the influence of "traits" in our study.

2. Language overall needs improvement. Too many commas used. Too many sentences that are confusing (many are mentioned in specific comments below).

Response: Updated as suggested.

3. Abstract needs more quantitative results in it

Response: Thank you, this section was revised.

4. Introduction does not discuss the importance of this particular reservoir more.

Response: Agreed, the introduction was too general, especially regarding specific in-

formation about the Belo Monte complex. More details concerning Belo Monte and its controversy were added to the text as suggested by both reviewers.

5. Methods – description of how reservoirs are connected is not clear. In the map figure there appears to be a channel connecting them too. Please improve the description of how the reservoirs interact, including flow directions, which should be on your Figure 2, and individual surface areas.

Response: At the left margin of the Xingu river channel the water flow is adducted through a 28 km channel to feed the main power house (Eletrobrás, 2009). This channel links both reservoirs, since XR is located in the river channel and regulates the IR water flow. The channel description and reservoir interaction was clarified. Also, Figure 2 was updated as suggested.

6. I find section 3.1 of the results very confusing to read and absorb fully. There are a lot of numbers that are perhaps not necessary and very distracting from understanding what you are trying to describe. I would suggest a schematic to help describe the temporal (high vs low water) variability you see that also includes the spatial variability (across environments). You can use weighted markers for the various fluxes and concentrations that correspond to high and low values, if not the real values.

Response: Thank you, we appreciate this suggestion. The results section had some data not essential for addressing our hypothesis. This section was revised for conciseness and clarity. After these changes the text became clearer and we believe that a schematic figure is not needed.

7. Figure 2 – needs arrows for direction of flow.

Response: Done.

8. Figure 3 – You can make these 4 plots into just 2 in the following manner: put the white boxplots from (a) and (b) that are pCO2 in the beginning of (c) labeled 'High water' and 'Low water', and the gray boxplots that are for FCO2 in the beginning of

(d) with the same labels. Also, are the environments in c and d labeled in the proper order – from one are to another? Or does it not work like that because of the reservoir geomorphology? Either way, I would put downstream the dams on the right side since most people read left to right and you naturally think downstream to the right.

Response: Thank you for the interesting suggestion. The environments were previously organized in alphabetical order on the plots. However, we agree that it will be easier for the reader to follow the downstream orientation. Therefore, it was corrected to flow order. We added more plots to this image according referee 1 suggestion, with season separately and an additional variable (k600). The categories were also changed to "unaffected river upstream", "XR", "IR", "downstream the dams" and "unaffected river downstream".

9. Figure 4 – you need units listed for the values; direction of flow arrows would be good; and mention in caption that (a) includes 2 years of data while (b) only has one year (and list which years).

Response: Updated as suggested.

10. Figure 5 – you mention these figures in terms of stats but there are no lines on it and no equations or states in the figure caption.

Response: Both figures are related to k600 and FCO2 correlation pattern with wind data, representing the interaction of these variables. Spearman correlation is ranked and do not have mathematical model or equation, as so Rho values were added to each image. In addition since figure 3 was updated with k600 panels, as suggested by referee 1, this figure will be included in the supplement material.

11. The discussion seems like a bunch of descriptive paragraphs thrown together. It is lacking some cohesive red line to follow and it is hard to locate your main points. Perhaps you can start to fix this by using subsections. Looks like you broke it down into the following: Seasonal variability; Vertical heterogeneity; FCO2; Spatial variability;

Comparison to other reservoirs; k600; Operation. These are all just descriptions of data in reality. You want to discuss the most interesting findings of your study and then compare them with other studies. Figure out your few most important findings and try to arrange the discussion around those first. You also measured the system right after flooding, which is when emissions should be highest. This needs to be addressed in your conclusions.

Response: The discussion was rearranged and divided into subsections that we believe are now more connected with our main findings as nicely suggested. We also gave some attention to the text in order to clarify our hypothesis. In addition, we highlighted in the manuscript that measurements were made during the first years after impounding.

