## Author revision notes to *Biskaborn et al.: Diatom responses and geochemical feedbacks to environmental changes at Lake Rauchuagytgyn (Far East Russian Arctic)*

## Referee #2

## General comments to the Author

This manuscript explores past environmental changes during the last 29k years based on diatom and geochemical records of a well-dated lake sediment core in Chukotka, which is a less investigated region. The results are interesting, particularly the relationships between diatom accumulation rates, organic carbon accumulation rates and mercury accumulation rates. I have one major concern on the driving force on diatom flora shifts (see details as follows). I suggest that this manuscript can be acceptable after major revions.

Major concern:

Although authors have provided potential driving forces for diatom flora shift, the mechanism is still ambiguous. The major trends in diatom flora are that an increase in benthic species during the early Holocene, and then the gradual replacement of benthic taxa by planktonic species. This general trend might be closely linked to temperature- driven changes in ice-cover period. For example, short ice-cover period in the early Holocene promote light penetration and the availability of littoral habitats.

In addition, effects of DOC on diatom flora should be considered during lake ontogeny since the deglaciation. DOC can be an important resilience against from external driving forces.

Some references might be useful

Engstrom, D. R., et al. (2000). "Chemical and biological trends during lake evolution in recently deglaciated terrain." Nature 408(6809): 161-166.

Hu, Z., et al. (2018). "The Landscape–Atmosphere Continuum Determines Ecological Change in Alpine Lakes of SE Tibet." Ecosystems 21(5): 839-851.

Chen, X., et al. (2018). "Direct and indirect effects of Holocene climate variations on catchment and lake processes of a treeline lake, SW China." Palaeogeography, Palaeoclimatology, Palaeoecology 502: 119-129.

Wischnewski, J., et al. (2011). "Terrestrial and aquatic responses to climate change and human impact on the southeastern Tibetan Plateau during the past two centuries." Global Change Biology 17(11): 3376-3391.

I suggest that authors could clarify the major underlying driving forces of diatom flora shifts, specify the meanings of PC1 and PC2.

**Author final response**

**Dear Reviewer #2**

Thank you very much for taking your time to review the manuscript. We are grateful for the comments you provided to ecology and environmental interpretation of diatom community shifts. We find that your comments on the increase of benthic species in course of changing ice cover period in the Early Holocene fits well into our discussion that was focused on stratification. We extended our discussion taking into account the ice-cover related mechanisms as well as DOC as a factor driving diatom species changes. We also included the literature you recommended while doing so. We added: “*Over the deglaciation period, in parallel to development of catchment vegetation, the lake ontogeny was likely driven by changes in the load of dissolved* *organic carbon (DOC). As shown in lake evolution studies (Engstrom et al., 2000), young lakes in freshly deglaciated terrain have low DOC and rather alkaline conditions, which is reflected by the benthic species assemblage in the record, such as fragilariod species successively accompanied by Encyonopsis descriptiformis and Brachysira neoexilis."*

We also used the PCA, i.e. PC1, to explain the major change at the Pleistocene-Holocene boundary (from planktonic to benthic taxa). The revised discussion of underlying driving forces of diatom shifts is now in accord with the PCA results as suggested: "*The P/H is also characterized by a distinct increase of the first axis sample scores of the PCA (Fig. 8) pointing to the most prominent increase benthic diatom taxa in the record. The PCA biplot depicts grouping of planktonic Lindavia versus benthic Staurosira and Psammothidium species along the primary axis while Aulacoseira species are oriented along the secondary axis (Fig. 7). This general shift to benthic communities can be explained by temperature-driven changes in the duration of the ice-cover period. Longer open-water seasons in the Early Holocene promote light penetration and the availability of littoral habitats, while input of DOC and nutrients enhances benthic production in the littoral zone (Hu et al., 2018; Engstrom et al., 2000).*"

And in the last sentence of the discussion: *"This is amplified by the fact that boreal lakes have either already passed important ecosystem thresholds, or are about to exceed ecological tipping points upon further warming (Wischnewski et al., 2011) and are believed to not represent pristine ecosystems anymore (Smol et al., 2005)."*

Referee #2

Other minor revisions:

1) L31-32: the responses to climate events are not very clear, probably due to low resolution of diatom records

Thank you for the comment. We agree and changed to "moderate responses". We think that this wording reflects the signals in the diatom record, fitting well to the age model and what is known from climate history in the region.

2) L33-34: 'human-induced environmental change', please specify, atmospheric deposition?

