Dear Dr. Clare Woulds,

Please, see the revised version of our manuscript attached. Thank you for the opportunity to submit it again. We believe the manuscript has improved considering the comments and suggestions made by the reviewers. The changes we made to the text are marked as red-bold sentences. We also edited *Figure 5* according to the recommendation made by the reviewers. We hope our manuscript is now suitable for publication on Biogeosciences.

On behalf of the other authors,

Gabrielle Quadra (gabrielle.quadra@ecologia.ufjf.br)

RESPONSE TO REVIEWER 1

I. General comments:

This paper estimates the storage of sediment OC in an Amazonian reservoir. It also shows the CH4 ebullition potential (high). The data set is sound and the conclusions more or less appropriate. This paper was reviewed before in the open review process at BG, and this version is solid and addressed the reviewer concerns. I still had a lot of comments, but these are less about the scientific merit of the work, but rather ways to improve the presentation of the work. I have no major concerns, but plenty of minor ones.

Response: Thank you for the positive comments and for helping us to improve our paper.

II. Specific comments:

69. The "However..." does not really follow from the first sentence. as the thread goes from reservoir to temperature and runoff

Response: We changed this part of the text to make our message clearer. It now reads: "*To the best of our knowledge, OC burial has so far not been studied in an Amazonian reservoir. However, it is likely that reservoirs in tropical rain forest areas bury OC at a comparatively high rate, as temperature and runoff were identified as important drivers of OC burial in lakes and reservoirs (Mendonça et al., 2017). Indeed, OC burial in Amazonian floodplain lakes was reported to be much higher than in other lakes (Sanders et al., 2017). " (Page 4, lines 69 – 74)*

78. delete it has been shown that

Response: We deleted it.

96 Because both OC...

Response: We deleted "since" from the sentence and restructured the paragraph also in accordance to reviewer 2. It now reads: "Both OC burial and CH₄ production take place in sediments. Here, we present results of a study approaching these processes on sediments of an Amazonian hydroelectric reservoir during hydrologically different seasons, which was motivated by an absence of such studies even though sediment carbon processing in Amazonian reservoirs may potentially be high. We aimed at providing a spatially-resolved quantification of OC burial, as well as a mapping of CH₄ saturation in the sediment porewater, which is indicative of the potential occurrence of CH₄ ebullition. Thereby, this study is intended to contribute to improved understanding of the potential biogeochemical effects of the current expansion of hydropower (Almeida et al., 2019) on the Amazonian carbon budget." (Page 5, lines 102 - 111)

116. SD on the right of the plus/minus sign?

Response: Yes. We now mentioned at the first appearance that the numbers are shown as mean \pm SD.

215. It is best to use variables in equations and not text. But his equation is so simple, it might be easiest to simply leave the text as is in lines 212 and 213.

Response: As a previous reviewer asked for an equation, we prefer to keep it.

230. Use variables, the numerator in this equation looks like it reads "organic carbon mass in the post minus flooding sediment", which of course is meaningless.. Use multiplication sign, not *.

Response: We changed the equation for:

$$Organic \ carbon \ burial \ rate \ = \ \frac{OC \ in \ reservoir \ sediment}{core \ area \ \times \ reservoir \ age}$$

231 Saying correlation and using regression is incorrect. If correlation analysis simply state r and maybe a p value. 5 significant digits is way too high for high uncertainty parameters such as these.

Response: Based on this comment and on a comment from Reviewer 2 we changed the text in this part for: "*The empirical relationship between SAR and OC burial rate (see Results;* y = 159x - 4.4; $R^2 = 0.87$; *Fig. S3) was used to estimate the OC burial rate (g C m*⁻² *yr*⁻¹) for the remaining 95 *coring sites where OC content was not analyzed*". Moreover, we also changed the significant digits in the Figure S3 and S5. (Page 12, lines 247 – 248)

243 Delete in order

Response: We deleted it.

254. See 116

Response: Please, see our reply to 116.

285 Isn't M supposed to be written as mol L-1?

Response: Although M (molar) is equal to mol L⁻¹, we changed it throughout the manuscript and figures for a better understanding.

289. This statistical method needs to be described in the methods. Simply saying "We did a t-test for …" is fine. But with the SD higher than the mean, and no way for negative numbers, the data are assuredly no normally distributed thus preventing the application of a t test. log transform might do the trick.

Response: Thanks for the comment. You were right. We tested the distribution of our data set and normal distribution was not observed, even log-tranforming the data set. Then, we run a non-parametric test (*Wilcoxon*) but the outcomes were the same – the difference between seasons was not observed. We added the results of the test ("S = 33213, Z = -1.27863, Prob>/Z/ = 0.20") to the lines 311-312 (page 15) and the information regarding statistical analysis to the 'Data analysis' section, as follows: "*To verify the differences between CH*⁴ concentrations in the two seasons (rising and falling water), the non-parametric Wilcoxon Test was performed using the software JMP 14.1.0 (SAS)". (Page 13, lines 266 - 268)

262. Is it possible to estimate a confidence interval for this flux? It might be more difficult than plus/minus 2*SD/sqrt(n) due to skewed distribution of rates and spatial autocorrelation.

Response: We now give the 95% confidence intervals. In these sentence, we give simple descriptive statistics of the results, which do not account for spatial autocorrelation. Please, find the confidence interval values in the figure below.

⊿				⊿ 💌 OC Burial rate (gC m-2 y-1)							
4	🛛 💌 Confide	 Confidence Intervals 				4	🛛 💌 Confid	ence Intervals			
	Parameter	Estimate	Lower Cl	Upper Cl	1-Alpha		Parameter	Estimate	Lower Cl	Upper Cl	1-Alpha
	Mean	0.599123	0.526877	0.671368	0.950		Mean	91.0193	79.68361	102.355	0.950
	Std Dev	0.389348	0.344531	0.447676	0.950		Std Dev	61.09089	54.05875	70.24281	0.950

265 ditto

Response: See our reply to the previous comment.

291. What is saturation conc? Never mind, I see it on the figure.

Response: Ok. The satuation concentration varies between sites depending on water depth, hence there is no common saturation concentration for all the sites.

293 In most of the

Response: The sentence was changed and moved to discussion section based on a comment from Reviewer 2. It now reads: "The high amount of pore water CH_4 profiles with samples above the CH_4 saturation concentration indicates a high likelihood of gas bubble formation in most of the sampled sites, and thus the possibility of CH_4 ebullition (Table S5). Importantly, however, the link between bubble presence in the sediment and CH_4 ebullition flux is entirely qualitative, and can not be used to estimate the magnitude of CH_4 ebullition." (Page 24, lines 467 – 472)

Fig 3. This figure could use some work to improve readability. Make font nearly the same size for axis labels and titles (9-11 pt). No need for bold font, it distracts readers to the titles and labels. And because all the axes are the same, they do not all need to be titled. One y and x axis title is enough. The numbers following the F and R don't mean much to readers (37? 21?); they seems like some sort of internal labeling code. Rename them.

Response: We made the suggested changes, but we prefer to keep the numbers following F and R because they correspond to the site codes presented in Table S1. We now explain it in the figure caption by adding the following sentence: *"The numbers following the letters F and R correspond to the site codes in Table S1"*.

311. A leading paragraph in the discussion outlining the main findings would be useful. The first sentence, that water slows entering a reservoir, is not really a finding from the study.

Response: We added a paragraph summarizing the main findings of the study, as suggested.

"Despite the intense OC mineralization in the tropics, this study found that OC burial in the sediment of the Amazonian Curuá-Una reservoir was high when compared to sub-tropical and other tropical reservoirs, probably due to the high carbon inputs from the forest. However, autochthonous material was also an important component of CUN sediment. CH₄ concentrations in the sediment pore-water were frequently supersaturated, indicating that the sediment of CUN also has the potential to emit CH₄ to the atmosphere via ebullition." (Page 18 – 19, lines 332 – 338)

362. What are units of mineralization?

Response: The unit is g C m⁻² yr⁻¹. We now give the equation separated from the text (see next response) and the unit appears right below the equation at line 393.

363. What is the x here? A multiplication sign? Confusing way to write math.

Response: We added the following equation in the manuscript:

OC mineralization = $(1.52 + 0.05) \times Temperature$

364. Use the prediction uncertainty from the regression to derive uncertainty on the 325. I note that Cardosa et al regressed log mineralization with temp, and they have prediction error from 100-1100 at 29degC (wow what a nice analysis in that paper). That makes burial efficiency range from 8 to 48%, a huge range. I do think the authors can safely say that the range is not the 67 or 87% found in other places, but by scaling the uncertainty makes them more certain in that conclusion!

