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Interactive comment on "Effects of eutrophication on sedimentary organic carbon cycling in five temperate lakes" *by* Annika Fiskal et al.

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Interactive comment on "Effects of eutrophication on sedimentary organic carbon cycling in five temperate lakes" by Annika Fiskal et al.

Anonymous Referee #2

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General comments

The paper studies sediment records of five different lakes that differ in trophic state and investigate the relationships between TOC accumulation, burial and historical P levels (eutrophication). I like the approach of comparing measured, modeled and re-

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constructed TOC to understand how sediment record was affected by eutrophication history. The MS is also informative by providing a nearly complete set of porewater chemistry data.

Answer: The authors thank the anonymous referee for the positive review and the constructive suggestions. Below are our answers to the detailed comments. All changes to the ms in response to the referee comments are highlighted in blue in the main document (please see supplement of this document for the revised manuscript).

However, I suggest the authors better describe the modeling methods, particularly the terms used (TOC accumulation, burial, TOC modeled, TOC reconstructed, etc.; see specific comments), which is important for the manuscript but poorly presented in the current version.

Answer: Thank you for this comment. We have completely revised the text in the Materials & Methods in which we define these terms and hope it is more clear now (p. 8, l. 9 – p. 9, l. 4).

I also find the results and discussions in cell counts, cell-specific rates less useful and largely speculative. I suggest reducing this part of the discussion so that the paper has a better focus.

Answer: We have shortened the above sections. While perhaps some focus could be gained by removing them, as stated in the ms we wanted to not only look at burial of OC but also at mineralization processes in order to give a holistic picture. Not many studies have attempted to do this so far, especially not for lake sediments. Our study demonstrates that calculations and interpretations based on independently obtained data (TOC vs. porewater dissolved) and models are internally consistent and provide complementary insights. Furthermore, we would like to add that this manuscript is the foundation for several other manuscripts that will be published in the near future, to which we allude in the Discussion. The proposed interpretations are for the most part not speculative, but in line with cited previous studies, and/or supported by mentioned unpublished data from our group. In the few cases that we speculate (e.g., p. 19, l. 24 & l. 23), we explicitly state this.

Specific comments 1. Page 1, line 1: It's not obvious what is not well known. The introduction states that eutrophication increase TOC burial (page 3, line 9-10 and the references cited).

Answer: We kindly refer this reviewer to the rewritten final paragraph of the Introduction. We hope it is much more clear now that this study is highly novel and lacks any similar precedent.

2. Page 1, line 25: I am not sure what "zonation of microbial respiration" means.

Answer: We have rewritten this sentence. For further background on the topic of zonation of microbial respiration reactions (aka "redox zonation") we refer to p. 2, l. 21-26, along with the listed references.

3. Page 1 line 29-30 "Instead, artificial lake ventilation, which is used to prevent water column anoxia in eutrophic lakes, may help sustain high rates of TOC burial and accumulation in sediments despite strongly reduced water column P concentrations." – This is speculative.

Answer: It is clear from our data that – among the three eutrophic lakes – Lake Baldegg, which has experienced the most stringent reductions in P concentrations and has been artificially mixed and aerated for ~35 years to eliminate seasonal anoxia is the only one that has not experienced a significant decrease in TOC burial or accumulation since the period of peak eutrophication (Figure 3; p. 11, l. 27 to p. 12, l. 9; p. 18, l. 26 to p. 19, l. 31). We think it is important to mention this fact both in the Abstract and in the Discussion. If this trend holds true for other eutrophic lakes, then it is something that is important to know for management purposes.

4. Page 30 – 35: very general statement. What insights?

Answer: We assume that this reviewer was referring to the end of the Abstract (p. 1,

l. 30-35). We have replaced this statement with a more informative general summary statement.

5. Page 4, line 9- 21: I found the detail description here not necessary because Figure 1 is very self-explanatory. However, this is just a minor suggestion.

