Reviewer 2

In their manuscript *Sea level rise in a coastal marsh: linking increasing tidal inundation, decreasing soil strength and increasing pond expansion*, Schepers et al. highlight an interesting mechanism – previously demonstrated experimentally – by which sea level rise and associated increases in tidal inundation may promote pond expansion and reduce vegetated marsh area via declines in soil strength, likely driven by reduced belowground biomass. I found the manuscript engaging and generally well written. However, I have several major and minor comments that I strongly encourage the authors to address. In particular, the observational nature of the study – and its inherent limitations – along with the analytical approach, require clearer justification and discussion.

We would like to thank the reviewer for the very insightful and critical comments on our manuscript. We have tried to include them in the manuscript.

MAJOR COMMENTS

1) The study is observational and conducted in a specific system (microtidal marsh with organic-rich soils), which limits causal inference. This is important to emphasize when comparing with other marsh types and when interpreting findings. Please add a paragraph in the Discussion outlining the study's limitations and potentially suggesting next steps. For instance, in L121-122, while site-specific elevation is acceptable, elevation-driven variation may influence soil strength. Unlike experimental approaches that isolate variables, your study interprets a natural gradient with inherent co-variation. This is valuable, but should be framed as such.

Thank you for the valuable comment. We have integrated your valid point into our discussion to highlight the observational nature and site-specific nature of our study and associated limitations:

Line 306-310: "Our study is to our knowledge the first providing direct empirical evidence of the relationships between increasing tidal inundation (induced by sea-level rise) , decreasing soil strength, and increasing marsh to pond conversion. Our study is observational and conducted in a specific system (a micro-tidal marsh with organic-rich soils), which intrinsically limits drawing generalized conclusions and causal relationships. While we do acknowledge such limitations, this does not take away that the relationships that we observe are there. Moreover, our findings are in line with other studies, ~~confirmed by similar studies, Although no previous studies a field gradient of increasing marsh to pond conversion exist, there are recent studies that demonstrate relationships between marsh soil strength and tidal hydroperiod,~~ based on marsh locations along a gradient from low to high marsh. For instance, Jafari et al. (2024) and Stoorvogel et al. (2024; 2025) found a decrease in marsh soil strength with increasing tidal hydroperiod along a field gradient from low to high marsh locations."

Further we have added the limitations you mentioned in the text where they apply.

On the use of shear vane measurements. Line 316-319: "Our first main finding is the increase in marsh shear strength (Fig. 3b) and penetration resistance (see Appendix, Fig A2) with increasing belowground vegetation biomass. This can be partly explained by the methodological choice of using a shear vane for soil strength measurements, since roots can be expected to directly affect the shear vane measurements (Brooks et al., 2023)."

On the space-for-time substitution. Line 350-352: "Of course, since we are using a space-for-time substitution, there could be other differences between sites (such as salinity and tidal range) that could influence the vegetation belowground biomass production, however given the agreement of our results with these previous findings, we believe that this effect is limited."

2) Your replication is at the site level, but the 5 locations within sites are treated as independent replicates. Thus, your statistical inference (but see Comments 3 and 4) is confounded with site. While I recognize the logistical constraints of field ecology, please acknowledge this in your limitations section (see Comment 1) and clarify the implications for interpreting your results.

Thank you for the valuable advise. We have changed our statistical analysis to linear mixed models, to include the random effect of site. See also response to comment 3 and 4.

3) There is no dedicated paragraph describing your statistical analysis. Readers need a clear overview of how hypotheses were tested, which variables were used, whether data were averaged, and which models were applied. Please add a paragraph detailing your statistical approach.

