

Observed thresholds in sea-level rise driving global tidal wetland loss

Corresponding Author: Professor Zhijun Dai

This file contains all reviewer reports in order by version, followed by all author rebuttals in order by version.

Version 0:

Reviewer comments:

Reviewer #1

(Remarks to the Author)

Luo and co-authors interpret existing global datasets of wetland area change in the context of spatially variable relative sea level rise to determine thresholds for marsh and mangrove survival. The authors identify a threshold sea level rise rate of 9 mm/yr for both marsh and mangrove survival, and conclude that area-based metrics of marsh vulnerability yield a higher threshold than previous studies focused on vertical metrics of marsh vulnerability. The authors further show that variability in rates of wetland area loss are influenced by tidal range and suspended sediment supply. I found the study to be well designed, including the sensible use of existing datasets, straightforward metrics (relative rate of area change), and strong statistical methods, though the methods are limited by the quality of input datasets available at the global scale. The most novel implication of the work is the development of area-based threshold rates of sea level rise, and that these thresholds are higher than previous accretion-based thresholds, indicating that wetland migration has thus far offset global wetland losses at low-moderate rates of relative sea level rise.

I went back and revisited the most relevant papers addressing this topic at the global scale. Campbell et al. (2022) and Murray et al. (2022) present global changes in wetland area, but not in the context of relative sea level rise. Saintilan et al. (2022; 2023) identify sea-level rise rate thresholds at the global scale, but only in the vertical dimension. The most similar work is modeling based: Schuerch et al. (2018) show that future wetland area under sea level rise is fundamentally controlled by inland migration and Kirwan et al. (2010) show similar threshold sea level rise rates for marsh area change in generic salt marshes, and its dependence on tidal range and sediment supply. While this manuscript does not provide new conceptual ideas, it is unique in its ability to identify threshold rates of relative sea level rise based on global historical trends in wetland area. Though I have some critiques, I generally think the work is sound and the novelty is about right for Nature Communications.

Concerns:

1. The first paragraph of the discussion and central conclusion of the paper is that area-based metrics reveal higher wetland resilience to sea level rise than previous work focused on vertical accretion. I worry that the area-based metrics of wetland vulnerability are essentially lagging indicators, and that the finding of higher threshold rates than previous work simply reflects their metric of choice. The authors acknowledge that area-based metrics potentially lag behind vertical-based metrics (i.e. wetland accretion), citing lateral wetland migration. But there's a more fundamental reason that area-based metrics are lagging indicators: wetlands that start high in the intertidal zone take decades to centuries to drown vertically (Törnqvist et al., 2021; Langston et al., 2021). Therefore, there are potentially many locations in the authors dataset where thresholds for survival have already been exceeded (i.e. accretion rates < RSLR), but show up as stable because stability is defined as a change in area that occurs only after the wetland completely drowns (i.e. replaced by open water). Thus, the authors finding of a 9 mm/yr threshold might be optimistic. And their conclusion that their threshold rates are higher than previous studies may just reflect their area-based metric. Line 290 states: "By adopting this alternative definition for lateral thresholds, we avoid potential overestimation of collapse thresholds, thereby providing a more sensitive indicator of coastal vulnerability under sea-level rise." In reality, I think the lateral metric is a less sensitive indicator of coastal vulnerability.

2. Lagging indicators are especially problematic given the study's reliance on existing datasets of wetland area change over a relatively short duration (2000-2019). Regional studies of changes in marsh area are typically much longer in duration. For example, a regional study with similar findings (i.e. variability in sediment supply controls the rate of marsh expansion or contraction) was based on time series of 150 years (Ladd et al., 2019). Even satellite-based records often use the whole

period of landsat (1984-present) (Chen and Kirwan, 2022), roughly twice as long as the current study. If marshes are currently in the process of drowning vertically (Saintilan et al.), and it takes decades-centuries for drowning to occur, then it is perhaps too much to expect to detect complete conversion to open water in just 19 years.

3. The study is probably underestimating the creation of wetlands by inland migration. Regional studies indicate that historically the U.S. mid-Atlantic (Chen and Kirwan, 2022) and Gulf Coast of Florida (Raabe and Stumpf, 2016) have expanding marshes, yet they appear to show up as contracting on the author's change map (Figure 1). Similar conclusions were found by the global-scale analysis of Campbell, who highlighted the Chesapeake Bay as one of their case-studies of contraction. This manuscript uses the same input data so gets the same incorrect output. Essentially, the results are only as good as the underlying data, which of course is challenging at the global scale.

4. Could it be that the higher than expected threshold rates of sea level rise are due to marsh progradation into open water in large river deltas? As noted in the previous comment, I don't think the underlying dataset is correctly identifying net marsh expansion, at least in the mid-Atlantic, but the work does seem to correctly identify net wetland expansion in proximity to large deltas on the coast of China and India/Bangladesh. The current study attributes higher than expected thresholds to lateral migration of wetlands into uplands. Could progradation (Nienhuis et al., 2020), or even restoration (Murray et al., 2022) be a better explanation?

Matt Kirwan

(Remarks on code availability)

Reviewer #2

(Remarks to the Author)

The study analyzes two decades of satellite observations to identify thresholds in tidal wetland loss associated with relative sea-level rise (RSLR) at the global scale. The methodological framework is generally sound and clearly described, and the authors carefully consider uncertainties throughout the manuscript. By focusing on the lateral dynamics of wetland extent, the study provides a useful complement to previous work that has primarily examined vertical wetland adjustment to sea-level rise. Overall, the manuscript offers a potentially valuable contribution to the coastal wetland literature. I recommend publication after the following issues are addressed:

1. The tidal wetland change dataset used in the analysis could be further refined. In the current framework, the authors use gross loss as the response variable (relative rate of area change, RRAC). However, RSLR is not the dominant global driver of tidal wetland loss; anthropogenic clearing remains the primary cause, particularly for mangroves (Goldberg et al., 2020). As a result, a substantial portion of the RRAC signal likely originates from non-sea-level drivers.

Because these losses are not filtered out, they may obscure the signal of RSLR, especially at lower rates of sea-level rise. This has important implications for threshold detection: losses caused by other drivers may mask the early signal of RSLR, making the RSLR effect detectable only when rates become sufficiently high. Consequently, the estimated threshold (e.g., ~9 mm/yr) may be biased upward.

I therefore suggest restricting RRAC to wetland losses that are attributable to sea-level rise. A simple approach could be to focus on wetland areas that convert to open water, which is a common outcome of inundation-driven loss. For example, intersecting the wetland-loss layer with the 2020 ocean extent layer could provide a direct estimate of tidal wetland loss associated with sea-level rise. Note that aquaculture ponds should also be excluded, as they can produce similar land-water transitions but are unrelated to RSLR. This filtering step would substantially strengthen the causal interpretation of the analysis.

2. The identification of the RSLR threshold requires clearer and more quantitative justification. I may have overlooked it, but the manuscript does not explicitly explain how the value of 9 mm/yr was determined from the curves shown in Fig. 2.

The authors report similar thresholds (~9 mm/yr) for both salt marshes and mangroves and interpret the results as indicating that salt marshes gradually decline between 0-9 mm/yr while mangroves remain stable. However, visual inspection of Fig. 2 suggests that the breakpoint for salt marshes may occur closer to ~7.5 mm/yr, whereas mangroves indeed appear to exhibit a threshold near ~9 mm/yr. This pattern would imply that the two ecosystems may have distinct thresholds, with salt marshes reaching their tipping point at a lower RSLR rate. Prior to their respective thresholds, both ecosystems appear relatively resilient, but mangroves tolerate higher rates of sea-level rise. The manuscript would benefit from a formal breakpoint detection method (e.g., segmented regression or change-point detection) to objectively determine these thresholds.