Answer: We respectfully disagree. We think this short accompanying text is necessary to highlight the most important differences in eutrophication histories between lakes.

6. Page 5, line 11-12: Was air bubbling only done in oxygenated cores or all cores (e.g., cores under anoxia water)?

Answer: Gentle air bubbling was done in all cores to prevent development of anoxic conditions and a stagnant water phase, even for the deep station of Lake Zurich, which presumably had hypoxic bottom water. This is a common practice that does not significantly affect the O2 profiles in sediments, as O2 measurements were done immediately after retrieval and were typically completed within one hour of sampling. We saw no major effect on sediment O2 profiles based on the fact that three successively measured O2 profiles at three different locations within each core were nearly identical, and did not show a time-dependent trend, e.g. an increase in O2 concentrations or penetration depth over time.

7. Page 7-8, Modeling of OC burial and accumulation rates through time: The calculation (equations) should be spelled out. It's not clear how what are calculated and how they are calculated. There seem to be multiple calculations here: 1) TOC modeled: using the surface TOC% to calculate the subsurface TOC% (based on the Middleburg power law), and comparing to measured subsurface TOC%. The purpose of this calculation is explained "…subsurface TOC% values that are higher …", but it's better to spell out the equations, etc. 2) TOC reconstructed (but is this the same as TOC accumulation rate?) : using the TOC burial rate measured at depth to calculate TOC accumulation rate in the pass when the sediment of the specific depth was deposited at surface. The purpose of this calculation is not well explained. Also, the author should

consider explaining the calculations right after introducing TOC buried and TOC accumulation rate (line 9-11, equations 4 and 5). These calculations and purpose of the calculations are important for the paper, but overall poorly described.

Answer: Thank you for this comment. We have completely revised this section of the text according to this comment (p. 8, l. 9 to p. 9, l. 7).

8. Equation 8: "n is porosity" should be mentioned here.

Answer: The authors agree and added this below the equation (P9 L14).

9. Page 10, line 15- 17: Is this based on TOC% in deeper sediments in Lakes Greifen and Zug? It's not clear.

Answer: Yes. This refers to the lowermost centimeters of the cores from Lakes Greifen and Zug (p. 11, l. 4-7), which were deposited during periods prior to the onset of eutrophication in these two lakes, have low TOC contents and are dominated by fine calcium carbonate-rich clay ("Seekreide"). This authigenic carbonaceous clay dominates sediments that were deposited prior to the period of eutrophication.

10. Page 12, line 4-6: how were rates of aerobic respiration estimated? O2 fluxes?

Answer: They were estimated based on O2 concentration gradients and O2 penetration depths. The O2 concentration gradients were generally steepest and the O2 penetration depths shallowest in eutrophic lakes. Given that these are diffusion-dominated sediments, this indicates that aerobic respiration rates were highest in eutrophic lakes. We have changed the structure of Figure 5 to make the concentration gradients of O2 (and nitrate) more clearly visible.

11. Page 12, line 15-18: Bottom water NO3 may indicate denitrification rates in the water column, not necessarily denitrification in the sediments. Bottom water NO3 concentrations affects sediment NO3 penetrations, thus NO3 penetration depth in sediments is not a good indicator for sediment denitrification either. The authors may consider calculating NO3 fluxes, which is integrated rates (mmol/m2/d) for comparison.

Answer: Yes, there certainly appears to be denitrification in the bottom water overlying the deep stations of Lake Greifen and Lake Zurich, as is stated in the text (p. 13, l. 4-7). However, there clearly also is denitrification in the sediments of all stations, or else nitrate would not be consumed within the top centimeters of sediment (see revised Figure 5). Hereby – as for O2 – the concentration gradients and penetration depths of nitrate allow us to make qualitative distinctions between the denitrification rates in sediments of different lakes. In order to make more quantitative predictions about denitrification rates (that take into account nitrification rates; nitrification appears to produce nitrate in surface sediments of several stations), it would have been essential to measure porewater nitrate concentrations at higher depth resolution. We plan to do this in the future.