Thank you for the very valid suggestion. We have added a paragraph on the statistics:

Line 189-196: "2.5 Statistical analysis

The effect of hydroperiod on shear strength and belowground biomass was analysed using linear mixed models (LMM), using field site as a random effect to account for within site clustering. A separate LMM analysis was performed to evaluate the influence of organic matter content, bulk density, water content, hydroperiod and belowground biomass on shear strength, again incorporating field site as a random effect. The differences in bulk density, water content, organic matter, shear strength and belowground biomass between sites were analysed using pairwise Wilcoxon rank sum test with Bonferroni correction. All analyses were executed in R (R core team, 2022), using the lme4 package (Bates et al., 2015) for the linear mixed models. The p-value threshold used is 0.05. "

4) Related to the above: while correlation may be suitable for Fig. 3, hydroperiod is unlikely to be a response variable influenced by belowground biomass or soil strength. Therefore, regression would be more appropriate to suggest directional relationships in Fig. 2. If you intentionally chose correlation, please explain why. See also Comment 3 regarding the missing statistical analysis section.

Thank you for the advice. We have changed the statistical analysis from only correlation testing to also include linear mixed models (see response above).

RELATIVELY MINOR COMMENTS

5) L14: Replace "method" with "mechanism"; rephrase the sentence accordingly.

Thank you for the suggestion. We have changed the word.

Line 14: "Here, we propose another ~~method~~ mechanism..."

6) L14 and L51: Define "soil strength" clearly at first appearance in both the abstract and main text.

Thank you for the valuable suggestion. We have added a more detailed explanation on what is meant by "soil strength" both in the abstract and the main text.

Line 14-15 “Here, we propose another ~~method~~ mechanism between sea-level rise, increasing marsh inundation, and decreasing marsh soil strength (approximated here as resistance to shear and penetration stress),...”

Line 55:“...we investigate the hypothesis that the marsh soil strength (measured as resistance against shear and penetration stress)...”

7) L69-70: Clarify what is meant by "stable marsh system." Do you mean a system not subject to sea level rise?

Thank you for the suggestion. We have changed the text as such:

Line 72: “This relationship was however quantified in a ~~stable~~ marsh system without signs of degradation as a result of sea level rise”

8) L70: The phrasing suggests a direct link between soil strength, marsh loss, erosion, and pond expansion. Please revise to reflect the uncertainty of these associations.

Thank you for the suggestion. We have changed the sentence as such:

Line 78: “Our analysis ~~shows clear~~ suggests relationships between...”

9) L72: "Microtidal" should be hyphenated or not consistently throughout. Ensure consistency in terminology across the manuscript.

Thank you for noticing. The non-hyphenated version has been used throughout the whole text.

10) L82-84: Rephrase this section to introduce the experimental design first (number of sites, selection criteria) before referring to site numbers.

Thank you for the valuable suggestion. After all we have removed the mentioning of site numbers:

Line 86-87: “The mean tidal range decreases from 63 cm at Fishing Bay (bottom right of Fig. 1a) to 6 cm at Lake Blackwater (top left of Fig. 1a)”

11) L88-93 (Figure caption): (1) Capitalization of letters should match figure; (2) use "panel" instead of "figure" for subplots; (3) explain the inset; (4) clarify data source for marsh loss values.

Thank you for the suggestion. The caption has been changed accordingly.

Line 92-98: **Figure 1: a~~A~~: Aerial images of the Blackwater marshes (black: water, light grey: marsh) with sampling locations (Copernicus – Sentinel data [2025]. Retrieved from Google Earth Engine, processed by ESA). The marsh loss (i.e. proportion of shallow open water ponds to total marsh area) is quantified for each site based on Schepers et al. (2017) ~~as 2% for site 1, 11 % for site 2; 33 % for site 3 and 58 % for site 4~~. The inset map shows the location of the Blackwater marshes in the Chesapeake Bay. The green box is the extent of panel ~~figure~~ ~~B~~ b. ~~B~~ b: pond locations (white) sampled at site 4. Values in the legend of (b) refer to the average pond diameter in each category. The yellow box is the extent of panel ~~figure C~~ c. c~~C~~: marsh locations at the 58 % marsh loss site ~~site 4~~ with (green) and without (yellow) vegetation.**

12) L97-98: If you use cardinal directions, mark them on the figure. Otherwise, use terms like "left" or "right."

We added a northern arrow to the map to resolve this issue.

13) L104: Acknowledge limitations of space-for-time substitution briefly here and expand in Discussion (see Comment 1).