3. The section "Roles of tidal range and sediment availability" appears somewhat disconnected from the central research question of the paper. The primary objective of the study is to quantify the relationship between RSLR and tidal wetland area change, yet this section shifts the focus to examining the independent effects of tidal range and sediment availability on wetland change. A more consistent approach would be to incorporate tidal range and sediment availability as interaction terms in Eq. 3. This would allow the authors to test whether the effect of RSLR on wetland loss is modulated by tidal range or sediment supply, directly addressing how environmental context influences wetland resilience to sea-level rise.

Minor comments:

1. The current title "Observed thresholds in sea-level rise induced global tidal wetland loss" is somewhat imprecise. The threshold itself does not cause wetland loss; rather, loss accelerates once sea-level rise exceeds the threshold. A clearer title might be: "Observed thresholds in sea-level rise driving global tidal wetland loss".

2. Line 21: Some datasets extend beyond 2000-2019 (e.g., mangrove data include observations from 1996). A broader phrase such as "the past two decades" may be more appropriate.

3. Line 27-29: This sentence is somewhat unclear. Both lateral expansion and vertical accretion can enhance wetland resilience, but this point is not directly related to the detected threshold differences.

4. Lines 93–94: The statement that 96.4% of mangrove areas experienced RSLR and 72.2% experienced net loss may be misleading. These losses are not necessarily caused by RSLR and are often driven by deforestation or land-use change. Without restricting RRAC to RSLR-related losses, the comparison may unintentionally imply causality.
5. Figure 1a: The panel could be improved by reporting the percentage of global area represented by each category (e.g., $\Delta\text{RSL} > 0$ AND Loss).
6. Line 182–183: This finding is interesting and consistent with previous studies, but it also suggests that signals from other drivers are present in the dataset. As noted above, this could be addressed by applying a simple ocean mask to isolate inundation-related losses.
7. Line 276: The relatively high threshold detected in this study may also be caused by spatial resolution. Because the analysis relies on 30-m wetland change data, only relatively large changes were detected, potentially leading to higher threshold estimates compared with site-based or finer-resolution studies.
8. Line 453: How is the “stable” category defined? When comparing two time periods, small pixel-level changes are likely inevitable. It would be helpful to clarify whether minor changes (e.g., one or two pixels) are considered “stable” or classified as “change”.
9. Line 468: Why not use higher-resolution sea-level data? Downscaling from 2° to 0.25° represents a substantial interpolation ($64\times$). For example, the Copernicus Marine dataset provides 0.125° resolution sea-level data from 1992–2025, which may better match the spatial scale of the analysis.
10. Lines 475–476: Please clarify the purpose of this processing step. Is it intended to fill missing values in coastal grid cells?

Reference

Goldberg, L., Lagomasino, D., Thomas, N., & Fatoyinbo, T. (2020). Global declines in human-driven mangrove loss. *Global change biology*, 26(10), 5844–5855.

(Remarks on code availability)

Reviewer #3

(Remarks to the Author)

I would like to congratulate the authors with this interesting study exploring and quantifying the relationship between global tidal wetland loss and relative sea-level changes. The authors present a very thorough and sophisticated analysis of a compilation of readily available data, arriving at the unprecedented identification of relative sea-level rise thresholds for global tidal wetland loss. This work is very well written, and the analysis is supported by clear figures and extensive supporting materials. Both the methods applied and the interpretation of the results are comprehensive and convincing, and in support of the conclusions presented.

Apart from some minor suggestions and questions that I've set out below, there is one more fundamental point I would like to bring up. The presented RSL rise threshold for the lateral extent of tidal wetlands being higher than typical threshold values for wetlands' vertical extent (lines 275–276) makes me wonder if this elevated threshold comes at a loss of the elevation capital of the (remaining) wetlands. As the authors indeed argue in the discussion that lateral wetland adjustments are generally slower than vertical responses to RSL change (lines 276–277), I am afraid that the widespread assumption or application of the increased threshold that is established in this study would result in a non-linear increase of wetland (extent) loss over time, especially beyond the relatively limited timeframe (20 years) of the presented analysis. This would be in line with the increasing probability of wetland loss as RSL accelerates, observed by Saintilan et al. (2023) and quoted by the authors (lines 48–50)? Have the authors maybe looked into the wetland loss rates in relation to accelerations in the observed rates of RSL change [mm/yr²]? In this light, I suggest to elaborate and reflect more on the long-term effects and reliability of this newly established RSL rise threshold for tidal wetland loss, and to be a bit more cautious presenting this threshold to be higher than those following from studies into vertical wetland extent.

Detailed comments

28–29 (line numbers): It would be interesting to provide a bit more context to this notion that lateral expansion can enhance wetland resilience, by including a very brief reflection on the observed impact of tidal range and SSC in accommodating this resilience.

46–47: There are some words missing in the sentence ‘These contrasting...that accrete’.

50: Please remove the article ‘a’ before ‘global investigations’.

52: For clarity, please specify that the ‘divergent response thresholds’ concern wetlands’ response to accelerated RSL rise.

58: It is unclear to me what is meant by ‘lateral processes remain poorly constrained’. Could the authors please elaborate, in relation to the field data and models that have been addressed in the previous sentences?

69–70: The presented definition of the RRAC seems incorrect. Here, the yearly wetland gain in a cell is related to the global total extent in the reference year. However, in lines 457–460 the RRAC is expressed as the RAC in cell k as a fraction of the wetland area in the reference year in that same cell k. Please correct accordingly.

82–83: With the statement that ‘RSL (is) decreasing and RRAC increasing toward the poles’, I would suggest to specify that this observed increase in RRAC is observed over a much smaller latitudinal range than the much higher latitudes associated with the decrease of RSL. The present statement is confusing as the phrase ‘toward the poles’ suggests similar latitudinal ranges for both trends.

86: The abbreviation RSLR is not defined or used elsewhere in the manuscript. For consistency, I would suggest replacing it with ‘RSL rise’.

114–116: I struggle a bit with references to the rate of RSL in integers, whereas the labels in Figure 2 are positioned right

between the bins. What bins have actually been used in this analysis? And if the bins are indeed aligned with the labels in Figure 2 (i.e. separated at integers rather than centred around integers), shouldn't the references to these bins in the text mention their ranges (e.g. 12-13 mm/yr) rather than the lower limit of these bins?

116-117: The statement that 'the stable fraction maintains a relatively high mean portion of 24% under RSL-fall conditions' is incorrect for the largest RSL-fall rates in Figure 2a. Please correct this statement accordingly.

146: The threshold value θ has not been defined prior to this mention (as the methods are presented afterwards). Please provide a proper definition of this threshold here, in the results section.

160-161: Please correct references to the blue dashed line (not solid) for the 50% proportion and darker/lighter error bars (not solid/dashed) for the different likelihood intervals.

Fig. 3: I think the results presented in this figure could benefit from a violin-plot presentation rather than showing the scattered points in the background.

174-175: The numbers printed in purple are wrongly referred to as purple markers. The actual markers of the medians (the purple centrelines of the boxplots) are not purple.

184-186: To this point, it is not clear from the main text what the original cutoff was for the minimum wetland area in grid cells to be included in the analysis, hence I cannot quite comprehend how this compares to the new cutoff of 0.1 km² that is introduced here. Please provide the original value here, for comparison.

195: Please correct 'RSL rate threshold' to 'RSL change rate threshold'.