Specific comments

Line 16-17 – did you measure clearwater rivers yourself ? if not, then either change or delete this sentence because it makes it sound like you.

Response: Our measurements were done only on the Xingu river; therefore, we altered the sentence to clarify this issue.

Line 41 – You mention that 'inland waters' have an area of '624,000 km2' and cite who with regards to this number? This number is very small compared to the 2.5 – 5 million km2 range that actually exists for all inland waters surface area coverage. I think you mean to cite only rivers surface area with your 0.624 million km2 value so you need to be specific when you say 'inland waters' and you need a specific reference for this river surface area number. But then you cite the 1.8 – 3.8 Pg values, presumably from Drake et al. 2018 and those values are for all inland waters specifically. If you want to discuss inland waters surface area coverage total then you need to use either Downing et al. 2006, Verpoorter et al. 2014 or Messager et al. 2016 or Feng et al. 2016.

Response: Thank you, valid comment. The area number was related to Raymond et

al. 2013, and we only refer to rivers and streams. However, in this sentence our goal was really to discuss inland waters as a whole and on a global scale. The inland waters area estimate was corrected according to Downing et al. 2006 and Veerpoorter et al. 2014 and emissions based on Raymond et al. 2013, which estimate also describes inland water emission at global scale and Drake et al. 2018.

Line 45 – clean up language (e.g., don't need 'water' so many times

Response: Done.

Line 50 – should be: 'to the autochthonous respiration of OM deposited'

Response: Thank you, we have updated this sentence as suggested.

Line 54 – should explain more how the stimulation of OM decomposition via those two processes actually effects CO2 – similar to how you did in the first half of the sentence saying higher CO2 uptake

Response: Agreed, those processes were added to the text and briefly explained as suggested.

Line 66 – I believe it was actually DelSontro et al. 2010 and not 2016

Response: Absolutely, thank you. This citation was corrected.

Line 69-70 – Start a new sentence with 'Newly flooded reservoirs...' and then give examples/references of the few poorly studied reservoirs.

Response: We altered this sentence and added the reservoirs of Petit Saut an Eastmain-1 as examples, from Abril et al. 2005 and Teodoru et al. 2012, respectively.

Line 73 – should be 'variability' and not 'variation Response: Updated as suggested.

Line 73 – give the abbreviation for fluxes here '(FCO2)' that you will use the rest of the paper, and delete 'and its relevance for GHG fluxes'

Response: Thank you, properly corrected.

Line 75 – end this sentence with '..complex in eastern Amazon, a tropical region poised to gain XXX more hydropower projects in the coming decades (REF).' This puts your work into a bigger perspective at the end of your intro.

Response: Thank you, this sentence was included as suggested.

Line 83 – the 1984 study is quite old. . . Is there nothing newer?

Response: It is related to a classical study that classifies Amazonian rivers according to some physical chemical characteristics. Although relatively old, it is still largely used for Amazonian river classification.

Line 98-100 – in this sentence give the names of the two reservoirs after you mention them.

Response: This sentence was updated as suggested.

Line 101 – give more details about these calculates from Faria et al. 2015

Response: The residence time was calculated by the equation RT= V/ Q, where RT is the residence time in seconds, V is the reservoir volume in m3 and Q is the volumetric discharge in m3/s. To convert RT in days the value was divided by the number of seconds in a day. We altered this sentence and added this information in the text.

Line 104 – once you have given the XR abbreviation for Xingu Reservoir then use it for the rest of the paper, and do you mean 'as islands' instead of 'in islands'?

Response: Actually we meant to use 'on islands' and that was corrected. We altered also other Xingu Reservoir usages through the text to XR abbreviation.

Line 107 – 'classified' instead of 'denominated' – and this paragraph should contain the surface area of these reservoirs already

Response: Reservoirs surface areas were added to this paragraph and the sentence was corrected as suggested.