Response: The prediction interval gives the distribution of predicted individual observations. However, for our exercise, we are not concerned with the magnitude of individual observations, but with the mean of many observations. The OC burial of CUN was calculated as a mean of 114 observations, and accordingly a mean of mineralization can be estimated for a corresponding number of 114 individual predictions; it would not be correct to compare a mean of burial to an individual prediction of mineralization. When using the Cardoso et al. 2014 to predict 114 individual mineralization rates, the uncertainty of the mean mineralization rate becomes 0.4 g C m⁻² d⁻¹, using regular error propagation. This negligible uncertainty arises from the central limit theorem, which states that random errors converge to a normal distribution around a mean, and the more observations, the more does the uncertainty converge to the expected value, the mean (law of large numbers). We have added a clarifying statement to the text.

380. This conclusion seems dicey. I would want rather see carbon isotope evidence for this point.

Response: We agree that stable isotopic evidence would strengthen our conclusion. We did collect samples for stable isotopes and biomarkers analysis during the field campaings. However, these samples are still being analyzed, so we could not include these results into this paper. Nevertheless,

the C:N ratios give a rough and qualitative indication of the organic matter sources to the sediment, which is backed up by the given references, and we refrained from making any quantitative analysis based on it. We now make it clear at the discussion by modifying the following sentence: "Although we refrained from making quantitative analysis based on C:N ratios, higher C:N values at the river inflow areas (Fig. 2) may indicate input from the highly productive watershed and thus the high load of land-derived OC to the sediment." (Page 22, lines 415 – 418)

412 delete "is known to"

Response: We deleted it.

421. I was hoping there were such data. A figure with a simple carbon budget for this reservoir would be interesting, I realize that seston input might be unknown, but with sedimentation rate, mineralization and CO2 flux would make a nice picture.

Response: We agree that it would be interesting to show a carbon budget for the CUN reservoir, although the carbon inflow rates are indeed unknown. In fact, we have measured spatially resolved fluxes of CO₂ and CH₄ through diffusion and ebullition, and a part of the diffusion data are already published in Paranaíba et al 2018. However, the CH₄ ebullition data still needs to be analyzed, and ebullition tends to be an important component of the C budget in an Amazonian reservoir (Deemer et al. 2016). We therefore prefer to compare our OC burial data with the currently available estimate of emission from the CUN reservoir (Duchemin et al., 2000), and to publish a new C budget of CUN once our full suite of data is analyzed, particularly since this paper is focused on sediment-related processes and not on a system-scale C balance.

Fig 5. This figure is tough to interpret. The binning seem arbitrary and can skew the picture depending on how binned. Why not simply plot the proportion of samples > saturation vs burial rate? Or the actual % saturation vs burial rate. That way there is a continuous relationship. It is likely not going to be a clean line, but it might be a triangle, where high CH4 relates with low to high burial rate, but low CH4 is always low burial rate. Just a guess, but I think there are much better ways to show this plot.

Response: We replaced this figure with a new one, which shows the mean CH₄ saturation in the sediment layers against OC burial in each of the cores/sampling sites. We belive it more clearly shows a positive, albeit weak, tendency to higher CH₄ saturation with increasing OC burial. It also very clearly shows the overall high level of CH₄ saturation in CUN sediments. The new figure is also explained in the text.



469-471. This sentence seems to say "we have no idea of the C source" since the first part says the forest input is high and the second part says aquatic is high. I am totally fine with

this interpretation; these data do not really allow assessing the source (see 412). Are there primary production data from this reservoir?

Response: Unfortunately we do not have primary production data for this reservoir. What we meant to state is that although the forest seems to be the major source of OC to the CUN reservoir, autochthonous OC is also important in some specific areas. We edited the sentence to make it clearer. It now reads: "*The forest seems to be a major OC source to the reservoir although the relatively low C:N ratio in some parts of the reservoir suggests an also significant aquatic contribution to sediment OC burial*". (Page 26, lines 514 - 516)

476. Yes and also to scale how the building of reservoirs will alter regional and global carbon budgets. Based on the work here the ocean is missing 0.3 Tg of its riverine carbon input.

Response: Thank you for the comment. We added this information to the conclusion: "*Moreover, it will be critical to quantify the effect of the new Amazonian reservoirs on the ocean's carbon budget, since the CUN dam alone retains yearly 7,500 tons of OC and a part of it would likely reach the ocean in the absence of the dam.*". (Page 27, lines 523 – 526)

References

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Paranaíba, J. R., Barros, N., Mendonça, R., Linkhorst, A., Isidorova, A., Roland, F., Almeida, R. M., and Sobek, S.: Spatially resolved measurements of CO2 and CH4 concentration and gasexchange velocity highly influence carbon-emission estimates of reservoirs, Environmental science & technology, 52, 607-615, 2018.

RESPONSE TO REVIEWER 2

I. General comments:

This is a revised version of a manuscript focusing on sediment C accumulation and sediment CH4 concentration in a tropical reservoir. The study is an important addition to the literature about the net C and greenhouse gas emissions caused by hydropower reservoirs and dams. Valuable work has been done to estimate the sediment C accumulation rates and spatial patterns in this reservoir. The current work is not capable of closing the full C or GHG budget, but perhaps, that is the ultimate goal of the researchers. The work is topical as it seems that hydropower business is increasing, particularly in the tropics. I agree with the reviewers 1 and 2 that the study deserves to be published. I also agree with the criticisms raised by those reviewers.

It looks that the authors have improved the manuscript quite well according to the comments on the earlier version by the reviewers 1 and 2. I have, however, still some reservations. I think that the presentation needs some work to be publishable and I suggest a rewrite. I suggest introducing the big questions behind and how sediment C accumulation and potential for CH4 emissions relate to that. Is the question about the GHG emissions caused by hydropower reservoirs and dams and/or how sediment C accumulation affect catchment C and GHG budgets, or something else? In addition, I found problematic how the CH4 data were dealt. Authors considered the CH4 concentration data as an indicator of potential for CH4 ebullition if concentration high enough for bubble formation. This is a bit problematic, because CH4 concentration, or CH4 saturation if high enough, may not translate to actual CH4 emission. The 'potential' is not considered in quantitative manner in this study and the approach needs a motivation. I suggest that authors could elaborate the analysis or the text to the direction of quantitative analysis how the sediment and C accumulation and qualitative sediment properties determine the sediment CH4 concentration/CH4 saturation. I am confident that the authors can improve the presentation. I have listed some detailed comments and suggestions below.

Response: Thank you for the positive comments and for supporting the publication of our paper. We now clearly state our objective with this study at the end of the introduction. This part now reads: "Both OC burial and CH₄ production take place in sediments. Here, we present results of a study approaching these processes on sediments of an Amazonian hydroelectric reservoir during hydrologically different seasons, which was motivated by an absence of such studies even though sediment carbon processing in Amazonian reservoirs may potentially be high. We aimed at providing a spatially-resolved quantification of OC burial, as well as a mapping of CH₄ saturation in the sediment porewater, which is indicative of the potential occurrence of CH₄ ebullition. Thereby, this study is intended to contribute to improved understanding of the potential biogeochemical effects of the current expansion of hydropower (Almeida et al., 2019) on the Amazonian carbon budget." (Page 5, lines 102 - 111).

Regarding the pore-water CH₄ concentrations, we are aware that our measurements cannot translate into emission rates, and this was explicitly stated in the following part of the methods: *"The presence of gas bubbles is indicative for an elevated probability of CH₄ ebullition, but not necessarily relates quantitatively to ebullition flux, since ebullition flux to the atmosphere is also dependent on water depth, sediment grain size, and pressure fluctuations (McGinnis et al., 2006; Maeck et al., 2014; Liu et al., 2016)."*. Thus, we did not present a quantitative assessment of ebullition, and we do not attempt to make a link between bubble presence in the sediment and

ebullition flux. Qualitatively, however, the presence of gas bubbles in the sediment is the prerequisite for ebullition, thus bubble-rich sediments have a greater potential for ebullition flux than bubble-poor sediments. To further clarify this point, the following text was added to the discussion: "*The high amount of pore water CH*₄ *profiles with samples above the CH*₄ *saturation concentration indicates a high likelihood of gas bubble formation in most of the sampled sites, and thus the possibility of CH*₄ *ebullition (Table S5). Importantly, however, the link between bubble presence in the sediment and CH*₄ *ebullition flux is entirely qualitative, and can not be used to estimate the magnitude of CH*₄ *ebullition.*" (Page 24, lines 467 – 472)

II. Specific comments:

The title is awkward, because the emissions vs accumulation aspect was not really studied in the current study. How about: High sediment carbon accumulation and high sediment methane concentrations in an Amazonian hydroelectric reservoir. Other thing, I am more used to the term "carbon accumulation" rather than "C burial". I.e. sediment accumulation rate (SAR), carbon ccumulation rate (CAR), but up to you.