213-214: The statement in this sentence that 'are loss in salt marshes is more certain than in mangroves under low-to-moderate RSL-rise rates' is contradictory to the numbers presented in the next two sentences and the associated data in Figure 2. Please correct accordingly.

Figure 4: I find it confusing that the data are binned here in 10% bins of the RSL change rate, rather than bins of e.g. 2 mm/yr. The total range of the RSL change rates is different for salt marshes and mangroves and since panels e and f present data for all 10% bins for both salt marshes and mangroves, this would imply that the actual RSL change rate ranges of these bins vary between the wetland types and, more importantly, don't match with the RSL change rate ranges of the 10% bins of the merged results in panel d. I would suggest to use actual RSL rate change values for binning these results (e.g. bins of 2 or 3 mm/yr), rather than 10% intervals of the different ranges of these values. This will allow for better comparison between the wetland types and also for direct linking to the three different RSL change regimes that are distinguished in Figures 2 and 3.

341-344: The first part of this sentence addresses the 'counteracting of sea-level-driven coastal erosion through modifications of environmental drivers'. It seems to me that this statement refers to the observed positive impacts of tidal range and SSC at higher RSL change rates. However, tidal range can't really be considered an environmental driver that can be modified by human intervention. Please revise this statement.

354-357: The pixel-based RSLR shown in Supplementary Figure 7.b appears much less variable/sensitive (varying between 0-15 mm/yr) than the regional RSLR values from the field (varying between -5-20 mm/yr). Instead of mentioning the significant and positive correlation between these two, I would expect a reflection on the fact that the range of the RSLR values used in this study is only half the range of the observed RSLR rates in the field. Could the authors please elaborate on why they believe their reconstructed RSLR data is accurate and on the implications of this deviation?

394: Please correct 'validate' to 'valid'.

399: Please correct 'increase' to 'increases'.

438-445: The MGB dataset is selected to map mangrove area change rates, but at the same time the data in Supplementary Figure 11.b shows a much greater variation of the rates of area change for the MGB dataset than for the MGM dataset (corroborated by the 1.20 slope of the linear fit). To what extent could the focus on the MGB data for determining the RAC estimates have affected the results of this study? The mangrove rates of area change obtained from the MGM dataset seem much more in line with the salt marsh rates of change from the SMM dataset. Would the use of the MGM dataset have reduced the greater sensitivity of mangroves to RSL changes in comparison to salt marshes?

453: Please explain or include a reference to the 'existing global benchmark' for the latitude range used to identify stable regions.

459-490: Am I correct in assuming that this reference year (ref) is 2020? Or does the reference year still vary based on the temporal coverage of the base data? Please clarify.

479: Indices j and n remain undefined here.

483: Please update the reference to the next section to 'Uncertainty quantification'.

932: Please correct 'tidal wetland' to plural.

Supplementary Information

Figure 6: I assume the date ranges in the legend for gains and losses (2019-2019) is incorrect. Please correct.

Figure 7: Is the 'surface gain/loss' on the vertical axis in panel a the same as the RRAC? If so, please clarify in the figure or caption.

Figure 13: Instead of the input of 'SLR data' (top left corner), I would say 'RSL data' as sea levels can also drop. In addition, I'm wondering if the bottom two boxes of the maps reconstruction (RSL rate change and RRAC) should be considered results (grey box) instead of data (blue box), as these maps in themselves are an important output of this work.

(Remarks on code availability)

Version 1:

Reviewer comments:

Reviewer #1

(Remarks to the Author)

I thought the original manuscript was quite strong but raised 4 concerns that the reviewers have now addressed. Below, I walk through the author responses to each of these concerns, and have only suggested a few more minor edits.

1. The authors have admirably added text near the end of the discussion acknowledging that their metrics could be lagging indicators. But I would like the authors to additionally add the elevation capital argument to the first paragraph of the discussion, as I believe this is the primary reason for the higher threshold rates of sea level rise. They should explicitly use the "elevation capital" terminology as requested by another reviewer. I'm also left wondering if the area-based lateral thresholds (9 mm/yr) are really meaningfully higher than vertical thresholds (8mm/yr).
2. The authors have done a nice job addressing my concern about needing longer time series data by adding an analysis with higher temporal resolution, and also by acknowledging the issue. No further edits requested.
3. The concern about data quality as it relates to marsh migration can't really be addressed without substantial reworking of the input data, but the authors now acknowledge the issue, and give the Chesapeake Bay and Florida Gulf Coasts as examples. No further edits requested.
4. The authors have addressed my concern about wetland progradation near river deltas adequately by listing the various processes that could cause wetland gains.

I have one final request.

1. Incorporate the following reference to the discussion of how tidal range and SSC influence wetland vulnerability: Coleman et al., 2022. *Limnology and Oceanography*. <https://aslopubs.onlinelibrary.wiley.com/doi/abs/10.1002/lol2.10230>. It's an important paper about marsh vulnerability thresholds at the global scale, and particularly the role of SSC and tidal range.

Matt Kirwan

(Remarks on code availability)

Reviewer #2

(Remarks to the Author)

I sincerely appreciate the authors' substantial efforts in this round of revision. The manuscript has been substantially improved and is now more robust and insightful, particularly through the comparison of different datasets and the newly added Relative Rate of conversion to Open Water (RROW) metric. I recommend publication, subject to the authors addressing a few remaining concerns before acceptance.

1. The comparison between the relative rate of area change (RRAC) and RROW is a very interesting and useful addition. RROW represents wetland loss caused by inundation and therefore provides a more direct measure of how relative sea-level rise (RSLR) contributes to wetland loss. In contrast, RRAC is based on net area change, and thus describes the extent to which RSLR-induced wetland loss may be offset by wetland expansion. For this reason, I think the calculation of net area change in RRAC should also exclude losses caused by deforestation. Specifically, net area change should be calculated as gross gain minus wetland loss caused by inundation, rather than gross gain minus total gross loss, because gross loss includes substantial areas of human-driven deforestation that are not related to RSLR. For example, the wetland loss shown in Supplementary Fig. 5b is explicitly identified by the authors as deforestation associated with aquaculture ponds. Such areas are not related to RSLR and therefore should not be included in an analysis designed to assess wetland responses to sea-level rise. The authors should either provide a clear justification for including human-driven deforestation in the calculation of net area change in a sea-level-rise-focused study, or update the analysis so that RRAC more directly reflects the extent to which wetland expansion offsets inundation-driven wetland loss.
2. I do not think that RRAC and RROW reflect different dimensions of wetland response in the way currently described. Both metrics primarily capture lateral wetland area dynamics rather than vertical processes. The statement that RROW reflects lateral change whereas RRAC captures both lateral and vertical processes does not seem well supported. In my view, RRAC mainly indicates the degree to which wetland expansion can compensate for RSLR-induced wetland loss, rather than providing direct information on vertical wetland adjustment.
3. In line 61 of the change-tracked version of the main text, "but" should be replaced with "however".

(Remarks on code availability)

Reviewer #3

(Remarks to the Author)

I would like to thank the authors for their elaborate responses and revisions following the feedback of myself and the other reviewers. Both the responses as well as the revised manuscript are now convincingly presenting some highly relevant findings regarding the impacts of relative sea-level rise on global tidal wetlands.

Upon reading the revised manuscript, I have one question remaining in relation to the negative association between RRAC and SSC observed for mangroves. In the discussion (lines 372-372) it is stated that the underlying mechanisms remain unknown. Yet, I'm wondering whether this effect is related to dynamics at the fringe (drowning) or losses at the landward side of the mangroves. Have the authors considered to perform a similar multiple linear regression for RROW? My guess would

be that the association between RROW and SSC is negative (i.e. seaward expansion for higher SSC), so that the losses are somehow related to different anthropogenic impacts (possibly on the landward side). If the association between RROW and SSC is positive, a possible explanation would be that in highly turbid estuaries mangroves are actively removed from mudflats to maintain open water (this happens in for instance New Zealand).