Thank you for this valuable comment. We have added some nuance on the space-for-time substitution in the discussion:

Line 350-352: "Of course, since we are using a space-for-time substitution, there could be other differences between sites (such as salinity and tidal range) that could influence the vegetation belowground biomass production, however given the agreement of our results with these previous findings, we believe that this effect is limited."

14) L125: Instead of using site numbers, use ecologically meaningful descriptors, e.g., "high-inundation site."

Thank you for the valuable addition. We have changed the site numbers to the % marsh loss for each site as follow:

' 2% marsh loss site

11 % marsh loss site

33 % marsh loss site

58 % marsh loss site

lower elevation site

bare patches site'

15) L128: Clarify the phrase "5 in each of four categories". This was initially unclear. Introduce categories earlier.

See reply to comment 16 below.

16) L134-135: Remove sentence about north/south pond sampling. It's not in Fig. 1B and feels out of context. This should be explained later when reporting on data collection.

Reply to 15 and 16 combined: Thank you for two valuable suggestions. We have changed the order to first specify the categories of ponds and then state how much ponds of each category were sampled. We do believe that stating the north and south sampling at the ponds fits in the section of the sampling design, but we have removed the reference to Fig. 1b as it indeed might not be very clear there:

Line 135-143: "Additionally, we ~~selected 20 ponds (five in each category)~~ categorized ponds into four pond classes (Fig. 1b), ... Five ponds of each category were selected for sampling and for each pond, the north and south side was sampled."

17) L150: Clarify what "marsh point" means. Was there one measurement per location (n=20), or five per location (n=100)? Specify.

You are correct that it isn't very clear this way. We have added a clarification of which points are meant between brackets:

Line 158: "At each ~~all~~ marsh point (five plots in the 2 %, 11 % and 33 % marsh loss site and 17 in the 58 % marsh loss site),..."

18) L158: You sampled soil strength to 30 cm but only harvested biomass to 15 cm. Explain this methodological choice.

Thank you for this suggestion. The shear vane soil strength was measured at the top of the profile (0-10 cm) to investigate the relationship between soil shear strength and the amount of belowground biomass. The 30 cm measurement was assumed to be below the rooting depth of Schoenoplectus americanus, as to try and see the effect of belowground biomass on the soil shear strength. This assumption has also been verified in a field campaign for a different study in this area, where we noticed roots were hardly present anymore at deeper depths. We have also clarified this in the methodology.

Line 159-160: "...we measured the shear vane soil strength just below the soil surface (within the rooting zone) and at 30 cm below the soil surface (below the ~~within~~ rooting zone)

19) L162: Again, clarify what "each point" refers to (see Comment 17).

Thank you for the suggestion. We have added a clarification of which points are meant between brackets:

Line 169: "At the marsh locations (five plots in the 2 %, 11 % and 33 % marsh loss site and 10 in the 58 % marsh loss site ~~not ponds~~), soil cores..."

Line 174: "At each point (five plots in the 2 %, 11 % and 33 % marsh loss site and 17 in the 58 % marsh loss site),..."

20) L174: Use consistent past tense throughout the Results.

Thank you for noticing our inconsistency. The results section has been adapted to be in past tense.

21) L170-171: Briefly describe what red, white rhizomes, etc., are rather than only citing a source. What do they signify ecologically?

Thank you for the valuable suggestion. We have added this sentence to specify a bit more what the ecological significance is:

Line 184-186: *"*The different biomass fractions are characterised by differences in chemical composition (e.g. lignin content and C/N ratio), which has an effect on the decomposition rate (Saunders et al., 2006; Scheffer & Aerts, 2000).*"*

22) L177-178 and Table 1: Clarify how hydroperiod (% inundation) was measured and whether values vary within sites. Add standard deviations for variables with within-site variation, as in Table 2. Also, this statement cites Fig. 2, which shows biomass, not hydroperiod, so the reference may be misplaced.

In the method section, there is a part on the water level time series:

Line 150-152: "Further, we calculated for each sampling location the duration of tidal inundation (further referred to as the hydroperiod) as the % of time that the water level is higher than the soil surface elevation of the location (Table 1)."