Line 115 – the residence time of the IR reservoir is still ridiculously short (1.57 days). How do you call that a storage reservoir? Still want to know the surface area of these reservoirs already

Response: There was an error in our RT calculations due to the discharge data that we used. The previous RT values were based on an environmental impact study (EIA) that estimated the highest discharge values of each reservoir. We performed new calculations using the average historic discharge series from Water Agency of Brazil database. The corrected RT of 20.2 (IR) and 3.4 days (XR) were updated in the manuscript. In addition, we added the surface areas of the IR (154 km^2) and XR (342 km^2, including the 249 km^2 originally occupied by the river channel).

Line 116 – should give maximum depths of the reservoirs

Response: Thank you. Maximum depths were added to this sentence.

Line 117 – why did you give the total surface area of the 2 reservoirs together? You should provide values for the two different reservoirs. If this is difficult because of the difference between rainy and dry season then state this but still give approximate values for the individual reservoirs since you are evaluating them separately.

Response: Both reservoirs areas were added as suggested. In addition, river channel area was also included.

Line 121 – what is the 25.4 km2/MW? Why should I care about this value? Give some explanation behind your reporting of this value (or don't report it).

Response: Removed.

Line 131-132 – I really do not understand your description of water depth sampling. You classified the sampling sites based on their maximum depths? Where did you measure in the water column? If a site was 10 m deep, did you sample at 3 depths? Did you sample 0.3 m, 6 m, and 9 m? Be more explicit with your description here. Why did you pick 60% of max total depth for sampling?

Response: The sampling depth method was as you describe. Our 60% depth was a mid-depth sampling point to compare to surface and bottom waters. The three depths were sampled only in deeper sites where higher water velocity variation occurs. Since water flow and topography drives pressure gradients on sediment interface that affect particulate matter transport (Huettel et al. 1996), our goal was to sample depths with organic and inorganic matter differences. In shallower sites only 60 % category was sampled. We revised this sentence to clarify the text.

Line 136 – state that the flooded areas sampled were in both reservoirs if that is the case.

Response: Thank you, updated as suggested.

Line 143 – 'according' not 'accordingly'

Response: We corrected this word.

Line 148 – what did you collect the headspace air in?

Response: The air samples were collected using 60 ml syringes. We have updated this information in the sentence.

Line 150 – how were the gas samples transferred? Via needle and syringe because the vials were pre-capped, I presume.

Response: Exactly, gas samples were transferred into evacuated vials via needle and syringe. Vials were pre-capped with the butyl rubber stoppers and sealed with aluminum crimps. The vials were evacuated immediately before transferring samples. We updated this sentence in the manuscript.

Line 154-156 – combine these two sentences into one

Response: Thank you, we have made this change.

Line 158 – if you made measurements from a drifting boat in a river, I presume you

drifted quite a bit. Did you consider this drifting distance in your measurements of flux? This is an important point. How far did you drift? You need more details regarding this sampling approach.

Response: Drifting distance was not measured during deployments. Based on visualization in Google Earth we estimate that the maximum distance drifted may be approximately 1 km for measurements in the river channel up and downstream of the reservoirs. In sheltered areas located in bays and over islands with standing trees, where the water flow was very low, drifting was very short and caused by wind. An estimate of the drifting distance in the natural river channel and in the main channel of the Xingu Reservoir was obtained by using the average water velocity measured by the National Water Agency of Brazil at the Altamira station. We separated the historical values into before and after 2016, when the dams was completed. Therefore, representing estimates of water velocity in the natural river (between 2005 and 2016), and in the Xingu Reservoir main channel (after 2016). The average water velocities at Altamira are 0.74 and 0.24 m s-1 for before and after the dam, respectively. Assuming that there is no resistance of the boat with the water or air, drifting speed is similar to the water velocity. The total time of deployment was up to 30 minutes for the three consecutive measurements. Based on these we found that in the main channel of the Xingu Reservoir the drifting distance would be 432 m, and 1332 m for the natural river channel up and downstream the reservoirs. These details were added to supplementary material.