Otherwise, the manuscript reads very well and I only have a few very minor comments left.

Minor comments

75-77 (line numbers): The line 'we calculate the relative rate of net area change (still referred to as RRAC hereafter) and separately for the area converted to open water (hereafter RROW)' doesn't provide a very clear explanation of the RROW. I would suggest to revise the second half of the sentence to 'and, separately, for the relative rate of area converted to open water'.

210: Please remove either 'behaviors' or 'responses', these words are doubling.

223: 'cubic fit' should be plural.

Figure 3: The unit on the vertical axis uses Δ RSLC. RSLC is not defined in the manuscript up to here, but I believe it to be RSL change? In that case, does it make sense to also have the Δ in front?

239: Please correct 'an negative'.

262-263: Please add the unit after 'an increase in RRAC of 0.015', otherwise this could be confused with a percentage/relative increase.

340: Please remove 'be' in 'to be intensify'.

341: Please correct 'only ~3% of global wetland extent has experienced RSL rise rates'.

400: Please insert the article in 'at a preceding point'. Also please correct 'mean RROW increases'.

414: 'losses that is' should read 'losses that are'

678: Please see my comment re Figure 3; RSLC is not clearly defined.

682: Please remove 'the model' from 'This model was then applied the model'.

(Remarks on code availability)

Version 2:

Reviewer comments:

Reviewer #2

(Remarks to the Author)

I appreciate the authors' substantial efforts in this round of revision. My previous concerns have been well addressed, and I have no further comments. I congratulate the authors on conducting such a thoughtful and robust analysis.

(Remarks on code availability)

Reviewer #3

(Remarks to the Author)

I would like to thank the authors once again for their elaborate responses to my (and the other reviewers') suggestions. I am satisfied with the associated revisions of the manuscript. I had a final read and to my opinion the manuscript is ready for publication. I have no further comments. Congratulations with this solid and highly relevant paper!

Regards, Erik Horstman

(Remarks on code availability)

Open Access This Peer Review File is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

In cases where reviewers are anonymous, credit should be given to 'Anonymous Referee' and the source.

The images or other third party material in this Peer Review File are included in the article's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.

To view a copy of this license, visit <https://creativecommons.org/licenses/by/4.0/>

1 ***Reviewer comments are shown in black, author responses in blue, and***
2 ***revised manuscript text in grey italic.***

3 Previous manuscript ID: NCOMMS-26-009208

4 Title: Observed thresholds in sea-level rise driving global tidal wetland loss

5

6 Contents

7 ***Reviewer #1 (Remarks to the Author):*** 1

8 ***Reviewer #2 (Remarks to the Author):*** 16

9 ***Reviewer #3 (Remarks to the Author):*** 37

10

11

12 ***Reviewer #1 (Remarks to the Author):***

13 Luo and co-authors interpret existing global datasets of wetland area change in the
14 context of spatially variable relative sea level rise to determine thresholds for marsh
15 and mangrove survival. The authors identify a threshold sea level rise rate of 9 mm/yr
16 for both marsh and mangrove survival, and conclude that area-based metrics of marsh
17 vulnerability yield a higher threshold than previous studies focused on vertical metrics
18 of marsh vulnerability. The authors further show that variability in rates of wetland area
19 loss are influenced by tidal range and suspended sediment supply. I found the study to
20 be well designed, including the sensible use of existing datasets, straightforward
21 metrics (relative rate of area change), and strong statistical methods, though the
22 methods are limited by the quality of input datasets available at the global scale. The
23 most novel implication of the work is the development of area-based threshold rates of
24 sea level rise, and that these thresholds are higher than previous accretion-based
25 thresholds, indicating that wetland migration has thus far offset global wetland losses
26 at low-moderate rates of relative sea level rise.

27 I went back and revisited the most relevant papers addressing this topic at the global
28 scale. Campbell et al. (2022) and Murray et al. (2022) present global changes in wetland

area, but not in the context of relative sea level rise. Saintilan et al. (2022; 2023) identify sea-level rise rate thresholds at the global scale, but only in the vertical dimension. The most similar work is modeling based: Schuerch et al. (2018) show that future wetland area under sea level rise is fundamentally controlled by inland migration and Kirwan et al. (2010) show similar threshold sea level rise rates for marsh area change in generic salt marshes, and its dependence on tidal range and sediment supply. While this manuscript does not provide new conceptual ideas, it is unique in its ability to identify threshold rates of relative sea level rise based on global historical trends in wetland area. Though I have some critiques, I generally think the work is sound and the novelty is about right for Nature Communications.

We sincerely thank you for your positive assessment of the soundness and novelty of our work. We also wish to note that although Schuerch et al. (2018) presented valuable global-scale projections of wetland extent through modeling, their results were not validated against observed records of wetland area change. Our study addresses this critical gap by providing important observations on wetland dynamics, thereby offering empirical evidence that was previously lacking.

We have carefully considered all critiques raised and have improved the manuscript accordingly. Below, we provide a point-by-point response to each comment.

Concerns:

1. The first paragraph of the discussion and central conclusion of the paper is that area-based metrics reveal higher wetland resilience to sea level rise than previous work focused on vertical accretion. I worry that the area-based metrics of wetland vulnerability are essentially lagging indicators, and that the finding of higher threshold rates than previous work simply reflects their metric of choice. The authors acknowledge that area-based metrics potentially lag behind vertical-based metrics (i.e. wetland accretion), citing lateral wetland migration. But there's a more fundamental reason that area-based metrics are lagging indicators: wetlands that start high in the intertidal zone take decades to centuries to drown vertically (Tornqvist et al., 2021; Langston et al., 2021). Therefore, there are potentially many locations in the authors dataset where thresholds for survival have already been exceeded (i.e. accretion rates < RSLR), but show up as stable because stability is defined as a change in area that occurs only after the wetland completely drowns (i.e. replaced by open water). Thus, the authors finding of a 9 mm/yr threshold might be optimistic. And their conclusion that

their threshold rates are higher than previous studies may just reflect their area-based metric. Line 290 states: “By adopting this alternative definition for lateral thresholds, we avoid potential overestimation of collapse thresholds, thereby providing a more sensitive indicator of coastal vulnerability under sea-level rise.” In reality, I think the lateral metric is a less sensitive indicator of coastal vulnerability.

Response: Thank you for your insightful comments. We agree that the relationship between lateral and vertical metrics requires further clarification. In the revised version, we have addressed this point more thoroughly in the following ways:

(1) Regarding the comparison between lateral and vertical processes: We now complement the net areal change (gain minus loss) with inundation-related loss, quantified as the spatial intersection of wetland loss areas with permanent open water. Aquaculture water bodies were excluded to isolate natural open water, as detailed in the **Introduction and Methods**. While the former captures total lateral areal dynamics, the latter isolates wetland-to-open-water conversion, which represents vertical inundation at the seaward wetland boundary and is theoretically more sensitive to RSL rise, as you noted. The two metrics identify thresholds of ~ 9 and ~ 8 mm yr⁻¹, respectively, suggesting that overall lateral dynamics has partially buffered wetland vulnerability over the past two decades. We have revised **the first paragraph of the Discussion** accordingly, framing these findings within this lateral-process comparative framework rather than making direct comparisons with previous vertical studies.