Response: The title does not insinuate that emission was studied, instead it speaks of "potential for metane ebullition", which reflects the qualitative way in which we streat the CH_4 saturation data of this study. We believe that the term "potential for methane ebullition" is consistent with the data we generated in this study and we would there like to keep it in the title. Also, we prefer to use the term "burial", as it is used quite frequently in the literature.

Abstract 31-34. Difficult to read. Maybe make two sentences.

Response: We changed the sentences for: "This is the highest OC burial rate on record for lowlatitude hydroelectric reservoirs. Such high rate probably results from a high OC deposition onto the sediment, which compensates the high OC mineralization at 28-30°C water temperature." (Page 2, lines 31 - 34)

36. CUN, explain

Response: We now added the abbreviation after the first time that we mentioned the Curuá-Una reservoir (CUN) in the abstract.

46-47. It is not only transport from land to the Ocean, but also net sequestration by autotrophs at places.

Response: We removed "during transport from land to sea".

49. But see also Kortelainen et al. 2004, GCB

Response: The study by Kortelainen et al. (2004) reports OC burial rates for a large number of boreal lakes. However, OC burial is still understudied on a global scale when compared to emissions. We edited this sentence, which now reads: "*Many studies have been conducted on inland water carbon emissions, while the organic carbon (OC) burial in inland water sediments is comparatively understudied on a global scale (Raymond et al., 2013; Mendonça et al., 2017).*" (Page 3, lines 47 - 50)

61. You just gave an estimate so rewrite to express the uncertainty

Response: We added the range based on the different scenarios of global OC burial given by Mendonça et al. (2014): "~28 to 55% of total inland water OC burial." (Page 3, line 61)

75- Overall C accumulation is one component in the C and GHG budgets and you shoul acknowledge also the other parts. Examining the the sediment C accumulation is important, though.

Response: In this paragraph we are focusing on OC burial only and on the complete lack of such measurement in Amazonian reservoirs. In order to keep focus, we prefer not to cite other components of the carbon cycle in this part of the text.

83. There are also older references

Response: We added the reference Segers 1998.

87-88. Awkward, suggest editing. To capture the total emissions both high emission and not so high emissions sites count.

Response: We replaced the "even if" with "although".

94. Note that CH4 emission may not affect the C pool much even though it has significange as a greenhouse gas. How about CO2 and CH4 emissions.

Response: We added a clarifying statement: "While CH_4 emission typically consititutes a very small flux in terms of carbon mass, it is highly relevant to climate since CH_4 is a ~34 times stronger greenhouse gas than CO_2 (IPCC, 2013). The transformation of sediment OC (i.e. previously fixed CO_2) to atmospheric CH_4 therefore represents an amplification of radiative forcing in the atmosphere." (Page 5, lines 97 – 101)

96- Shoudn't you formulate research questions or hypotheses?

Response: We revised the last paragraph of the introduction in order to make the context, motivation and objectives more clear. It now reads: "Both OC burial and CH₄ production take place in sediments. Here, we present results of a study approaching these processes on sediments of an Amazonian hydroelectric reservoir during hydrologically different seasons, which was motivated by an absence of such studies even though sediment carbon processing in Amazonian reservoirs may potentially be high. We aimed at providing a spatially-resolved quantification of OC burial, as well as a mapping of CH₄ saturation in the sediment porewater, which is indicative of the potential occurrence of CH₄ ebullition. Thereby, this study is intended to contribute to improved understanding of the potential biogeochemical effects of the current expansion of hydropower (Almeida et al., 2019) on the Amazonian carbon budget." (Page 5, lines 102 - 111).

122-124. here and elsewhere, unnecessary use of parentheses.

Response: We removed the parentheses.

Fig S1. Why not in the main document.

Response: The historical water level shown in this graph provides general background information, and does not present key information related to understanding our study. We therefore prefer to keep it in SI.

140. Delete (see...)

Response: We removed it.

153-159. Specify that sampling capaigns were targeted to rising and falling water periods?

Response: We now specify it and the text reads: "In both sampling campaigns, targeted to rising and falling water periods, sediment cores were taken for the analysis of pore water CH_4 concentration profiles (n = 16 in February 2016 and n = 9 in September 2017)." (Page 8, lines 166 - 168).

158. Quite large GPS error!

Response: The distance of up to 100 m between sampling sites in different field campaigns is not only due to GPS error (the precision is ~3 m but can increase when different devices are used), but also because the boat drifts a bit during sampling.

184. Unnecessary parentheses

Response: We removed them.

185. Explain, how saturation concentration defined

Response: We added the explanation in the text: "*The saturation concentration, calculated here* from temperature and pressure along the sediment profiles, represents the maximum concentration that dissolves in pore water, above which bubbles are formed." (Page 10, lines 200 – 202)

192. Be specific, how many cores were measured for [CH4]

Response: We already mentioned this in the sampling section: "In both sampling campaigns, targeted to rising and falling water periods, cores were taken for the analysis of pore water CH_4 concentration profiles (n = 16 in February 2016 and n = 9 in September 2017)." (Page 8, lines 166 - 168).

199. Injected unnecessary > ...and analyzed for CH4 concentration within the same day using...

Response: We changed the sentence for: "The headspace was stored in the syringe, closed with a gas-tight valve, and then analyzed for CH₄ concentration within the same day using an Ultraportable Greenhouse Gas Analyzer (UGGA, Los Gatos Research) with a custom-made sample injection port. Then, the resulting peaks were integrated using R software (RStudio Version 1.1.383)." (Page 10, lines 214 - 218).

208. was lost

Response: Changed it.

218. do you mean that 'therefore, the mean accumulation rate cannot reveal short-term ...'

Response: Not exactly. It is true that this approach cannot reveal the short-term variability in sediment deposition, but we meant to state that the approach does incorporate any short-term variability as it represents the total sediment deposition since the reservoir was flooded divided by the year since flooding. The sentence was rephrased accordingly and it now reads: "*This approach returns the average sediment accumulation rate over the lifetime of the reservoir (Renwick et al., 2005; Kunz et al., 2011; Mendonça et al., 2014; Quadra et al., 2019), and therefore incorporates any short-term variability in sediment deposition, for example, caused by an episodic change in sediment load or internal sediment movement." (Page 11, lines 232 – 236).*

226. The average C accumulation rate (xx) was calculated dividing the total C mass (g C m-2) by the accumulation time

Response: We edited this part, which now reads: "Then, the mean OC burial rate $(g \ C \ m^{-2} \ yr^{-1})$ for each of these 19 sites was calculated dividing the total OC mass in post-flooding sediment $(g \ C)$ by the core surface area $(2.8 \ x \ 10^{-3} \ m^2)$ and the reservoir age (yr) at the sampling dates". We also fixed the formula. (Page 11 – 12, lines 242 – 246).

231. We used empirical relationship between SAR and CAR (y=..) to estimate the CAR for the reamining...

Response: We changed the sentence for: "*The empirical relationship between SAR and OC burial* rate (see Results; y = 159x - 4.4; $R^2 = 0.87$; Fig. S3) was used to estimate the OC burial rate (g C $m^{-2} yr^{-1}$) for the remaining 95 coring sites where OC content was not analyzed". Moreover, we also changed the significant digits in the Figure S3 and S5. (Page 12, lines 247 – 248)

235. 237. Suggestion, ... 'to produce maps of SAR and CAR'.

Response: We changed the sentence for: "To produce spatially-resolved maps of SAR and OC burial rate, the data from the 114 cores were interpolated to the reservoir area using the Inverse Distance Weighted algorithm (IDW, cell size of approximately 22 m x 22 m)" (Page 12, lines 250 -252)

245. was > were?

Response: We changed it.

260. Sediment and C accumulation rates

Response: We prefer to keep the term "burial", it is also used quite frequently in the literature.

262. Why supplement if the main result? To my opinnion belongs to the main document

Response: SAR is not considered a main result of the study, rather an intermediate result used to calculate OC burial. We therefore prefer to keep it in SI.

276. The same here

Response: The C:N ratio data is explored in Fig. 2, and this reference is now given.

278-279. to the site description

Response: We moved the information to the site description, but we kept more detailed results about the land use analysis on the results section (Methods: page 6, lines 120 - 123; Results: page 14, lines 293 - 300).

286. Isn't this unnecessary reference to the supplement, because you have fig. 3?

Response: We do have the whole data set on the supplement, while Fig. 3 compares the methane profiles in the same spot but at different seasons.