Thank you for the comment. We agree, better to make this clear, we changed the sentence to: "The short core data likely suggest recent change of the diatom community at 1907 CE related to human-induced warming but only little evidence of atmospheric deposition of contaminants."

3) L34-35:C/N ratios are generally larger than 10 during the Holocene, suggestive of the mixture of within lake production and terrestrial organic matter. Therefore, it should be cautious to draw this conclusion.

Thank you. We visited this lake and know that there is very little terrestrial catchment vegetation. However, you are right that the data alone cannot prove it. We therefore reworded to be more precise in this statement: "*Significant correlation between DAR and OCAR in the Holocene interglacial indicates within-lake* *bioproduction represents bulk organic carbon deposited in the lake sediment.*" Furthermore we checked the related statement in the conclusion and find that it is still correct as is.

4) Section 2 Study site: Please provide more details on aquatic plants in this lake. Are there macrophytes or mosses around the lake shore? This is important to explain the development of benthic diatoms during the Holocene. In addition, water chemistry data should be provided, such as pH, conductivity, and dissolved organic carbon,

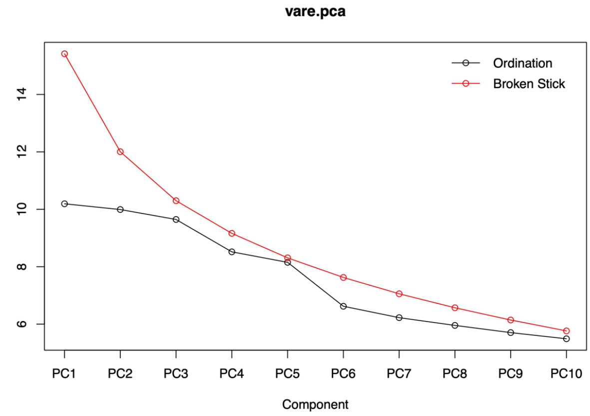
Thank you for the statement. Unfortunately, we have no reliable information on the water plants from our coring expedition and cannot visit this lake again, as it is located in the Far East Russian Arctic. However, we have the water chemistry data that you requested and provided it in the supplementary material to the paper. We also added the main hydrochemical preferences of the lake in the study site chapter: "*Hydrochemical data from July 2018 (supplementary material S2) showed that the lake water had dilute freshwater with low conductivity (85.5 µs cm$^{-1}$), medium transparency (secchi depth 3.9 m), slightly alkaline conditions (pH 7.8), and low dissolved organic carbon (0.9 mg L$^{-1}$)*".

We also used the values in the discussion of the core record:" *As shown in lake evolution studies (Engstrom et al., 2000), young lakes in freshly deglaciated terrain have low DOC and rather alkaline conditions, which is reflected by the benthic species assemblage in the record, such as fragilariod species successively accompanied by Encyonopsis descriptiformis and Brachysira neoexilis. Modern DOC measured in July 2018 (0.9 mg L-1) clearly below the global lake average of 3.9 mg L−1 (Toming et al., 2020) together with other hydrochemical parameters (supplementary table S2) indicates an overall dilute and alkaline lake system, suggesting even depleted conditions in the past.*".

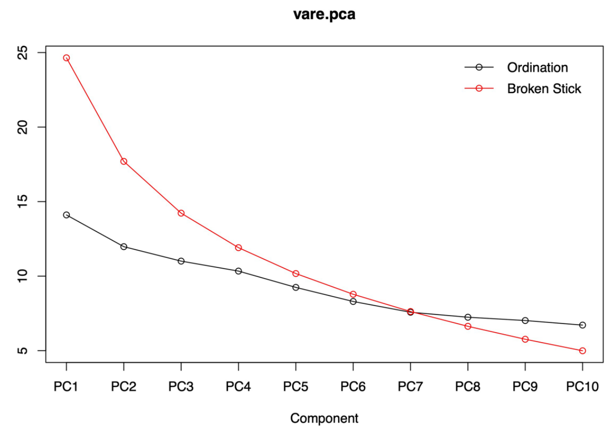
5) Section 3.5 Data processing and statistics: L 173, generally, square-root transformation of percentage data were used in CONISS, please check. In addition, the number of zones should be tested by the broken stick model (Bennett, 1996).
Bennett, K. D. (1996). "Determination of the number of zones in a biostratigraphical sequence." New Phytologist 132(1): 155-170.

Thank you for the comment. We agree and re-performed the CONISS analyses for both cores based on percentage data. The results are slightly different (in terms of values sum of squares and neighboring pairs) from the previous zonation gained from count data, but did not change the attribution of zonation.