(2) Concerning the lag in area-based thresholds: We fully agree that area-loss thresholds could emerge later than vertical accretion deficits, as planform loss through marsh-edge erosion or marsh inundation typically unfolds more slowly than changes to platform accretion (Langston et al., 2021; Mariotti and Carr, 2014). We have added relevant text in the **Discussion** to acknowledge this point explicitly.

(3) In addition, we examined how different threshold definitions for vertical versus lateral processes can lead to divergent estimates. Applying threshold definitions analogous to those used in previous vertical studies yields even higher thresholds (e.g., 13 mm yr⁻¹ for mangroves with a 90% probability of loss) than 8~9 mm yr⁻¹ reported here, which could result in overly optimistic projections. We therefore emphasize that threshold definitions must be selected carefully and have added a note in the **Discussion**, with further details provided in the **Supplementary Discussion**.

In the Introduction As:

“...To explore overall lateral dynamics and inundation-related loss in tidal wetlands, we calculate the relative rate of net area change (still referred to as RRAC

hereafter) and separately for the area converted to open water (hereafter RROW) ...” (See tracked version, Line 82-88)

In the Discussion As:

“Our observations confirm that lateral adjustment can partially mitigate tidal wetland area loss induced by relative sea-level rise. Among the two types of area changes we quantified, conversion to open water represents the lateral manifestation of vertical inundation processes, while net area change integrates both lateral and vertical processes. Under low-to-moderate RSL rise rates, both metrics show resilience, primarily attributable to vertical accretion: organic and mineral accumulations raise surface elevation, reducing submergence risk^{5,18,27,44} and, enable seaward progradation with sufficient external sediment supply in deltaic settings⁴⁵⁻⁴⁷, such as the eastern section of the Ganges-Brahmaputra-Meghna Delta (ref.⁴⁸; Fig. 1a) and the Changjiang Delta (ref.⁴⁹; Supplementary Fig. 4b). Our analysis on the function of SSC also corroborates this pattern (Fig. 4a-c). Notably, net change shows a higher area-based threshold ($\sim 9 \text{ mm yr}^{-1}$ versus $\sim 8 \text{ mm yr}^{-1}$) and a lower probability of decline ($> 66\%$, likely) under accelerating RSL rise compared to inundation-related loss ($> 95\%$, extremely likely) (Table 2; Table 3; Supplementary Table 2). This indicates that lateral reorganization has provided a quantifiable buffer against tidal wetland area degradation driven by high RSL rise rates...” (See tracked version, Line 410-431)

“Our interpretation of wetland vulnerability based on these results may be conservative. Furthermore, area change is an inherently lagged indicator relative to vertical processes: high-elevation wetlands require time to become inundated once vertical accretion falls behind RSL rise^{6,58,76}.” (See tracked version, Line 536-537; 547-548)

“We acknowledge that threshold estimates are definition-dependent. Our approach identifies abrupt loss acceleration positions, whereas previous vertical studies used submergence proportion to detect thresholds aligned with IPCC likely ranges^{14,21,79} (Table 1). Applying the latter method to the loss fractions in Fig.2b, c yields substantially higher thresholds: 12 mm yr^{-1} (66% for salt marshes) and 13 mm yr^{-1} (90% for mangroves). These values appear overly optimistic, underscoring the urgent need to establish which definition best captures threshold behavior (see Supplementary Discussion for details).” (See tracked version, Line 557-564)

131 *“In conclusion, we reveal a global nonlinear response in tidal wetland area change*
132 *with increasing relative sea-level rise, with thresholds of apparent loss*
133 *acceleration of $\sim 9 \text{ mm yr}^{-1}$ for overall lateral dynamics and $\sim 8 \text{ mm yr}^{-1}$ for*
134 *inundation-related loss. ” (See tracked version, Line 628-633)*

135 ***In the Methods As:***

136 *“As a counterpart to the overall lateral dynamics, we conducted a parallel analysis*
137 *of direct inundation-driven wetland loss. We first obtained the 2020 global*
138 *permanent surface water distribution⁸⁷. We removed areas overlapping with the*
139 *2020 global aquaculture pond clustering⁸⁸, yielding the natural open water mask.*
140 *We then intersected the loss pixels from the tidal wetland datasets with this natural*
141 *open water mask to extract wetland area converted to open water. Finally, we*
142 *applied the RRAC gridding procedure to calculate RROW (Relative Rate of*
143 *conversion to Open Water) for each valid grid cell.” (See tracked version, Line*
144 *712-719)*

146 **2.** Lagging indicators are especially problematic given the study’s reliance on existing
147 datasets of wetland area change over a relatively short duration (2000-2019). Regional
148 studies of changes in marsh area are typically much longer in duration. For example, a
149 regional study with similar findings (i.e. variability in sediment supply controls the rate
150 of marsh expansion or contraction) was based on time series of 150 years (Ladd et al.,
151 2019). Even satellite-based records often use the whole period of landsat (1984-present)
152 (Chen and Kirwan, 2022), roughly twice as long as the current study. If marshes are
153 currently in the process of drowning vertically (Saintilan et al), and it takes decades-
154 centuries for drowning to occur, then it is perhaps too much to expect to detect complete
155 conversion to open water in just 19 years.

156 **Response:** We sincerely appreciate your insightful comment regarding the potential
157 limitations of the 20-year observation window. As you rightly pointed out, wetland
158 drowning is a time-dependent process. Longer time series (such as those used in
159 regional studies spanning multiple decades to centuries) are often better suited to
160 capture the full trajectory of marsh response to sea-level rise, until a new equilibrium
161 arises.

162 However, the reason we can see the trends on such short timescales is because we
163 employ a global approach where we can substitute time for space. We do not have to

wait for RSL to change in any region, we simply compare marsh change between areas of persistently low versus high RSL.

That said, there is a risk in our analysis in the case of significant RSL accelerations. To test the temporal sensitivity of our findings, we performed an additional analysis using 3-year rolling windows based on the Murray et al. (2022) salt marsh and mangrove datasets, applying the same threshold-detection methodology as in the 20-year analysis. The results indicate that both net area change and inundation-related loss continue to exhibit comparable nonlinear thresholds across most 3-year intervals under RSL-rise conditions (see **Supplementary Figs. 6 & 7**). This suggests that, although wetland loss may exhibit hysteresis, the signal of accelerated loss under high RSL-rise rates is detectable even over shorter periods, within the context of the long-term, centennial-scale trajectory of global sea-level rise (Kemp et al., 2011; Mu et al., 2025).

These findings support the interpretation that wetland loss under RSL rise represents a chronic, progressive process, and that the 20-year observation window used in this study is sufficient to identify the nonlinear threshold behavior reported here. At the same time, we fully acknowledge that time-lagged responses and longer-term dynamics may influence threshold estimates, and we have incorporated a discussion of this limitation in the revised manuscript.

Corresponding methodological details, results, and caveats have been added to the **Methods, Results, and Discussion** sections.