289. Is the test mentioned in the M&M?

Response: Now we added the information regarding the statistical analysis to the M&M: "*To verify the differences between CH*⁴ *concentrations in the two seasons (rising and falling water), the non- parametric Wilcoxon Test was performed using the software JMP 14.1.0 (SAS)*". (Page 13, lines 266 – 268).

292. 'this indicates...' belongs to the discussion

Response: We moved it.

294. S5 unnecessary?

Response: In case other reserachers want to use our data, it is much more convenient for future work to have a table with the aggregate data set instead of getting all the numbers from figures.

295. So the same areas have also high CAR. Maybe emphasize.

Response: Exactly. We explored it in the discussion section (Lines 472 – 474, page 24).

317. What you mean with 'margins'?

Response: Margins is the same as the shores. A clarification was added.

323. What the 'muddy lake area' actually means?

Response: When the reservoir shows a higher SAR near the dam, the area has been called 'muddy lake area', according to the given references (Morris and Fan, 1998; Sedláček et al., 2016), connected to the transport of fine sediment all the way to the dam.

328. I think that the ref to S6 is unnecessary

Response: We removed it.

352. If CUN has high CAR (& other rates), why it is important? How these findings will improve our understanding on the reservoir systems?

Response: We now more clearly put our findings into a wider context in the Conclusions section: "Given the planned expansion of hydropower dams in the Amazon region, and the high OC burial rate in CUN shown here, future studies should quantify how OC burial and CH₄ emission may be affected by new Amazonian hydroelectric reservoirs. Moreover, it will be critical to quantify the effect of the new Amazonian reservoirs on the ocean's carbon budget, since the CUN dam alone retains yearly 7,500 tons of OC and a part of it would likely reach the ocean in the absence of the dam." (Page 26 - 27, lines 520 - 526).

386. Can you refer to the Fig 1 instead of the supplement?

Response: Yes, we changed it.

388- I found this section unclear

Response: This sentence was rephrased to : "*However, there was no strong relation between OC burial rate and C:N ratio (Fig. S7A), even though the C:N ratio has been shown to affect the OC burial efficiency (Sobek et al., 2009). Possibly, the strong effect of SAR on OC burial masked the potential effect of the C:N ratio.*" (Page 22, lines 421 – 424).

398. Can you include S6 in the main document

Response: The bathymetry map is a background information, not a a key finding of this study. We therefore prefer to keep it in SI.

401- Write open the idea behind

Response: We rephrased this sentence: "The source of buried OC has an important implication in terms of accounting for the sediment carbon as a new sink or not (Prairie et al., 2017), since the burial of aquatic OC can be ascribed to aquatic primary production in the reservoir, which would not have taken place in the absence of the dam, and thus represents a new C sink. However, our data do not allow us to make a quantitative estimate of the share of the CUN sediment carbon stock that is of aquatic origin, and thus may be accountable as a new carbon sink resulting from river damming (Prairie et al., 2017)." (Page 22 – 23, lines 433 - 439).

417. Mention that the C:N in the sediment is a mixture

Response: This was already explicitly stated in lines 379–380 of the previous submission: "*The C:N ratio indicates that the sediment OC in CUN consists of a mixture of land-derived and internally-produced OC.*" (now lines 411–413, page 22).

444. How about diffusive transport? Totally neglected

Response: Our study does not attempt to quantify CH₄ transport, neither via ebullition, nor via diffusion. This study was designed as a sediment study, not a gas flux study.

Fig5. A scatterplot instead?

Response: This figure was replaced by a different figure that shows continuous data. See below.



Figure 5. Regression model of average percentage of CH_4 saturation (%) in the sediment pore water and OC burial rate (g C m⁻² yr⁻¹). Each circle represents one sampling site.

448-457. I found this only marginally relevant

Response: We think it is impotant to point out that bubble release during sampling is likely, and that thus the reported shares of layers with supersaturated CH_4 is probably conservative, which also means than any differences between reservoirs should be interpreted with caution. This aspect was now clarified.

458. What the earlier CUN study says about the CH4 ebullition? Do you have own measurements? If [CH] stays the same, what it means? A stable reservoir with no release but no production either / continuous production and emission at same rates/

Response: There is just one study that reports CH_4 ebullition on CUN, which is from Duchemin et al. (2000), and we use this data. Without a highly resolved record on both porewater CH_4 concentration and CH_4 ebullition flux, we can only speculate about the links.

474. But there are earlier CH4 flux measurements.

Response: We use the earlier flux measurement (Duchemin et al. 2000) to discuss our results, but they have just two sampling points in the reservoir, which is hard to compare or link to our data.

475- Net effect on what? Reservoir radiative forcing, catchment C balance? What are the other components in the budgets?

Response: We rephrased to "net effect on the regional carbon budget".

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1	High organic carbon burial but high potential for methane ebullition in the
2	sediments of an Amazonian hydroelectric reservoir
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21 Reservoir sediments sequester significant amounts of organic carbon (OC), but at the same time, high amounts of methane (CH₄) can be produced and emitted during the 22 23 degradation of sediment OC. While the greenhouse gases emission of reservoirs has received a lot of attention, there is a lack of studies focusing on OC burial. In particular, 24 25 there are no studies on reservoir OC burial in the Amazon, even though hydropower is expanding in the basin. Here we present results from the first investigation of OC burial 26 and CH₄ concentrations in the sediments of an Amazonian hydroelectric reservoir. We 27 performed sub-bottom profiling, sediment coring and sediment pore water analysis in 28 29 the Curuá-Una reservoir (CUN; Amazon, Brazil) during rising and falling water periods. Spatially resolved average sediment accumulation rate was 0.6 cm yr⁻¹ and a 30 average OC burial rate was 91 g C m⁻² yr⁻¹. This is the highest OC burial rate on record 31 32 for low-latitude hydroelectric reservoirs. Such high rate probably results from a high OC deposition onto the sediment, which compensates the high OC mineralization 33 34 at 28-30°C water temperature. Elevated OC burial was found near the dam, and close 35 to major river inflow areas. C:N ratios between 10.3 and 17 (average \pm SD: 12.9 \pm 2.1) suggest that both land-derived and aquatic OC accumulate in CUN sediments. About 36 23% of the sediment pore water samples had dissolved CH₄ above the saturation 37 concentration. This represents a higher share than in other hydroelectric reservoirs, 38 indicating a high potential for CH₄ ebullition, particularly in river inflow areas. 39

Keywords: Amazon, carbon cycling, C:N ratio, dam, pore water, river inflow

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43 Introduction

44	Although freshwater ecosystems represent a small fraction of the global area
45	(~4% of terrestrial area) (Downing et al., 2012; Verpoorter et al., 2014), they play an
46	important role in the global carbon cycle, both emitting carbon to the atmosphere
47	and burying carbon in the sediments (Cole et al., 2007; Tranvik et al., 2009). Many
48	studies have been conducted on inland water carbon emissions, while the organic
49	carbon (OC) burial in inland water sediments is comparatively understudied on a global
50	scale (Raymond et al., 2013; Mendonça et al., 2017). Since a part of the buried OC may
51	offset a share of greenhouse gas emission, it is essential to include OC burial in the
52	carbon balance of inland water ecosystems (Kortelainen et al., 2013; Mendonça et al.,
53	2017).

Freshwater OC burial rate varies both in space and time due to many factors, 54 55 such as land cover, hydrological conditions, OC and nutrient input and climate change (Radbourne et al., 2017; Stratton et al., 2019). Several studies have shown that 56 57 reservoirs bury more OC per unit area than lakes, rivers and oceans (Mulholland and Elwood, 1982; Mendonça et al., 2017), which may be attributed to the high 58 sedimentation rate caused by the extensive sediment trapping when water flow is 59 60 dammed (Vörösmarty et al., 2003). Considering the importance of reservoirs as a carbon sink (~28 to 55% of total inland water OC burial; Mendonça et al., 2017) and 61 62 the increasing number of hydroelectric dams (Zarfl et al., 2015), the limited number of studies on OC burial in reservoirs severely hampers the understanding of this important 63 component in the carbon balance of the continents (Mendonça et al., 2017). In 64 65 particular, large regions of the Earth are at present completely unsampled concerning inland water carbon burial. Approximately 90% of the sites sampled for carbon burial 66

69	To the best of our knowledge, OC burial has so far not been studied in an
70	Amazonian reservoir. However, it is likely that reservoirs in tropical rain forest
71	areas bury OC at a comparatively high rate, as temperature and runoff were
72	identified as important drivers of OC burial in lakes and reservoirs (Mendonça et
73	al., 2017). Indeed, OC burial in Amazonian floodplain lakes was reported to be
74	much higher than in other lakes (Sanders et al., 2017). Moreover, many new
75	hydropower dams are planned in the Amazon due to the high potential of the area for
76	hydroelectricity (da Silva Soito and Freitas, 2011; Winemiller et al., 2016). However,
77	there is currently no data to gauge the potential effect of hydropower expansion in the
78	Amazon on carbon burial.

