First round of review

RC1: 'Comment on egusphere-2025-5053',

Anonymous Referee #1

27 Jan 2026

Shoreline exposure controls teal carbon accumulation in boreal lakes

This study entitled "Shoreline exposure controls teal carbon accumulation in boreal lakes" presents valuable insights into soil carbon accumulation in teal carbon environments of boreal lakes. Through a large soil core sampling, the authors quantified sediment organic carbon stocks in shallow vegetated areas of Finland Lakes and identified the main biotic and abiotic parameters controlling these stocks. Additionally, authors compare lake SOC stocks with those of freshwater and marine environments to assess the relative contribution of boreal lakes in teal carbon accumulation. The introduction is logically constructed, and the study's objectives are clear. The authors have made efforts to use statistical tools to highlight the main biotic and abiotic drivers controlling SOC stocks. The manuscript is well written, the results are well presented, and the organization is coherent. The manuscript clearly falls within the scope of the target journal, but several aspects of the analysis, presentation, and interpretation require strengthening before it can be considered for publication.

Reply: *Thank you for the constructive review. We attempted to improve the data analysis and its interpretation. The detailed modifications are described below.*

Introduction

Part of the introduction discusses carbon sequestration in freshwater wetlands, whereas your study focuses on the shallow littoral areas of Finnish lakes. Did you take sediment samples from lacustrine wetlands?

Reply: *For this manuscript, we analysed samples only from sediment cores retrieved from the shallow littoral areas.*

Materials and Methods

90-92. Please specify whether the sampled lacustrine zones (i.e. the shallow vegetated littoral zone, called teal carbon environments) represent large or weak surfaces on the scale of the lake.

Reply: *We calculated estimates of how much these shallow vegetated littoral areas represent of each lake and added the values to Table 1.*

96. What is the trophic state of the Oulujärvi lake? Could you explain in more detail why you chose these three lakes?

Reply: *Oulujärvi is dysoligotrophic, and we will include this information in the text (line 98). We chose these lakes because we had evidence of the existence of large shallow vegetation patches and because they have been sampled before for other projects. So, there is data regarding their overall water and sediment quality. However, we focused on areas that had less sampling coverage based on existing data and covering different regions (sub-basins) of each lake.*

110. If surficial deposits influence OC accumulation, then add this information to Table 1 by adding a row to better distinguish the variability between the lakes.

Reply: *The surficial deposits around each lake will influence the type of sediment found in each lake, which we found that is a key factor influencing the OC accumulation. We added this information in Table 1.*

123-126. You can add in parenthesis the range of the standing water depth for each shoreline zone to better distinguish your three sampling areas. From 0.15 to 0.60 m in the landside zones, from 0.29 to 1.13 m in the transitional zones and from 0.37 to 1.23 m in the waterside zones (from Table S2).

Reply: *We added this information as suggested (lines 135 to 140).*

179. There is an inconsistency between the text (L174-178) and equation 4a. TOC inventory for a given sample [g] was calculated multiplying the TOC content [%] by the DBD [g cm-3] and the sample volume [cm3]. However, in the equation 4a, TOC inventory is: (TOC x DBD x depth) x 1000.

Reply: *We corrected the formula (lines 192 to 194). The correct parameter is sample volume, and not only sample depth.*

Results

Figure 3. Could you add the Tukey test results in the graphs using letters (and the number of samples per group)? Same comment for the figure 5.

In the figure 3, can you add below two other boxplots for TOC distribution grouped by lakes and shoreline zones?

Reply: *We made the suggested modifications (see Figures 3 and 5).*

247. Could you add in parenthesis the shoreline zone and grain size class for the minimum and maximum values of SOC stocks?

Reply: *We added the information as suggested (lines 283 and 284).*

249-254. Could you provide the results of the ANOVA tests for the comparison between lakes and shoreline zones?

Are you able to provide a more accurate statistical analysis in order to rank the contribution of different environmental predictors (lakes, shoreline zones, plant species and grain size class) to SOC stocks using a multiple factor analysis of variance per example?

The results of the generalized linear model can be added to the manuscript (table S6) to strengthen your findings.

Reply: *We added the ANOVA results, including from the multiple factor analysis, in the Supplementary Material (Tables S3 and S4). We moved the results of the GLM to the main text (Table 3).*

Discussion

285-287. The strong relationship between TOC content and grain size is the first clear finding in your study and this deserves to be included as a figure. I suggest that the authors insert Figure S23 into the manuscript, probably near the Figure 3. Can you study this relationship in more detail using a non-linear equation?

Reply: *We included the plots of Figure S23 in Figure 3, making it a 6-panel figure, and also included a gamma regression line in the plots.*

297-298. This statement is not very detailed and deserves further discussion.

Reply: *We improved the explanation of the effect of water regulation on sediment input to Oulujärvi (lines 339 to 345).*

300. I encourage the authors to complete this sentence in order to provide greater precision. "As pointed out by Tangen and Bansal (2020) in inland freshwater wetlands, SOC stocks are highly variable ..."

Reply: *We modified the text as suggested (line 347).*

302. Please replace "ranging from zero to more 40 kg m-2 " by "ranging from 0 to 40.8 kg m-2 " for more precision.

Reply: *We modified the text as suggested (line 349).*

303. To tie in with the previous paragraph, please indicate that fine-grained sediments are rich in organic matter such as: "Several environmental parameters could influence the entrapment of organic-rich fine-grained sediments, such as...".

Reply: *We modified the text as suggested (line 350).*

309-311. The strength of this statement is not fully supported by your data. From a statistical point of view, we can observe significantly higher SOC stock values without Phragmites compared to the Phragmite group in the Figure 5-e. We can observe this statistical result in the Table S5 and in lines 249-250-251. The type of vegetation is probably not a major factor in SOC stocks compared to sediment size, but you cannot ignore it.