In the Discussion As:

*“The loss of global tidal wetlands likely emerges as a chronic, progressive process under high rates of RSL rise. In a parallel analysis using area changes computed over successive 3-year intervals, we still detect nonlinear threshold responses in both RRAC and RROW, similar to those obtained from the two-decade analysis (Supplementary Fig. 6 & 7). This suggests that, at the global scale, degradation processes exceeding the RSL threshold emerge even at shorter timescales, rather than requiring multi-decadal observation windows to manifest. In view of the very likely existence of a secular, centennial-scale global mean sea-level rise prior to the satellite altimetry era^{56,57}, the detection of such phenomena over shorter periods is to be expected, even given potential time-lagged responses^{6,54,58}.” (See **tracked version, Line 442-456**)*

196 “...Furthermore, area change is an inherently lagged indicator relative to vertical
197 processes: high-elevation wetlands require time to become inundated once
198 vertical accretion falls behind RSL rise^{6,58,76} ...” (See tracked version, Line 547-
199 549)

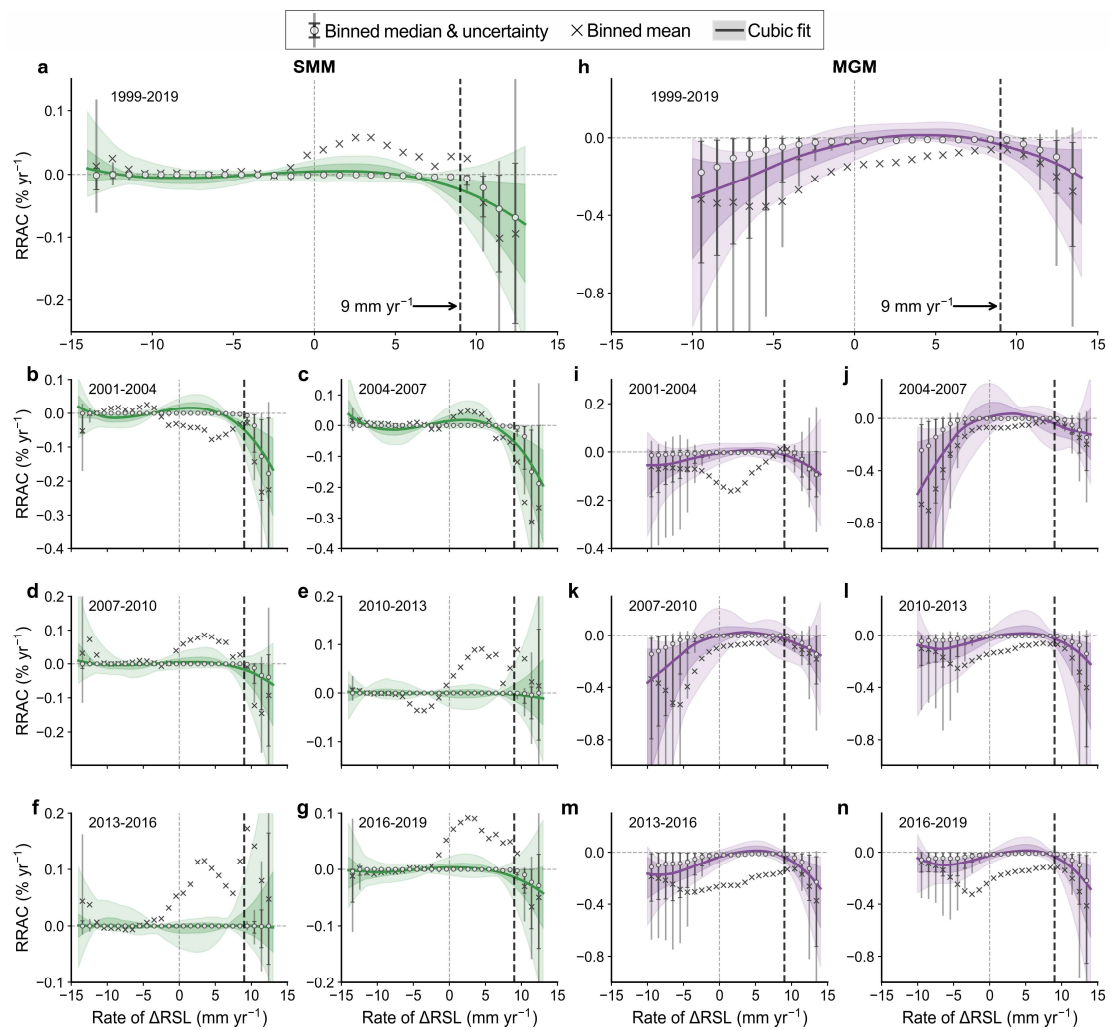
200 “...Third, the relatively short observation period (~20 years) and the use of linear trend
201 estimation may mask ongoing accelerated losses that is not yet apparent⁵⁸,
202 especially given that the global sea-level rise rate has doubled over the past three
203 decades⁷⁸ ...” (See tracked version, Line 551-553)

204 “...Looking forward, future studies should explicitly integrate lateral processes,
205 species-specific interactions, longer-term response monitoring and heterogeneous
206 coastal boundary conditions to enable more robust and site-specific projections.”
207 (See tracked version, Line 639-641)

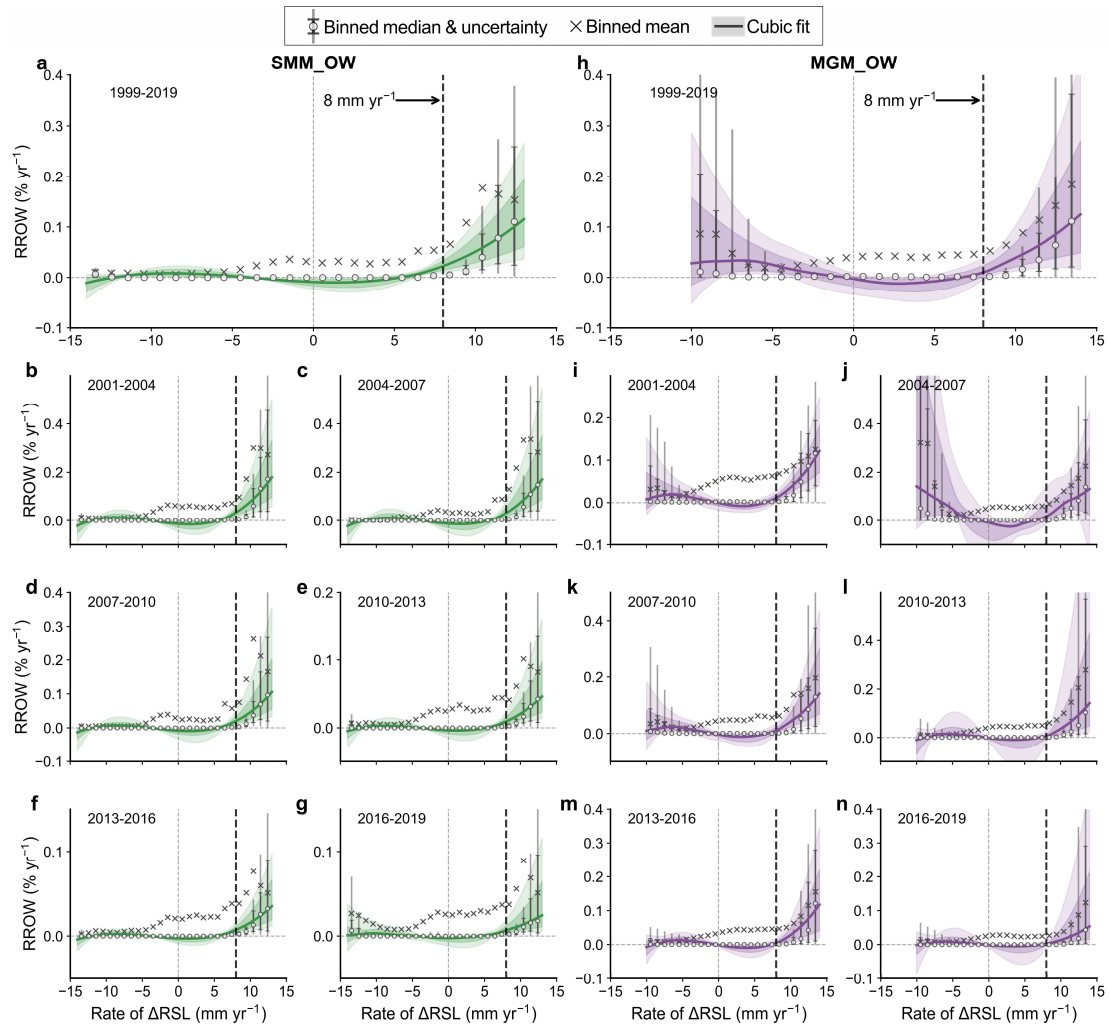
208 ***In the Methods As:***

209 “To test the robustness of our main findings across selections of temporal and spatial
210 scales and wetland datasets, we repeated the same methodological framework
211 under alternative configurations.