79 Besides the significant potential of trapping OC in the sediment, reservoirs can be strong sources of methane (CH_4) to the atmosphere (Deemer et al., 2016). 80 Several studies have shown a positive relationship between CH₄ production and 81 temperature in freshwater ecosystems (Marotta et al., 2014; Wik et al., 2014; Yvon-82 Durocher et al., 2014; DelSontro et al., 2016; Aben et al., 2017), and also organic matter 83 supply to sediment is an important regulator of CH₄ production and emission (Segers, 84 85 **1998**; Sobek et al., 2012; Grasset et al., 2018). Thus, tropical reservoirs, especially 86 those situated in highly productive humid tropical biomes, such as the Amazon, may produce more CH₄ than temperate ones due to higher annual temperatures and 87 availability of organic matter in their sediments (Barros et al., 2011; Mendonça et al., 88 89 2012; Fearnside and Pueyo, 2012; Almeida et al., 2013), although highly-emitting 90 reservoirs can also be situated in temperate regions (Deemer et al., 2016). Further, in many reservoirs, CH₄ ebullition (i.e., emission of gas bubbles) is an important or 91

92	dominant emission pathway, but it is very difficult to measure due to its strong
93	variability in space and time (McGinnis et al., 2006; Deemer et al., 2016).
94	Measurements of dissolved CH ₄ concentration in sediment pore water may, therefore,
95	help to identify if ebullition is likely to occur (CH4 concentrations close to the sediment
96	pore water saturation), and thus to judge if the sediments act mainly as carbon sinks, or
97	also as CH4 sources. While CH4 emission typically constitutes a very small flux in
98	terms of carbon mass, it is highly relevant to climate since CH4 is a ~34 times
99	stronger greenhouse gas than CO ₂ (IPCC, 2013). The transformation of sediment
100	OC (i.e. previously fixed CO ₂) to atmospheric CH ₄ therefore represents an
101	amplification of radiative forcing in the atmosphere.
102	Both OC burial and CH4 production take place in sediments. Here, we
103	present results of a study approaching these processes on sediments of an
104	Amazonian hydroelectric reservoir during hydrologically different seasons, which
105	was motivated by an absence of such studies even though sediment carbon
106	processing in Amazonian reservoirs may potentially be high. We aimed at
107	providing a spatially-resolved quantification of OC burial, as well as a mapping of
108	CH4 saturation in the sediment porewater, which is indicative of the potential
109	occurrence of CH4 ebullition. Thereby, this study is intended to contribute to
110	improved understanding of the potential biogeochemical effects of the current
111	expansion of hydropower (Almeida et al., 2019) on the Amazonian carbon budget.
112	Material and methods

Study area

Curuá-Una is an Amazonian reservoir (CUN; 2°50' S 54°18' W) located in the
Pará state (North of Brazil), created in 1977, and used mainly to produce energy. The

average water depth of CUN is 6 m (Fearnside, 2005; Paranaíba et al., 2018) and it has 116 a maximum flooded area of 72 km² (Duchemin et al., 2000; Fearnside, 2005). The main 117 118 tributary is the Curuá-Una River, contributing with most of the reservoir's water 119 discharge (57.4%), but rivers Moju (11.7%), Mojuí (4.4%), Poraquê (3.2%) and other 120 small ones (2.9%) are also important (Fearnside, 2005). While tropical rain forest covers 90.8% of the total CUN catchment area, managed lands, which covers 8.9% 121 122 of the total catchment, contribute with a high share (up to 41%) of the land cover in some sub-catchments (Fig. 1). 123

The reservoir is characterized by a high amount of flooded dead trees (area with trees covers ~90% of the total reservoir area), which may be expected to decrease water flow and promote sedimentation. According to a previous study (Paranaíba et al., 2018), CUN is oligotrophic (total nitrogen (**TN**): 0.7 mg L⁻¹, **average**; total phosphorus (**TP**): 0.02 mg L⁻¹, **average**), the surface water is warm (**average** ± **SD**: 30.1 ± 1.4 °C), slightly acidic (pH of 6.1 ± 0.7), with low conductivity (16 ± 11 µS cm⁻¹) and moderately oxygenated (6.7 ± 1.9 mg L⁻¹).

131 Sampling

132 We carried out two samplings in the CUN reservoir. In February 2016, during the rising water period (Fig. S1), we used an Innomar SES-2000 parametric sub-bottom 133 profiler operating at 100 kHz (primary frequency) and 15 kHz (secondary frequency) to 134 determine the bathymetry and sediment thickness from which we planned to acquire 135 136 spatially resolved sediment accumulation rates and OC burial rate, similar to Mendonça 137 et al. (2014). Sediment thickness was difficult to observe with the sub-bottom profiler, though, presumably because of the widespread presence of gas bubbles in the sediment 138 which reflect the sound waves very efficiently, preventing them from reaching the sub-139

bottom layer. Therefore, OC burial rates were determined from sediment cores only. In
September 2017, during the falling water period (Fig. S1), additional sediment cores
were then taken to cover the reservoir as much as possible.

We took a total of 114 sediment cores during the two sampling occasions, 143 144 approximately evenly distributed along the reservoir, both longitudinally and laterally, to measure sediment thickness and, thus, estimate sediment accumulation and OC burial 145 rates (Fig. 1, Table S1). Cores were retrieved using a gravity corer equipped with a 146 hammer device (UWITEC, Mondsee, Austria) to sample the entire sediment layer, 147 including the pre-flooding material. The layer of transition between post- and pre-148 149 flooding material was visually identified. Visual identification is possible because the 150 moment when the reservoir was flooded is the onset of a lacustrine depositional regime, which is characterized by different sediment texture and composition in relation to the 151 152 pre-flooding soil or fluvial sediment (Fig. S2). The thickness of the post-flooding sediment was noted in all cores and used to calculate sediment accumulation rates 153 ('data analysis'). Nineteen sediment cores, from sites spread out evenly over the 154 reservoir were sliced in 2 cm thick slices and dried at 40 °C for further laboratory 155 analysis. The samples were weighed before and after drying and the results are, then, 156 157 expressed in dry weight.



158

Figure 1. Organic carbon burial rate (OC burial; g C m⁻² yr⁻¹) of the Curuá-Una reservoir. The circles show the land cover of each sub-catchment, delineated by white lines. The numbers near the circles show the area in km² for each sub-catchment. The black dots represent the sediment sampling sites to estimate OC burial rates. The arrows represent the main river inflows. The houses represent settlements at the reservoir. The bottom-right map shows the location of the reservoir in Brazil (the green area is the Brazilian Amazon region) and the total extension of each sub-catchment.



the exact same location at different periods due to the water level changes, GPS error
and boat drifting. Thus, the repeated samplings at these eight sites were within < 100 m
distance.

Water temperature and dissolved oxygen profiles were measured with a
multiparameter sonde (YSI 6600 V2) in a total of 28 depth profiles, distributed across
the reservoir at both sampling occasions. Air pressure and temperature were measured
with a portable anemometer (Skymaster SpeedTech SM-28, accuracy: 3%), water depth
was measured with a depth gauge (Hondex PS-7), and sediment temperature with a
thermometer (Incoterm), which was inserted into the sediment right after core retrieval.