12. Page 13, SO4: it may be interesting to compare SO4 fluxes at the SWI.

Answer: We agree that this would be interesting to do in one of our next studies, but it is beyond the focus of this manuscript.

13. Page 15, line 30-31 "Thus, sediments deposited during the pre-eutrophication, early and mid eutrophication periods have similar RRtotal today...": it's not clear how this conclusion is reached?

Answer: We think this is very clear based on this figure, but suspect that perhaps the text is not clear. Thus, we have added in parentheses "i.e. from 1840-1960" to explicitly which sediments have similar RRtotal, despite having very different original TOC accumulation rates.

14. Page 16, line 20-22 "Yet, even though water column P concentrations in most lakes have decreased close to pre- eutrophication levels since the _1970s, TOC burial and accumulation rates in eutrophic lakes remain significantly higher than before the eutrophication era (Figs. 3 and 4).": This is an interesting observation, and also agree with studies that show persisting high primary productivity after P reduction.

Answer: We agree.

15. Page 16, line 23-25: “Despite the increase in TOC burial, lake sediments are not a static sink for OC. Increases in TOC accumulation and burial increase remineralization by stimulating microbial respiration (Fig. 6).”: this is an interesting statement, however, quantitative estimation is needed. With increasing TOC deposition (sedimentation), the net burial of TOC (long-term burial) may still be higher compared to pre-eutrophication period, even though microbial respiration increase.

Answer: Our measurements (Figure 5) and quantitative estimations (Figures 6 and 7) show clearly that mineralization rates are higher in eutrophic lakes. Nonetheless, as stated throughout the manuscript, TOC accumulation and burial rates are also highest in the eutrophic lakes (Figures 2-4). Therefore, net mineralization rates are not high enough to override differences in the original amounts of TOC that were deposited and subsequently buried.

16. Page 18, line 25-26 “Despite the observed decreases in TOC accumulations in two of the three eutrophic lakes, our calculated TOC accumulation rates for the period after peak eutrophication have remained well above those during pre-eutrophication times (Fig. 3).”: Does primary productivity also decrease to pre-eutrophication times?

Answer: Publicly available data from BAFU data indicate a decrease but continuously high phytoplankton concentrations in the eutrophic lakes. Presumably this elevated primary productivity is a prerequisite for the continuously high TOC accumulation rates. We discuss possible drivers behind the sustained high TOC accumulation, e.g. P remobilization from sediments as a driver of continued high primary productivity, in the Discussion (P19, L. 3-31).

17. Page 19 Zonation and rates of dominant respiration processes: Rates were not quantified, and comparing zones in different sediments are less meaningful. I don’t quite understand what the authors mean by “zonation”. I suggest removing this part of the discussion.

Answer: We refer this reviewer to the Introduction section (p. 2, l. 21-26) where we introduce the concept of redox zonation and provide extensive literature on redox zonation and the underlying concepts. We especially recommend the provided references by Froelich et al. 1979, Jørgensen & Kasten 2006, Canfield et al. 2005, and Canfield & Thamdrup 2009.

The purpose of our analyses was not to quantify rates of different redox reactions, but to investigate their distributions with respect to each other. It is a central (yet contested) dogma in the field of sediment biogeochemistry that microbial respiration reactions are separated into zones based on the energetically most favourable available electron acceptor. Most past studies investigating this dogma have focused on marine sediments. We wanted to determine if it applied to lacustrine sediments, and if trophic state, due to its effects on electron donor availability (TOC), has an impact on redox zonation. Our results indicate that there is no clear separation of dominant respiration reactions into "redox zones" in any of the lakes. This is an important finding for our understanding of what controls (or does not control) the distribution of OC terminal mineralization reactions.

Please also note the supplement to this comment:
https://www.biogeosciences-discuss.net/bg-2019-108/bg-2019-108-AC2-supplement.pdf

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