Line 161 – 'calculated' instead of 'done' and delete 'the eq. (1)'

Response: Thank you, done.

Line 168 – use 'erroneous' instead of 'same sampling site'

Response: Thank you, updated as suggested.

Line 171 and eq. 2 – you say that k was based on the flux measurements but I do not

see them in equation 2. I guess it is somehow in the partial pressure measurements since some are in the chamber but I think this needs a better explanation. You didn't find k using FCO2, but rather using the concentrations in the chamber? That is how I perceive this equation.

Response: Thank you, that is correct. The calculations were not made with fluxes, but with the CO2 partial pressures inside the chamber. We corrected this sentence in the manuscript.

Line 176 – need 'respectively' at the end of the sentence

Response: We have altered this sentence.

Line 177 – grammar is poor here

Response: Thank you, sentence rewritten.

Line 184 – give a bit more detail here about how the gas transfer velocities were not calculated from 2016 data. I am guessing it is because the other loggers did not allow it somehow, but I don't see why you couldn't perform the calculations using concentrations from those loggers too.

Response: The gas transfer velocities were not calculated from 2016 data due lack of headspace sampling in this campaign. The only season without k600 was 2016 high water, the calculations were made using loggers concentrations too. This sentence was removed to a more brief and concise manuscript.

Line 187-188 – I do not understand why or how these measurements were made according to the water depth classes. Do you just mean depths? And did you do this at each sampling site?

Response: We made depth profiles at each sampling site. To standardize the data with pCO2 the values were selected from near bottom (0.5-1.0 m above the sediment interface), 60% (at 60% of total water depth) and surface (up to 0.3 m of water depth).

Line 199 – what does 'assessed separately by season' mean?

Response: Thank you for the observation. That is related to the data statistically tested individually, since there was no inter-calibration among the different sampling method on each season.

Line 208 – you should restate here specifically that you are comparing high and low water from 2017 only.

Response: We have added this statement as suggested.

Line 208 – replace 'presented a significant variation' with 'varied significantly'

Response: Thank you, we have altered as suggested.

Line 221 – it gets confusing a bit when you go between comparing seasons to looking at the whole dataset so be specific when you can. For example, I would add 'From the overall dataset,' before 'Higher pCO2 was registered..'

Response: Thank you, we have reevaluated this section to clarify the manuscript. This sentence was altered as suggested.

Line 223 – I am confused by this sentence and what is respective to each other. Rewrite this one.

Response: This sentence was rewritten as suggested.

Line 228 – Because you only had pCO2 data for 2017 then I guess you couldn't find a correlation between pCO2 and FCO2 in the 2016 data, correct? You need to specific again here and state that the correlation was only for the one method.

Response: Actually there was correlation between pCO2 and FCO2. The data corresponds to 2017 samplings and was evaluated separately by season. Since that it was not clear this sentence was rewritten.

Line 232-234 – does it really matter if the two sensors were not cross calibrated in

terms of absolute concentrations if it is just the slope of the increase of concentration over time that you need for flux calculations? If it is merely slope then you should be able to estimate and then compare the rates of flux, no?

Response: We agree but are being cautious considering there are not published results comparing the two systems.

Line 235-237 – how is it that that the low water season had the highest and lowest FCO2 values but was also homogeneous? This is very confusing.

Response: The homogeneity in the FCO2 occurred when both reservoirs were evaluated together, however when each reservoir is considered separately the fluxes differed. Therefore, the pattern observed in low water season is driven by the reservoirs characteristics, not the spatial heterogeneity. In the low water season the IR reached its highest FCO2 due the capacity to accumulate organic matter in the substrate and plant-derived material left from vegetation clearing. Otherwise XR decreased its FCO2 both to a probable raise in photosynthetic activity as lower retention of organic matter due rocky and sandy substrates that domain most of the reservoir that is composed by the natural river channel.