180 *Carbon and nitrogen analysis*

OC and TN concentrations were determined in a sub-set of 19 cores, distributed 181 evenly across the reservoir area. In each of these cores, the first and second layers (0 to 182 183 4 cm deep, containing the fresher OC), the last sediment layer above the pre-flooding 184 soil surface (containing the older OC) and one sample every ~8 cm in between (OC of 185 intermediate age) were analyzed. This selection of layers for carbon and nitrogen analyses was motivated by the exponential decrease of OC mass loss rates during 186 187 sediment degradation (Middelburg et al., 1993; Gälman et al., 2008). Linear interpolation was used to derive OC and TN concentrations of layers that were not 188 measured. 189

Dried sediment samples were ground in a Planetary Ball Mill (Retsch PM 100) equipped with stainless steel cup and balls. Sediment was packed in pressed tin capsules and analyzed for TC and TN with a Costech 4010 elemental analyzer. The molar **carbon to nitrogen** (C:N) ratio in the surface layers was then calculated. The presence of carbonates was checked in the samples qualitatively by adding drops of acid and

197 *CH*⁴ concentration in pore water

The CH₄ concentration in pore water was measured according to Sobek et al., 198 199 (2012) to determine if CH₄ is close to saturation concentration and, thus, prone to form 200 gas bubbles. The saturation concentration, calculated here from temperature and 201 pressure along the sediment profiles, represents the maximum concentration that dissolves in pore water, above which bubbles are formed. The presence of gas 202 203 bubbles is indicative for an elevated probability of CH₄ ebullition, but not necessarily relates quantitatively to ebullition flux, since ebullition flux to the atmosphere is also 204 205 dependent on water depth, sediment grain size, and pressure fluctuations (McGinnis et 206 al., 2006; Maeck et al., 2014; Liu et al., 2016). The top 20 cm (February 2016) or 40 cm 207 (September 2017) of the sediment cores were sampled every 2 cm. Deeper sediment 208 was sampled every 4 cm until the bottom or pre-flooding material. Using a core liner 209 with side ports, 2 ml of sediment were collected using a syringe with a cut-off tip, added 210 to a 25 mL glass vial with 10 ml of distilled water, and closed with a 10 mm thick butyl rubber stopper. The slurry (2 mL sediment + 10 mL distilled water) was equilibrated 211 212 with 13 mL headspace of ambient air (void volume of the glass vial) immediately after 213 sampling by vigorously shaking the glass vial, and then the headspace was transferred 214 to another syringe. The headspace was stored in the syringe, closed with a gas-tight valve, and then analyzed for CH4 concentration within the same day using an 215 Ultraportable Greenhouse Gas Analyzer (UGGA, Los Gatos Research) with a custom-216 217 made sample injection port. Then, the resulting peaks were integrated using R software (RStudio Version 1.1.383). The CH₄ concentration in the pore water was calculated 218 from the headspace CH₄ concentration, based on the Henry's law constants. The 219

saturation concentration of CH₄ in each sediment layer was calculated based on air
pressure, water depth, sediment temperature, and sample depth within the sediment
core. The sediment layers with CH₄ concentrations above 100% saturation were
considered as prone to ebullition. This is a conservative assumption because it is likely
that a part of the CH₄ in the sediment was lost to the atmosphere due to pressure drop
during core retrieval, as well as during sample processing.

226 Data analysis

The average sediment accumulation rate (SAR; cm yr⁻¹) was calculated for each of the 114 cores by dividing the thickness of the post-flooding sediment (cm) by the years since the reservoir construction (39 years in 2016 or 40 years in 2017), according to the equation:

231 Sediment accumulation rate =
$$\frac{\text{sediment thickness}}{\text{reservoir age}}$$

This approach returns the average sediment accumulation rate over the lifetime 232 233 of the reservoir (Renwick et al., 2005; Kunz et al., 2011; Mendonça et al., 2014; Quadra 234 et al., 2019), and therefore **incorporates any** short-term variability in sediment deposition, for example, caused by an episodic change in sediment load or internal 235 236 sediment movement. The large amount of core samples distributed evenly across the 237 reservoir body also covers the spatial variability in sediment deposition, for example due to sediment focusing (sediment movement with preferential deposition in deeper 238 239 areas).

OC burial rates (g C m⁻² yr⁻¹) were calculated for the sub-set of 19 sites where OC content was analyzed. OC mass (g C) in each sediment slice was calculated as OC content (g C g⁻¹) multiplied by dry sediment mass (g). Total OC mass (g C) in the cores was the sum of OC mass in all post-flooding sediment layers. Then, the **average** OC burial rate (g C m⁻² yr⁻¹) for each of these 19 sites was calculated **dividing** the total OC mass **in post-flooding sediment** (g C) **by the** core surface area ($2.8 \times 10^{-3} \text{ m}^2$) and the reservoir age (yr) at the sampling dates, according to the equation:

247
$$Organic \ carbon \ burial \ rate = \frac{OC \ in \ reservoir \ sediment}{core \ area \ \times \ reservoir \ age}$$

The empirical relationship between SAR and OC burial rate (see Results; y = 159 x - 4.4; $R^2 = 0.87$; Fig. S3) was used to estimate the OC burial rate (g C m⁻² yr⁻¹) for the remaining 95 coring sites where OC content was not analyzed.

To produce spatially-resolved maps of SAR and OC burial rate, the data from the 114 cores were interpolated to the reservoir area using the Inverse Distance Weighted algorithm (IDW, cell size of approximately 22 m x 22 m). From the spatiallyresolved average OC burial rate, the reservoir age (40 years) and total flooded area (72 km²), we calculated the total OC stock in the reservoir sediment. Using the same approach, we interpolated the pore water CH₄ concentration, and C:N ratio for the whole reservoir area. Spatial analyses were performed in ArcGIS 10.3.1 (ESRI).

To investigate any potential relationships between the land cover of subcatchments and the spatial distribution of sediment characteristics and rates, land cover
data were derived from maps of 1 km resolution (Global Land Cover Project,
GLC2000), made available by the European Commission's science and knowledge
service, including 23 land cover classes. The classes found in the CUN watershed were
then grouped in three main classes: (1) forest (tree cover, natural vegetation, shrub, and
herbaceous cover); (2) managed areas (cultivated and managed areas, cropland and bare

267 To verify the differences between CH₄ concentrations in the two seasons
268 (rising and falling water), the non-parametric Wilcoxon Test was performed using
269 the software JMP 14.1.0 (SAS).

270 **Results**

271 Water column profiles

The water column temperature profiles showed a **average** of 30 ± 1 °C, 29 ± 1 °C and 29 ± 2 °C (average \pm SD) in the surface, the middle and bottom layers,

respectively. The dissolved oxygen **average** was $7 \pm 1 \text{ mg } L^{-1}$, $6 \pm 1 \text{ mg } L^{-1}$ and $5 \pm 1 \text{ mg } L^{-1}$ in the surface, the middle and bottom layer, respectively. These water profiles suggest that the relatively shallow water column does not develop stable stratification over any extended periods of time, even if short-lived stratification events can occur (**Table S2**).

279 Sediment accumulation and organic carbon burial rates

SAR in the coring sites (n = 114) varied from 0 to 1.7 cm yr⁻¹ (0.6 ± 0.4 cm yr⁻¹, 280 **95% confidence interval: 0.5-0.7 cm yr⁻¹; Table S1**). In some areas of rocky or sandy 281 bottom, especially near river inflows and along the main river bed, sediment could not 282 be retrieved with our corer and SAR was considered as zero (total of 10 sites). OC 283 burial rate in the coring sites (n = 114) varied from 0 to 269 g C m⁻² yr⁻¹ (91 \pm 61 g C m⁻ 284 ¹ yr⁻¹, **95% confidence interval: 80-102 g C m⁻¹ yr⁻¹; Table S1**). The highest values of 285 OC burial were observed near the dam, at the confluence of the major inflowing rivers, 286 287 and in the inflow area of the main tributary, Curuá-Una River (Fig. 1). Our sampling

288	was representative of the whole system, from the margins, where there is a greater
289	presence of dead tree trunks, to the river bed, where the sedimentation was lower (Fig.
290	1). Therefore, the simple average OC burial from the cores resulted in the same
291	average OC burial rate derived from the spatial interpolation (91 g C m ⁻¹ yr ⁻¹). The total
292	burial rate for the CUN reservoir area was $6.5 \times 10^{10} \text{ g C yr}^{-1}$, corresponding to an
293	accumulation of 0.3 Tg C in CUN sediments since its construction.

294 *C:N ratio and land cover*

The C:N ratio of the surface layers of sediment (n = 19), used as an indicator of organic matter source, varied from 10.3 to 17 (12.9 \pm 2.1, **Table S3, Fig.2**). Higher C:N ratios were observed in the dam area and at the river inflows (**Fig. 2**).

Tropical rain forest was the dominant land cover in CUN, covering from 60.6 to 98.6% of the sub-catchment areas. Managed areas covered 1.4 to 40.9% of the sub-catchments areas, with the higher values occurring in the northwestern tributaries, which were also smaller compared to the southern ones (Fig 1). Water surfaces covered 0.3% of the total CUN catchment area (Table S4).

303



Figure 2. C:N ratio of surface sediment in Curuá-Una reservoir. The black dots
represent the sampling sites. The houses represent the settlements at the reservoir.