212 *Temporal coverage.* To test whether our main findings depend on long-term monitoring,
213 we applied an identical analytical framework to Murray et al.’s data (ref.³), which
214 provides continuous 3-year change intervals (2001-2004, 2004-2007, 2007-2010,
215 2010-2013, 2013-2016, 2016-2019), paralleling the 20-year span analysis.
216 Consistency between the two temporal scales was evaluated to assess sensitivity
217 to monitoring duration.” (See tracked version, Line 885-893)



Supplementary Fig. 6 | Comparison of RRAC trends across rates of RSL change calculated over 20-year and 3-year periods. (a) and (h) show trends for salt marshes and mangroves, respectively, across the entire 1999-2019 period from the Murray et al. (2022) dataset. The panels below present trends for RRAC calculated in the same manner over successive 3-year intervals, with (b-g) corresponding to salt marshes and (i-n) to mangroves. The time span of the data used is indicated in the upper-left corner of each panel. Circles and crosses denote the medians of binned medians and binned means, respectively. Grey error bars represent the 66% and 90% uncertainty ranges. The black vertical dashed line marks the threshold position. The colored curves show cubic fits to the binned medians, with darker and lighter shaded envelopes indicating the 66% and 90% uncertainty ranges, respectively. RRAC: Relative Rate of net Area Change in tidal wetlands.



Supplementary Fig. 7 | Comparison of RROW trends across rates of RSL change calculated over 20-year and 3-year periods. (a) and (h) show trends for salt marshes and mangroves, respectively, across the entire 1999-2019 period from the Murray et al. (2022) dataset. The panels below present trends for RROW calculated in the same manner over successive 3-year intervals, with (b-g) corresponding to salt marshes and (i-n) to mangroves. The time span of the data used is indicated in the upper-left corner of each panel. Circles and crosses denote the medians of binned medians and binned means, respectively. Grey error bars represent the 66% and 90% uncertainty ranges. The black vertical dashed line marks the threshold position. The colored curves show cubic fits to the binned medians, with darker and lighter shaded envelopes indicating the 66% and 90% uncertainty ranges, respectively. RROW: Relative Rate of conversion to Open Water.

3. The study is probably underestimating the creation of wetlands by inland migration. Regional studies indicate that historically the U.S. mid-Atlantic (Chen and Kirwan, 2022) and Gulf Coast of Florida (Raabe and Stumpf, 2016) have expanding marshes,

yet they appear to show up as contracting on the author's change map (Figure 1). Similar conclusions were found by the global-scale analysis of Campbell, who highlighted the Chesapeake Bay as one of their case-studies of contraction. This manuscript uses the same input data so gets the same incorrect output. Essentially, the results are only as good as the underlying data, which of course is challenging at the global scale.

Response: Thank you for your thoughtful and constructive comments. In response, we have implemented the following revisions and clarifications:

(1) Data selection and regional interpretation: For the integrated salt marsh data, we used the longer-term dataset from Murray et al. (2022) rather than that of Campbell et al. (2022). For the two regions you highlighted, we extracted a regional 0.25° grid-cell salt marsh change map from our global product (see attached **Fig. R1**). The map indicates that ~50% of the area remain stable, while ~11% exhibit net gain. According to our definition of stability ($|\text{RRAC}| < 0.01\% \text{ yr}^{-1}$), some of the stable regions likely correspond to relatively modest expansion relative to total wetland extent, which is not necessarily inconsistent with the findings of Chen & Kirwan (2022) and Raabe & Stumpf (2016).

(2) Dataset discrepancies and robustness checks: We acknowledge spatial discrepancies between the two salt-marsh datasets and between the two mangrove datasets at the grid-cell level (**Supplementary Fig. 13**). To ensure that our global-scale patterns are not unduly influenced by local errors in any single dataset, we conducted integrated analyses using multiple datasets. To test whether regional differences affect our overall conclusions, we applied the same analytical workflow to each dataset individually (**Supplementary Fig. 15**). The results consistently show similar nonlinear trends and threshold locations, confirming that our global-scale findings remain robust across both individual and integrated datasets despite dataset-specific regional biases. Relevant text has been added to the **Methods** and **Discussion** sections.

(3) Improved visualization of spatial patterns: In **Figure 1a**, solid circles have been replaced with hollow circles, with rim color representing categorical classification. This adjustment addresses the issue where large circles representing extensive wetland areas overlapped and obscured information in adjacent grid cells. Specifically, in southern Florida, mangrove-dominated grid cells showing loss previously masked the

stable/expanding signals of neighboring salt-marsh grids to the north. The revised display allows these signals to be seen clearly.

(4) **Limitations regarding global-to-regional inference:** We agree that translating global-scale monitoring to region-specific insights remains a challenge, and we have added corresponding limitations in the **Discussion**.

All corresponding additions and revisions are included in the revised manuscript.

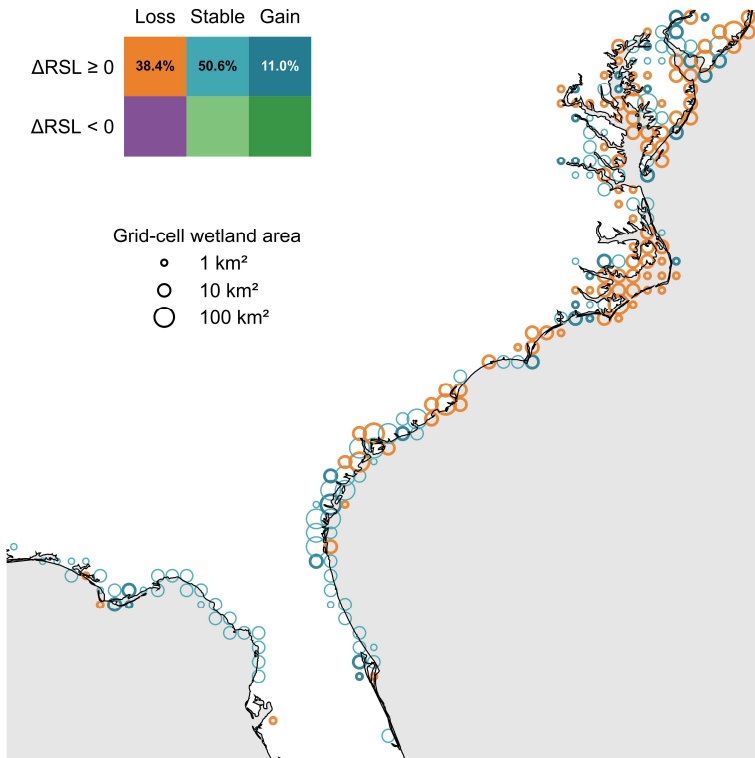


Fig. R1 | Grid-cell wetland area change under sea-level change along the southeastern U.S. coast, showing stable or inland migration around the Gulf Coast of Florida and Chesapeake bay.