Line 242-243 – this sentence is kind of just hanging here by itself. Shouldn't it belong somewhere in a paragraph.

Response: We have removed this sentence.

Line 244 – I would rename this section a bit more specific to what you are doing: 'pCO2 and FCO2 in ROR versus storage reservoir'

Response: Thank you, we have altered the section name as suggested.

Line 245-246 – if you consider the standard deviation of your measurements then I would say the differences are not so significant between seasons as they then overlap, especially for IR

Response: Sites that maintained the high pCO2 even on low water season due the constant organic matter source may have caused some overlapping on XR standard deviation. Otherwise it was not general since river channel and outside reservoirs pCO2 drastically decreased. The seasonal difference consequently was most apparent and especially driven by XR, however our point was to highlight that pCO2 in IR has not decreased.

Line 249 – the difference in IR is much more significant than XR. I would point that out here.

Response: Thank you, we have added this alteration to the manuscript.

Line 250-252 – I don't understand what you mean here. You did a spatial analysis but lumped all spatially different environments together? I think you mean to say that you compared the total emission from XR to the total emission of IR despite the emitting environment. Is that right?

Response: Thank you, this was exactly what we meant. We have better addressed this in the text.

Line 252-255 – I don't understand how you see no significant difference between pCO2 of XR and IR but then suddenly find that XR had pCO2 721 uatm lower. And lower than what? I guess IR. These few sentences are very confusing.

Response: When XR and IR pCO2 from whole 2017 periods was evaluated, separately from other variables (i.e. depth, unaffected river channel and season), a difference of 721 μatm was observed. However if depth, unaffected river channel, and season are considered, no significant difference is observed in the pCO2. More details were added in the text to make it clearer and we have removed T-Test analysis since it is related to a descriptive result.

Line 256 – You cannot just present an idea like 'Standing vegetation type in XR flooded areas influenced pCO2' without explaining the data that led you to that conclusion.

Response: Thank you. We have altered this sentence and better detailed the data.

Line 264 – use ‘especially’ instead of ‘specifically’ Response: Done.

Line 266 – what is a ‘gradient pattern downstream’??

Response: We refer to the pattern of both pCO2 and FCO2 that are higher directly downstream the dam and decreases on the sites most distant from the reservoir. We have altered this sentence and added a most suitable term.

Line 272 – again with this ‘separately to each season’ – I still do not understand what this means. You have to come up with a better way of describing this.

Response: Since the FCO2 data was sampled with different equipment, different datasets were created according to the sampling season to run the statistical analysis. This sentence was removed following referee 1 suggestion.

Line 274 – use ‘without significant spatial heterogeneity across environments’

Response: Thank you, we have modified this sentence as suggested.

Line 275 – use ‘k600 strongly correlated with wind. . .’ and does this relate to Fig 5b? Should you reference this?

Response: Yes, this sentence has relation with fig 5b. We altered the text and added such reference.

Line 280 – there is not environmental breakdown in the data in Figure 5

Response: Thank you, this reference was removed.

Line 287 – so you have water column data? Where is this data?

Response: We made depth profiles to pH, O2, conductivity and temperature on 2016 and 1027 high water. A supplement material was created and those data were added to it.

Line 303 – decrease in what?

Response: The pCO2 decreased due the transition from high to low water probably due to raise on primary production as Rasera et al. 2013 observed on clearwater rivers. We have rewritten this sentence.

Line 344 – what is ‘vegetal suppression’? I figured out that it is when you remove vegetation prior to flooding but is this the correct term for this? It sounds very strange.

Response: Vegetation clearing is the most adequate term. This was altered through whole text.

Line 344-345 – this sentence is too long with poor grammar

Response: Thank you, this sentence was rewritten.