307 *Pore water CH*⁴ *profiles and saturation*

308 The overall average CH₄ concentration in pore water from CUN was 1729 ± 1 **939 µmol** L^{-1} of CH₄ with similar **averages** during rising (1 700 ± 1 637 µmol L^{-1} of 309 CH₄, Fig. S4) and falling water (1 764 \pm 2 243 µmol L⁻¹ of CH₄, Fig. S4) periods. At 310 eight sites, we could make paired observations of CH₄ concentration in sediment pore 311 water at both rising and falling periods (Fig. 3). These data show that the seasonal 312 313 difference of CH₄ concentration in pore water was low and not significant (S = 33213, Z = -1.27863, Prob> $|\mathbf{Z}| = 0.20$). Of the 25 pore water CH₄ profiles, 20 contained at least 314 315 one sample with pore water CH₄ above the 100% saturation concentration; of the total of 386 pore water samples, 90 samples (23%) were above the CH₄ saturation 316 concentration. Pore water CH₄ saturation was higher in river inflow areas, especially in 317

- sampling sites in the Curuá-Una main river. The confluence of the rivers and the dam
- area were also characterized by high pore water CH₄ (Fig. 4). The widespread
- 320 appearance of gas bubbles in the sediment is in accordance with the sub-bottom profiler
- data, which for a large part of the reservoir could not be used to identify sub-bottom
- 322 structures, because of a very strong acoustic reflector in surficial sediment, presumably
- 323 gas bubbles.



Figure 3. Paired observations of pore water CH_4 profiles during rising (R) and falling (F) water periods at eight different sampling sites across the reservoir. Black lines represent the CH_4 saturation concentration (µmol L⁻¹) and grey lines represent the

328 measured CH₄ concentration (μ mol L⁻¹) over sediment depth. The numbers following



329 the letters F and R correspond to the site codes in Table S1.

Figure 4. Percentage of sediment layers with CH₄ concentration above saturation. The
black dots represent the sampling sites to produce the interpolation. The houses
represent the settlements at the reservoir.

334 Discussion

335 Despite the intense OC mineralization in the tropics, this study found that 336 OC burial in the sediment of the Amazonian Curuá-Una reservoir was high when 337 compared to sub-tropical and other tropical reservoirs, probably due to the high 338 carbon inputs from the forest. However, autochthonous material was also an 339 important component of CUN sediment. CH4 concentrations in the sediment pore-

342 SAR and OC burial in an Amazonian reservoir

When a river enters a reservoir, the water flow tends to decrease, favoring the 343 344 deposition of suspended particles (Fisher, 1983; Scully et al., 2003). Typically, reservoir sedimentation rates are higher in the inflow areas and lower near the shores (Morris and 345 346 Fan, 1998; Sedláček et al., 2016). CUN showed high SAR near the inflow areas, especially in the main tributary, but in contrast to other reservoirs (e.g. Mendonça et al., 347 348 2014), we did not observe any decrease in SAR towards the margins (i.e. the shore). In CUN, sediment accumulation across the entire reservoir area is favored by the shallow 349 topography of the area, and by the presence of dead tree trunks along the reservoir 350 351 including the margins, which reduce water flow and wave-driven resuspension. 352 Accordingly, our data show that SAR was randomly distributed in relation to the water column depth (Fig. S5). Some reservoirs show higher sedimentation rates near the dam, 353 354 which can be called 'muddy lake area' (Morris and Fan, 1998; Sedláček et al., 2016), and occurs in reservoirs where the fine sediment is transported all the way to the dam 355 (Morris and Fan, 1998; Jenzer Althaus et al., 2009; Sedláček et al., 2016; Schleiss et al., 356 2016). CUN may be one of those cases (Fig. 1), possibly because water retention time is 357 low in the main river channel which is narrow and well separated from the dead tree 358 359 area, permitting transport of fine-grained sediment until the deeper dam area, where sediments tend to accumulate (Lehman, 1975; Blais and Kalff, 1995). Sediment 360 accumulation was also high at the confluence of the three main tributaries (Fig. 1), 361 362 probably due to sediment deposition as water flow slows down when the rivers enter the main body of the reservoir. 363

Although average SAR in CUN (0.6 cm yr⁻¹) was only slightly higher than that 364 of non-Amazonian reservoirs in Brazil (e.g. Mendonça et al., 2014: 0.5 cm yr⁻¹; 365 Franklin et al., 2016: 0.4 cm yr⁻¹), OC burial rates were much higher in CUN than in 366 other hydroelectric reservoirs in the tropics and sub-tropics. For example, OC burial 367 was four times lower in Lake Kariba (23 g C m⁻² yr⁻¹, Zimbabwe, Kunz et al., 2011) and 368 about two times lower in Mascarenhas de Moraes (42 g C m⁻² yr⁻¹, Brazil, Mendonça et 369 al., 2014) and other Brazilian reservoirs $(40 \pm 28 \text{ g C m}^{-2} \text{ yr}^{-1}, \text{Brazil}, \text{Sikar et al., 2009})$ 370 371 when compared to CUN. Even though natural lakes tend to bury OC at lower rates than artificial reservoirs (Mendonça et al., 2017), some Amazonian floodplain lakes showed 372 higher OC burial rates than the CUN reservoir (266 ± 57 g C m⁻² yr⁻¹; Sanders et al., 373 2017). This is probably due to their smaller sizes which may result in a higher SAR 374 since there is little area for sediment deposition, but high sediment load from the river 375 376 during periods of high discharge. While a comparison with the latest global estimate of OC burial in reservoirs – median of 291 g C m^{-2} yr⁻¹ (Mendonça et al., 2017) may lead 377 378 to the conclusion that OC burial in CUN is low, it must be accounted that this global 379 estimate (Mendonça et al., 2017) includes many small agricultural reservoirs (farm ponds), which are generally highly eutrophic systems that receive high sediment inputs 380 from agriculture, resulting in extremely high OC burial rates (Downing et al., 2008). 381 382 Hence, if compared to other hydroelectric reservoirs at low latitudes, our conclusion remains that OC burial in CUN is high. Importantly, comparisons of average SAR and 383 OC burial rate between studies may be complicated by different sampling schemes, as 384 385 sedimentation can vary in space and time (Radbourne et al., 2017; Stratton et al., 2019); for example, while in some studies, sites along the margins with zero sedimentation 386 387 were sampled (e.g. Mendonça et al., 2014; our study), in other studies it was not (Moreira-Turcq et al., 2004; Knoll et al., 2014). 388

The high OC burial in CUN when compared to other low-latitude hydroelectric reservoirs is probably due to the high OC inputs from the productive Amazonian rain forest (Zhang et al., 2017), which compensates the intense sediment mineralization rates caused by high temperature. Using the linear regression model from a compilation of mineralization in freshwater sediments from the literature (Cardoso et al., 2014),

394

OC mineralization = $(1.52 + 0.05) \times Temperature$

395	and the average temperature of the bottom water in CUN (29°C), sediment OC
396	mineralization is estimated at a average of 325 g C m ⁻² yr ⁻¹ . This estimation assumes
397	the same sample size as OC burial (n = 114), and consequently that the random
398	error of each individual prediction (Cardoso et al., 2014) largely averages out and
399	becomes negligible (<1 g C m ⁻² yr ⁻¹) for the average of predicted OC
400	mineralization. This estimate of the average sediment OC mineralization rate is in the
401	upper end of the range of values found for Brazilian reservoirs (Cardoso et al., 2014),
402	but may even be conservative given that the CUN reservoir is located in a highly
403	productive biome with high organic matter supply. The total OC deposition rate onto
404	the sediment (OC mineralization + OC burial) of CUN is thus 418 g C m ⁻² yr ⁻¹ ,
405	returning a estimated average OC burial efficiency of 22 % (OC burial efficiency =
406	OC burial / OC deposition rate; Sobek et al., 2009). As expected, due to the positive
407	effect of temperature on mineralization, the estimated average OC burial efficiency in
408	the CUN reservoir is low in comparison to other reservoirs (at least 41% in the tropical
409	lake Kariba (Kunz et al., 2011); average of 67% in the sub-tropical Mascarenhas de
410	Moraes reservoir (Mendonça et al., 2016); average of 87% in the temperate lake
411	Wohlen reservoir (Sobek et al., 2012)). A low OC burial efficiency allows high OC
412	burial only if OC deposition onto the sediment is high enough, and we suggest that the

413 high productivity of the surrounding Amazonian rainforest constitutes a strong OC414 supply to CUN sediments.