Reply: *We understand the reviewer comment. We did not put too much emphasis on the relationship between the vegetation type and SOC stocks because the 2nd and 3rd highest SOC stocks were observed in sites with Phragmites even though the median is much lower. But we will modified the text to reflect that the vegetation might have an impact of SOC accumulation (lines 357 to 360).*

313-317. Please provide means and standard deviations of SOC stocks for average fetch length < 500 m and for average fetch length > 500 m to strengthen your statement. Please specify whether the trend is similar for SOC stocks (0-20 cm).

Reply: *We modified the text as suggested (line 363 to 367).*

319-320. Please add here that vegetation density plays a significant role in SOC stocks in exposed conditions (c.f., figure S25).

Reply: *We modified the text as suggested (lines 370 to 373).*

339- 345. Please clearly conclude concerning the effects of bathymetry and shoreline's slope on SOC stocks. Have you tested the influence of bathymetry, shoreline's slope and stem density on SOC stocks in conditions where the shoreline is protected (average fetch length < 500 m)?

For each lake, you present the ecological status, the main land use type and the main anthropogenic pressures (Table 1). Do these factors influence the grain size distribution and the lake SOC stock?

Reply: *We added a clear conclusion about the effects of bathymetry and shoreline's slope on SOC stocks (lines 406 and 407). We did not test their influence in only protected sites because the sampled "n" would be too small (only 3 sites, with their zones) to make any inference with confidence.*

Regarding the ecological status, the main land use type and the main anthropogenic pressures, they probably don't play a significant role in controlling grain size distribution in these teal carbon environments. If they did, we would have seen significant differences between the lakes but not between the sites within each lake, what did not happen (Figure 4).

375-410. The authors have correctly compared their results with SOC values from freshwater marshes, coastal lagoons, and blue carbon environments in marine areas. However, the authors should also compare their results with similar studies in lakes worldwide. Could the difference in magnitude be related to a difference in sampling strategy? Please discuss the inclusion of shallow vegetated coastal areas in the organic carbon stocks of lakes. Please discuss the importance of sampling shallow coastal areas of lakes in order to obtain a realistic estimate of organic carbon stocks, unlike certain studies that have conducted sediment core sampling in the deepest part of the lake.

Reply: *Because the focus of this research was on vegetated areas, we preferred not to compare with data from deeper areas of lakes, as it would lead to a whole new discussion about the controlling factors affecting both areas. But we emphasized the importance of shallow areas to obtain realistic lacustrine OC stock estimates (lines 469 to 471).*

RC2: 'Comment on egusphere-2025-5053',

Anonymous Referee #2

26 Feb 2026

This manuscript represents a timely contribution to the journal. Freshwater wetlands along shorelines ("teal carbon" ecosystems) remain underrepresented in continental carbon budgets, despite growing recognition of the importance of inland waters in global carbon cycling. By quantifying sediment organic carbon (SOC) stocks across boreal lake shorelines and identifying shoreline exposure (fetch length) and sediment grain size as primary controls, the study provides insight into the spatial variability in carbon storage.

While the dataset is geographically limited (three Finnish lakes), the study helps in understanding process-based controls and offers transferable implications for carbon budgeting in lake-rich boreal regions. The sampling framework (27 sediment cores across lakes, sites, and shoreline zones) is appropriate for examining small-scale spatial variability.

A notable strength is the explicit evaluation of environmental predictors (vegetation density, water depth, slope, fetch), with average fetch length emerging as the strongest predictor of SOC stocks. The discussion presents results in the context of existing literature on fine-grained sediment controls, wave energy, and wetland carbon storage. One limitation of the study was the inability to establish sediment accumulation rates because the ^{137}Cs profiles were unclear, leading to reliance on stock estimates rather than burial rates. The authors acknowledge this clearly and interpret shoreline zones as areas of temporary storage rather than permanent sinks, however, some additional discussion of temporal stability and implications for long-term sequestration would enhance the manuscript.

Reply: *Thank you for the constructive review. We clarified and improved the discussion regarding long-term C sequestration (lines 245 to 250). The detailed modifications are described below.*

Other Improvements could include:

- Tightening the discussion to reduce repetition regarding grain-size controls.
- ***Reply:*** *We revised the discussion, but we kept the focus on grain-size control since it was one of the main results of this study.*
- Clarifying the distinction between carbon "storage" and "long-term sequestration," the latter may not be an appropriate term here given the lack of accumulation-rate estimates.
- ***Reply:*** *We avoided the terms "long-term" and "sequestration" when discussing our data.*

Because the ^{137}Cs profiles could not be used to estimate C accumulation rates and suggest sediment mixing, the authors should be clear that long-term accumulation is not reported (e.g., line 213).

Reply: *We clarified it and avoided the term "sequestration" whenever possible.*

Fetch length was found to be the strongest predictor of SOC stocks. The authors might consider including a simple conceptual diagram summarizing the exposure → wave energy → grain size → SOC pathway.

Reply: *We made a conceptual diagram summarizing this idea (Figure 8).*

Finally, and in light of the goals of the paper, the authors might consider adding discussion on how these site-level findings scale to regional boreal carbon budgets, and whether sheltered shoreline areas can be mapped remotely to upscale SOC estimate

Reply: *We added a few sentences explaining how these findings can be used to upscale SOC estimates (lines 474 to 478). However, we prefer not to discuss it in much detail as this is outside the scope of this manuscript, and we are currently investigating it in further work.*