Line 354-356 – combine those sentences

Response: Done.

Line 356 – how many of the environments? Do you mean all except IR? This is confusing. If it is just IR that is the exception then you need to state it as ‘all except IR’

Response: Exactly, only IR had raise on FCO2 and pCO2 on low water. The sentence was altered as suggested.

Line 357-358 – negative fluxes can be replaced with ‘observed CO2 uptake’

Response: Thank you, done.

Line 358 – ‘light penetration and low suspended sediment’

Response: Thank you, updated as suggested.

Line 363-365 – you already spoke about this earlier. Try not to be redundant

Response: We have altered this sentence detailing the influence of vegetation prior flooding on FCO2.

Line 370 – need ‘which’ before ‘would’

Response: Done.

Line 372-373 – I don’t think you need these values here in the discussion.

Response: We agreed, altered as suggested.

Line 387 – can you give a site number for the ‘site downstream IR’?

Response: Absolutely, this site is P21. This information was updated in the manuscript.

Line 391 – I don’t think this true and I don’t think you need this sentence about a reference for natural FCO2 values

Response: Agreed. We have removed this sentence.

Line 397-398 – do you mean that the downstream sites resembled river channel sites in terms of pCO2 and FCO2 values? Don’t use ‘traits’ to describe this. Traits more refers to features that don’t vary. Yes, that was what we meant in this sentence. The word ‘traits’ was removed and the sentence rewritten.

Line 408-409 – are you saying that the old reservoir you are using for comparison is Tucurui? The grammar here is confusing.

Response: Exactly, Tucuruí reservoir was compared to both XR and IR. To clarify this sentence it was rewritten.

Line 412 – what do you mean by hypolimentical waters? It should be ‘hypolimnetic’ by the way. But this just means bottom waters with an implication of stratification, but what specifically do you want to express here?

Response: We have removed this sentence. Line 419 – bad grammar in last sentence

Response: Thank you, we revised that sentence.

Please also note the supplement to this comment:

https://www.biogeosciences-discuss.net/bg-2019-53/bg-2019-53-AC2-supplement.pdf

Interactive comment on Biogeosciences Discuss., https://doi.org/10.5194/bg-2019-53, 2019.