415	The C:N ratio indicates that the sediment OC in CUN consists of a mixture of
416	land-derived and internally-produced OC. The surface sediment C:N ratio varied from
417	10.3 to 17.0 (Table S3), and the C:N ratios of phytoplankton are typically 6-9, of
418	aquatic macrophytes >10, of land plants >40 (Meyers and Ishiwatari, 1993; Grasset et
419	al., 2019) and of Amazonian topsoils 10 to 14 (Batjes and Dijkshoorn, 1999). Although
420	we refrained from making quantitative analysis based on C:N ratios, higher C:N
421	values at the river inflow areas (Fig. 2) may indicate input from the highly productive
422	watershed and thus the high load of land-derived OC to the sediment. Tropical rain
423	forest is the dominant land cover in the CUN catchment (91%, Fig. 1), which may
424	suggest that that the high OC burial rates in CUN are related to a high OC input from
425	the watershed. However, there was no strong relation between OC burial rate and C:N
426	ratio (Fig. S7A), even though the C:N ratio has been shown to affect the OC burial
427	efficiency (Sobek et al., 2009). Possibly, the strong effect of SAR on OC burial
428	masked the potential effect of the C:N ratio. In addition, the middle section of the
429	reservoir was characterized by relatively low C:N ratio, indicating a significant share of
430	aquatic OC in the sediment (Fig. 2). Likely, the higher water transparency downstream
431	from the river inflow areas due to particle settling stimulate aquatic primary production.
432	Possibly, also sewage input from riverside communities (represented as houses in Fig.
433	2) contributes with N to the reservoir and thus further stimulates aquatic production,
434	since a comparatively low C:N ratio was found near these settlements. Also, even at low
435	C:N ratios, OC burial rates were high (Fig. S6A). Hence, it is evident that internally-
436	produced OC makes up an important contribution to the OC buried in the sediments of
437	CUN. The source of buried OC has an important implication in terms of accounting for

the sediment carbon as a new sink or not (Prairie et al., 2017), since the burial of
aquatic OC can be ascribed to aquatic primary production in the reservoir, which
would not have taken place in the absence of the dam, and thus represents a new
carbon sink. However, our data do not allow us to make a quantitative estimate of the
share of the CUN sediment carbon stock that is of aquatic origin, and thus may be
accountable as a new carbon sink resulting from river damming (Prairie et al., 2017).

The spatial pattern of OC burial suggests that the catchment size affects 444 sediment load and sedimentation, since the largest sub-catchment (6966 km²), entering 445 CUN from the south, corresponds with high OC burial rates in the southern river inflow 446 447 area (Fig. 1). The northwestern tributaries, which drain only 2111 and 300 km², are not 448 associated with high OC burial in the northeastern tributary (Fig. 1), possibly because 449 they are smaller, even though they have a higher share of managed land (34 and 41%, 450 respectively) than the southern sub-catchment (4%). Apparently, even though land management increase erosion (Syvitski and Kettner, 2011), we cannot detect any such 451 452 effect on sediment OC burial. Also concerning the C:N ratio, an effect of land cover is 453 not evident, since the inflow area of the forest-dominated sub-catchment in the southwest (2855 km²; 99% forest) had a similar C:N ratio as the tributary of the 454 455 northwestern sub-catchments, with their higher share of managed land. Possibly, the effect of land cover is masked by other factors affecting sediment OC and C:N, such as 456 internal productivity and local particle settling patterns. 457

Despite being high compared to other hydroelectric reservoirs, OC burial in CUN represents only 15% of the total carbon emission to the atmosphere reported for the CUN reservoir (509 g C m⁻² yr⁻¹, Duchemin et al., 2000). Similarly, a study conducted in a boreal Canadian reservoir found that OC burial corresponded to 10% of reservoir **carbon emission** (Teodoru et al., 2012), although burial in other reservoirs can be close to (70%, Mendonça et al., 2014) or even much higher than the total carbon
emission to the atmosphere (1600%, Sobek et al., 2012). The magnitudes of carbon
burial in relation to the emission in reservoirs depends on many factors (Mendonça et
al., 2012). Therefore, although freshwater carbon emission tends to be consistently
higher than OC burial in Amazonian freshwater systems (Mendonça et al., 2012), we
cannot speculate in how far the results of this study applies to other reservoirs in the
Amazon region since many factors affect the carbon processing in inland waters.

470 *High potential for CH*⁴ *ebullition*

471 The high amount of pore water CH₄ profiles with samples above the CH₄ saturation concentration indicates a high likelihood of gas bubble formation in 472 473 most of the sampled sites, and thus the possibility of CH₄ ebullition (Table S5). 474 Importantly, however, the link between bubble presence in the sediment and CH4 ebullition flux is entirely qualitative, and can not be used to estimate the 475 magnitude of CH4 ebullition. Sites with higher OC burial rate, i.e. river inflow areas, 476 especially the Curuá-Una river, the confluence of the three main rivers and the dam area, 477 also showed a tendency towards higher extent of CH₄ saturation (Fig. 4). However, 478 479 while the relationship between average CH₄ saturation and OC burial at the 480 different sites was positive, it was also weak, but clearly shows the overall high level of CH₄ saturation in CUN sediments (Fig. 5). Hence, the CH₄ production in 481 482 CUN sediments may rather be **influenced** by the OC supply rate to anaerobic sediment layers than by the reactivity of the sediment OC, since there was no association between 483 the C:N ratio and the extent of CH₄ saturation (Fig. S7B). Links between high 484 485 sedimentation rate and sediment CH₄ pore water concentration as well as CH₄ ebullition have been reported previously (Sobek et al., 2012; Maeck et al., 2013), and in addition, 486 fresh land plant-derived organic matter such as leaves transported by the rivers may fuel 487

substantial CH₄ production at anoxic conditions (Grasset et al., 2018). This highlights
that sediment accumulation bottoms close to river inflow areas can be prone to exhibit
high CH₄ ebullition (DelSontro et al., 2011), not least because the shallow water column
in inflow areas (**Fig. S6**) facilitates CH₄ bubble transport to the atmosphere.



492

Figure 5. Regression model of average percentage of CH₄ saturation (%) in the
sediment pore water and OC burial rate (g C m⁻² yr⁻¹). Each circle represents one
sampling site.

Compared to other reservoirs, CUN had a higher share of sites (20 of 25) with
pore water CH₄ concentration over the saturation threshold. In the Mascarenhas de
Morais reservoir (Brazil), 6 of 16 sites with pore water CH₄ concentration over the
saturation threshold were found (Mendonça et al., 2016). In Lake Wohlen
(Switzerland), 4 of 8 sites with pore water CH₄ concentration over the threshold were
found (Sobek et al., 2012). However, these differences should be interpreted with
caution. Using the 100% saturation concentration as a threshold may underestimate the

503	potential for ebullition, since changes in the pressure may result in bubbles release
504	during sediment sampling, especially in layers above 100% saturation. Therefore, our
505	results of the degree of pore water CH ₄ saturation, as well as the results from the
506	literature cited above, are conservative.

507	We did not find statistical difference between CH ₄ pore water concentration
508	during rising and falling periods (Fig. 3), although other studies suggest a strong
509	influence of water level or pressure changes on CH4 ebullition (Mattson and Likens,
510	1990; Eugster et al., 2011; Maeck et al., 2014). Interestingly, 2 of the 8 sites with
511	generally low CH ₄ pore water concentration were low at both sampling occasions,
512	indicating that there may be an important spatial component in sediment CH ₄
513	production and saturation (Fig. 3, sites F24 x R16 and F57 x R39), which however was
514	not related to the C:N ratio or OC burial rate at these sites.

515 **Conclusions**

516 The comparatively high OC burial rate of the Amazonian CUN reservoir 517 probably results from high OC deposition onto the sediment, since the warm water (28-518 30°C) implies a high sediment OC mineralization rate. The forest seems to be a major 519 OC source to the reservoir although the relatively low C:N ratio in some parts of the 520 reservoir suggests an also significant aquatic contribution to sediment OC burial. In 521 some parts of the reservoir, particularly in the river inflow areas, sediments are probably a CH₄ source by ebullition. Therefore, large inputs from a highly productive forest 522 523 probably boost the OC burial rate, as well as CH₄ production, with a still unknown net 524 effect on the regional carbon budget. Given the planned expansion of hydropower dams in the Amazon region, and the high OC burial rate in CUN shown here, future 525 526 studies should quantify how OC burial and CH₄ emission may be affected by new

527	Amazonian hydroelectric reservoirs. Moreover, it will be critical to quantify the
528	effect of the new Amazonian reservoirs on the ocean's carbon budget, since the
529	CUN dam alone retains yearly 7,500 tons of OC and a part of it would likely reach
530	the ocean in the absence of the dam.

531 Data availability. All the data used in this study can be found in the manuscript and in532 the Supplement.

533 Author contributions. GRQ, JRP, AI, RM, RV carried out the sampling campaings.

534 GRQ processed the data. AI analyzed the samples. GRQ and JRP prepared the figures.

RM, SS, FR designed the study. All authors contributed to interpreting data and writingthe manuscript.

537 **Competing interests.** The authors declare that they have no conflict of interest.

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