We have added the standard deviations of the elevation and hydroperiod in the table.

Table 1: Overview of properties of the field sampling locations (Fig. 1): number of samples per location, mean surface elevation (m above local mean sea-level (m amsl)), tidal range (m), and hydroperiod (% of time that a location is inundated by tides). The numbers in the pond location categories refer to the average diameter of the ponds.

Sampling location	Vegetation present?	Number of locations (n)	Mean elevation (m amsl)	Hydro-period (%)	Mean tidal range (m)
Marsh locations:					
2% marsh loss site	Yes	5	0.35±0.006	29.4±0.82	0.63
11 % marsh loss site	Yes	5	0.16±0.007	54.3±1.43	0.31
33 % marsh loss site	Yes	5	0.12±0.005	58.2±1.60	0.20
58 % marsh loss site	Yes	5	0.11±0.002	73.7±0.93	0.06
, Lower elevation site	Yes	5	0.07±0.014	86.5±3.66	0.06
Bare patches site	No	7	0.04±0.031	91.7±5.29	0.06
Pond locations:					
<10 m, unconnected ponds	No	10	-0.06±0.027	100	0.06
10-20 m, unconnected ponds	No	10	-0.08±0.059	100	0.06
>20 m, unconnected ponds	No	10	-0.08±0.068	100	0.06
>20 m, connected ponds	No	10	-0.21±0.115	100	0.06

Figure 2 shows the relationship between hydroperiod and biomass on the left, so we do believe the reference here is placed correctly.

23) L186 and L191: For L191, correlation makes sense when focusing on sites 2-4. For L186, correlation across all sites obscures the non-linear relationship (increase then decrease across hydroperiod). Suggest describing the pattern visually instead and removing the correlation. Please, see my Comment 4 as well.

Thank you for the valuable suggestion. We have changed the text to remove the correlation and described the pattern visually and mentioned that the linear mixed models gave no significant effect:

"Even though the regression analysis indicated no significant effect of hydroperiod on belowground biomass nor shear strength (p=0.31 and p=0.24 respectively), our ~~results~~ graphs seemed to indicate~~d~~ that the hydroperiod has ~~a strong control~~ an influence on the belowground biomass ~~(Pearson's correlation r=-0.51, p<0.05)~~ (Fig. 2a) and the shear vane soil strength (Fig. 2b) of the marsh topsoil samples (0-15 cm soil depth). There was an increase in belowground biomass and soil strength from locations at the 2 % marsh loss site (with the lowest hydroperiods around 30 %), to the 11 % marsh loss site 2 (with intermediate hydroperiods around 55 %), followed by a decrease from the 11 % marsh loss site to the lower plots of the 58 % marsh loss site (with highest hydroperiods up to >90 %). For hydroperiods ranging from 55 % up to more than 90 %, the shear vane soil strength of the topsoil decreased systematically with increasing hydroperiod ~~(Pearson's correlation r = -0.83, p <0.001)~~ (Fig. 2b)."

24) Figures 2 and 3: Why are correlation lines and Pearson coefficients shown only in Fig. 3? Ensure consistency. Also, adjust axes to a 1:1 ratio to avoid overemphasizing y-axis variation. This may mislead interpretations (e.g., Fig. 3b).

Thank you for the valuable suggestion. We have removed the correlation analysis for fig. 2 (see comment 23). We have removed fig3b as it was altogether based on your next comment.

25) L206: Remove. Claiming weaker correlations requires a test for slope differences through e.g. a regression-type analysis. Pearson values alone are insufficient, and the differences are not clearly meaningful (please, see my Comment 4 as well).

Thank you for the valuable comment. We have removed the correlation analysis on the different root types entirely and simply stated the following:

"Additionally, we investigated whether the different root fractions had an influence on soil shear strength, but the results indicate that total root biomass rather than the biomass of individual root fractions are related to soil shear strength."

26) L215: Clarify whether p-value is exactly <0.05 or a general threshold. With such a strong correlation, p should be lower. Inconsistent p-value reporting across the manuscript (sometimes 0.0001 has been used). See Comment 3 on need for a statistical methods section.