Following your advice we tested the broken stick statistic for the long core




And also applied it to the short core




However, we doubt that – in this case – the broken stick analysis provides valuable information on the number of useful CONISS zones. We assume that the hierarchical clustering and stratigraphical constrained order of zones causes complications for this statistical method. We describe that we use the CONISS clustering as a "guide" to establish the zones. But the number of zones (or possible sub-zones) is given by the entire 'holistic' view on the data and the known chronological variability in the region, i.e. is done by us as the authors. The precise selection of boundary is still following the CONISS analysis, and we are grateful for your comment that surely made it even more solid (using the percentage data and checking for the broken stick behaviour in the data set). We modified the text in the method section accordingly: *"To create diatom zones along the cores we used the package 'rioja' for constrained incremental sums-of-squares clustering (CONISS) based on Bray-Curtis dissimilarity after log transformation of all percentage data to downweigh abundant species (Grimm, 1987). Attribution of diatom zones are guided by CONISS results and shifts of relevant indicator variables in relation to meaningful chronologies in the region (Andreev et al., 2021; Anderson and Lozhkin, 2015; Andreev et al., 2012)."*

6) L243-246, please check the units of DVC and DAR, superscript should be used.

Thank you for finding this typo. We corrected it.

7) L330-331: thick ice due to long ice-cover period probably reduces light penetration?

Thank you. Yes, we agree that this also is a mechanism supporting low abundancy of benthic taxa. We added this to our interpretation: "*Low abundance of benthic diatoms may result from thick ice due to long ice-cover periods and reduced light penetration, as well as in-wash of clay during deglaciation (Vyse et al., 2021) leading to low-transparent and narrow littoral zones in an overall deep basin.*"

8) L339-340: more detailed explanation for the linkage between diatom flora shift and climate. During this stage, the major change is the disappearance of Linvidavia bodanica and L. cyclopuncta

Thank you for the comment. We agree and added a more detailed explanation:" *Corresponding to the Younger Dryas (YD) period our diatom data show disappearance of L. bodanica and L. cyclopuncta but relative increase of heavy Aulacoseira valves (Fig. 5 and 8) indicating to turbulent water conditions. Complex diatom responses within the YD associated with increase of Aulacoseira species have been found in Lake Baikal (Mackay et al., 2022). In many boreal lakes YD cooling weakened lake thermal stratification leading to turbulent conditions resulting in similar diatom responses as observed in Lake Rauchuagytgyn (Neil and Lacourse, 2019).*".

9) L354-355: rising alkalinity might be linked to enhanced chemical weathering intensity of bare rocks under warmer and wetter climate during the early and mid-Holocene

Thank you. We agree and modified this sentence to: "*Increased chemical weathering of bare rocks during warmer and wetter interglacial conditions, and the development of roots (Andreev et al., 2021) in fresh soils, all led to enhanced ion supply (Herzschuh et al., 2013) and eventually increased alkalinity of the lake water.*"

10) L371: the influx of melted water during the spring and summer probably increase the mixing?

Thank you. We agree and modified this sentence to: "*Early ice-out, the influx of melt water during spring and summer associated to increased and longer spring circulation supported Aulacoseira species (Horn et al., 2011) and led to a distinct change in the Rauchuagytgyn species assemblage.*".

11) L396: Here, potential effects of nitrogen deposition?

Thank you. Yes, we added a sentence in this paragraph:" *As a pennate planktonic diatom, Tabellaria often responds with increased abundancy to atmospheric nitrogen deposition (Rühland et al., 2015), corresponding to increased nitrogen levels between 1970 and 1980 CE (Fig. 9).*"

12) L488-489: prolonged ice-free period increases the availability of littoral habitats

Thank you. Yes, according to our modification of the discussion we changed this paragraph in the conclusion to:" *The Early Holocene diatom community reflects a shallower lake with larger littoral zones and higher alkalinity that we relate to prolonged ice-free periods and vegetation development in the catchment, supported by high carbon to nitrogen ratios.*"

13) Figure 7: legends for the two figures are needed, depths can be changed to 'ages'

Thank you for the advice. We agree and added a legend that explains the symbols and colors used, i.e. attributing chronologies to the samples shown.

14) Figure 8: for the total percentage of light Lindavia, L. bodanica might be different from other species, since this taxon has relatively heavy valves, which are similar to some Aulacoseira species (see the review by Saros and Anderson, 2015, The ecology of the planktonic diatom Cyclotella and its implications for global environmental change studies).

Thank you for the hint. We knew about this before and this was why we did not include *L. bodanica* in the group of "light *Lindavia*", it was and is just represented as single species percentages.