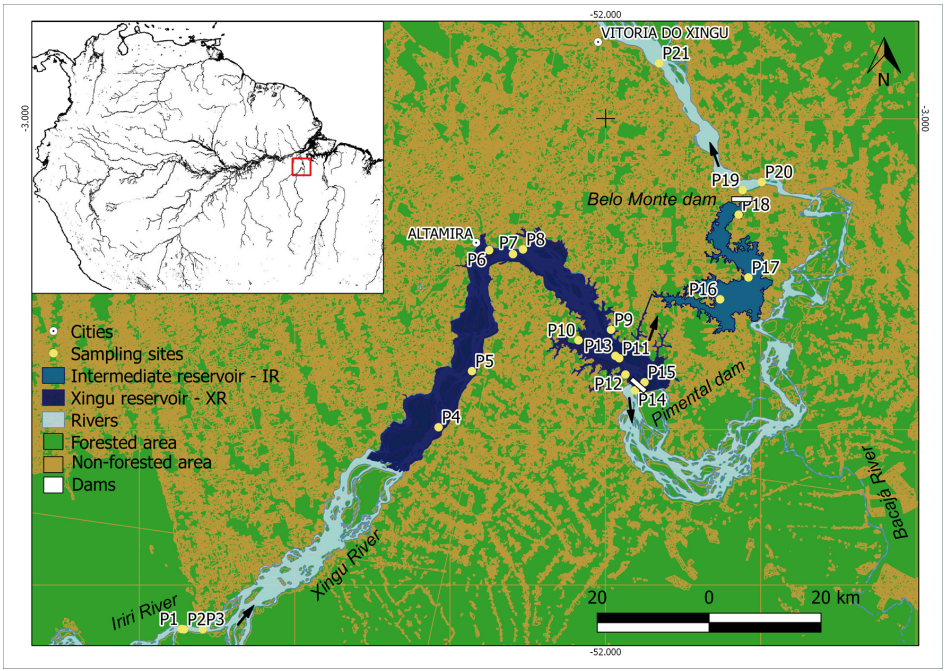

Fig. 1. Fig.2

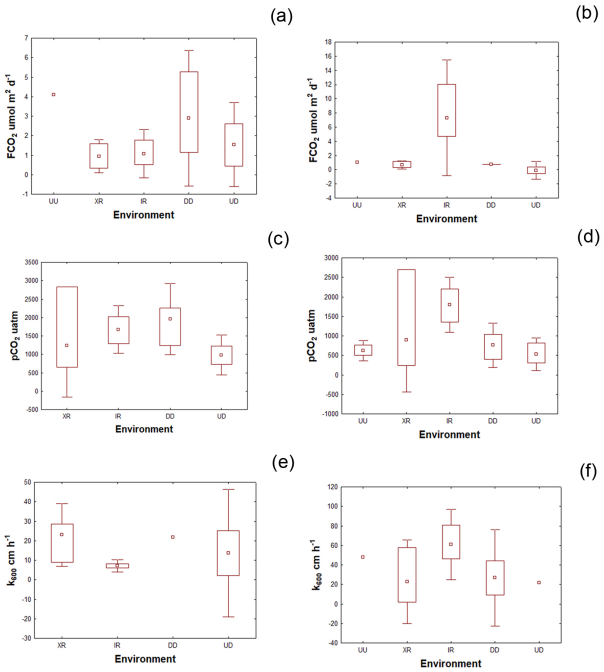

Fig. 2. Fig.3

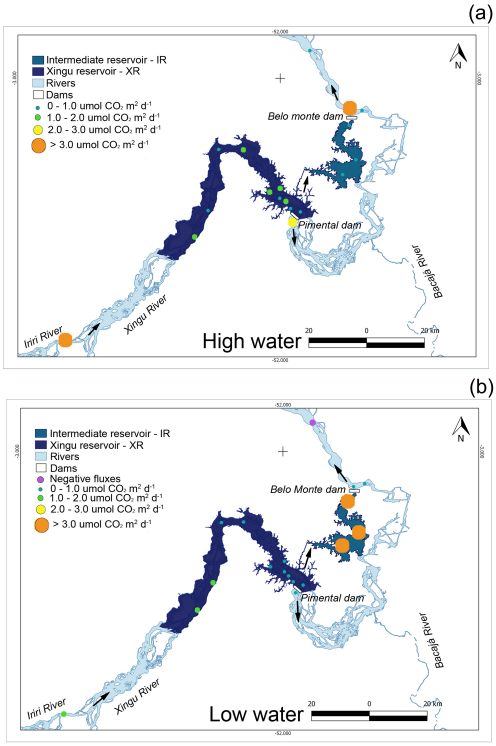
(a)
Intermediate reservoir - IR
Xingu reservoir - XR
Rivers
Dams
0 - 1.0 umol CO2 m2 d-1
1.0 - 2.0 umol CO2 m2 d-1
2.0 - 3.0 umol CO2 m2 d-1
> 3.0 umol CO2 m2 d-1
Belo monte dam
Pimental dam
Bacajá River
Iriri River
Xingu River
High water
20
0
20 km
(b)
Intermediate reservoir - IR
Xingu reservoir - XR
Rivers
Dams
Negative fluxes
0 - 1.0 umol CO2 m2 d-1
1.0 - 2.0 umol CO2 m2 d-1
2.0 - 3.0 umol CO2 m2 d-1
> 3.0 umol CO2 m2 d-1
Belo Monte dam
Pimental dam
Bacajá River
Iriri River
Xingu River
Low water
20
0
20 km

Fig. 3. Fig.4