Thank you for the suggestion. We have added the statistical analysis as suggested in comment 3 and specified there that 0.05 is the general threshold. We have changed it throughout the manuscript so that it is consistent now.

27) L232: Figure reference is unclear. In Fig. 5, pond and vegetated marsh soil strength seem similar (e.g., same significance letters). Yet you also refer to Fig. 3a. Clarify which figure supports which comparison.

Thank you for the suggestion. In this paragraph we compare the results from the pond bottoms with the marsh values, both at the top soil and in the subsoil. Therefor both Fig 5 (compares the pond to the marsh subsoil) and figure 3A (shows the marsh topsoil) are necessary in this paragraph.

28) L259: Revisit earlier comments (especially Comment 1) to ensure limitations and uncertainty are clearly reflected in the Discussion.

Thank you for this comment. As mentioned in our reply to comment 1, we have added the limitations of the study throughout the discussion where they fit best in our opinion.

29) L260-261: Sentence is incomplete or missing a word. Please revise.

Thank you for noticing. As a result of one of your comments and a comment of reviewer 1, this sentence has been removed altogether.

30) L264: Remove redundant citation – already referenced at the beginning of the sentence.

Thank you for noticing, the citation has been removed at the end of the sentence.

31) L300: Depth-related variation affects more than just belowground biomass. Ensure other variables are considered in the limitations paragraph (see Comment 1).

Thank you for this very valuable comment. We have added a paragraph in the discussion going into more detail on other potential influencing factors.

Line 362-379: "We recognise that other factors, which are not considered in our study, may influence vertical variations in soil strength. For instance, higher water content has been shown to decrease the soil penetration resistance (Gillen et al., 2021; Stoorvogel et al., 2025). As soil water content may be higher in deeper soil layers, this may also contribute to lower soil strength deeper in the profile. Yet we expect this plays a minor role as field observations typically indicate water saturated soils over the whole soil profile. Additionally, variations in soil strength along the spatial marsh degradation gradient may be related to factors we did not account for. For instance, higher nutrient loading has been shown to decrease the soil organic matter content and belowground vegetation biomass and has been reported to be related to reduced soil strength

(Turner et al., 2020). Bioturbation, especially burrowing by crabs, can increase the oxygenation of the sediment and facilitate the breakdown of belowground biomass (Wilson et al., 2012). Yet we have no data to test whether such factors varied along the spatial marsh degradation gradient and if they contributed to the observed spatial pattern of decreasing soil strength with increasing marsh degradation. Lastly, sediment properties such as organic matter content, bulk density and clay content may play a role in the cohesion of sediment (Feagin et al., 2009; Gillen et al., 2021; Joensuu et al., 2018). Higher organic matter content may increase the sediment erosion resistance, which corresponds to our finding of higher organic matter content in the sites with higher shear and penetration resistance. Studies have shown that both higher bulk density and clay content decrease the erodibility of the marsh sediment (Brooks et al., 2022; Feagin et al., 2009b; Gillen et al., 2021; Lo et al., 2017; Stoorvogel et al., 2025). These studies are however located in minerogenic marsh systems, where bulk densities and clay contents are generally higher than in organogenic systems as ours. Therefor we believe that the influence of belowground biomass on shear and penetration resistance will dominate over the effect of bulk density and clay content.

32) L305-308: Define jargon (e.g., "undercutting," "cantilever failures") or replace with simpler language. Ensure accessibility to non-specialist readers.

Thank you for this valuable suggestion. We added the definition of both terms in the text between brackets:

Line 380-385: "Moreover, once ponds are formed, we may expect that the marsh edges surrounding the ponds are vulnerable to increased erodibility of the exposed weaker subsoil, which may promote undercutting of the rooted top layer (i.e. erosion of the deeper subsoil) and subsequent cantilever failures (i.e. when the topsoil block remaining after undercutting collapses), a mechanism that is found to be important in driving lateral erosion of scarped marsh edges with undercutting (Bendoni et al., 2016).