In the Discussion As:

“...Fourth, local resilience may be overestimated because regional variability is smoothed in a globally aggregated response, potentially obscuring site-specific sensitivities and adaptation limits^{4,51,75}.” (See tracked version, Line 554-556)

“Global-scale datasets may inaccurately resolve coastal wetlands regionally. For example, Campbell et al. (ref.³⁴) likely underestimates historical salt marsh

expansion along the U.S. mid-Atlantic and Gulf Coast of Florida, diverging from region-focused studies^{82,83}.” (See tracked version, Line 599-602)

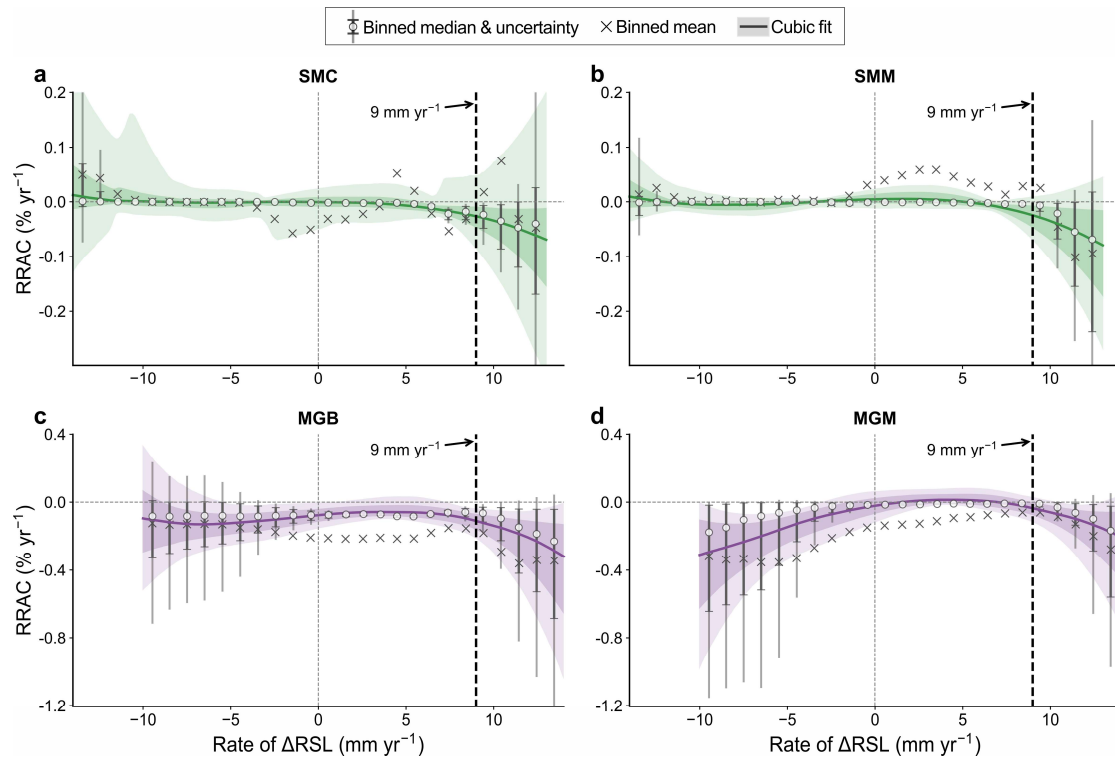
“...Repeating the Fig. 2f-g analyses across individual datasets further validates the nonlinear RRAC threshold trends (Supplementary Fig.15).” (See tracked version, Line 621-623)

“...Looking forward, future studies should explicitly integrate lateral processes, species-specific interactions, longer-term response monitoring and heterogeneous coastal boundary conditions to enable more robust and site-specific projections.” (See tracked version, Line 639-641)

In the Methods As:

“...in order to maximize observed change detection and cross-validate the robustness of global patterns against localized errors.” (See tracked version, Line 667-669)

“Individual datasets. For each individual area-change dataset, we performed a binned loss-gain analysis based on the corresponding RSL change rates, without introducing uncertainties associated with total extent estimates or the identification of no-change areas. Additionally, we calculated RRAC for individual datasets, to assess consistency across different area-change products.” (See tracked version, Line 913-917)



Supplementary Fig. 15 | RRAC trends across RSL change rates from individual wetland area change datasets. Each panel corresponds to an individual wetland area change dataset analyzed as a function of RSL change (SMC: salt marshes from Campbell et al. (2022); SMM: salt marshes from Murray et al. (2022); MGB: mangroves from Bunting et al. (2022); MGM: mangroves from Murray et al. (2022)). Circles and crosses denote the medians of binned medians and binned means, respectively. Grey error bars represent the 66% and 90% uncertainty ranges. The black vertical dashed line marks the threshold position. The colored curves show cubic fits to the binned medians, with darker and lighter shaded envelopes indicating the 66% and 90% uncertainty ranges, respectively.

4. Could it be that the higher than expected threshold rates of sea level rise are due to marsh progradation into open water in large river deltas? As noted in the previous comment, I don't think the underlying dataset is correctly identifying net marsh expansion, at least in the mid-Atlantic, but the work does seem to correctly identify net wetland expansion in proximity to large deltas on the coast of China and India/Bangladesh. The current study attributes higher than expected thresholds to lateral migration of wetlands into uplands. Could progradation (Nienhuis et al., 2020), or even restoration (Murray et al., 2022) be a better explanation?

Matt Kirwan

Response:

We wish to stress that indeed there are likely numerous other drivers of wetland change, some of which may be more impactful even on a global scale.

However, the point of our paper is to detect the effect of RSL. This is of course relevant because of anticipated future change in RSL. But as you know it has been proven very challenging exactly because of its subtle effect thusfar.

In response to your suggestion, we have refined the mechanistic interpretation in the revised **Discussion**. We now frame the lateral resilience of wetlands as resulting from a combination of processes, including inland migration, seaward progradation (especially in sediment-rich deltaic systems; Hou et al., 2024), and human-led restoration (FAO, 2023). This broader perspective better aligns with the complex drivers of wetland area change and provides a more nuanced explanation for the elevated threshold for lateral change identified in this study.

As: “... Under low-to-moderate RSL rise rates, both metrics show resilience, primarily attributable to vertical accretion: organic and mineral accumulations raise surface elevation, reducing submergence risk^{5,18,27,44} and, enable seaward progradation with sufficient external sediment supply in deltaic settings⁴⁵⁻⁴⁷, such as the eastern section of the Ganges-Brahmaputra-Meghna Delta (ref.⁴⁸; Fig. 1a) and the Changjiang Delta (ref.⁴⁹; Supplementary Fig. 4b). Our analysis on the function of SSC also corroborates this pattern (Fig. 4a-c). Notably, net change shows a higher area-based threshold ($\sim 9 \text{ mm yr}^{-1}$ versus $\sim 8 \text{ mm yr}^{-1}$) and a lower probability of decline ($>66\%$, likely) under accelerating RSL rise compared to inundation-driven loss ($>95\%$, extremely likely) (Table 2; Table 3; Supplementary Table 2). This indicates that lateral reorganization has provided a quantifiable buffer against tidal wetland area degradation driven by high RSL rise rates. This likely arises because when RSL rise exceeds vertical accretion capacity, wetland area may not decline immediately if landward migration is possible (refs.^{4,50-52}; Supplementary Fig. 4c, Supplementary Fig. 5b), and gains can sometimes exceed losses¹⁹. Sediment derived from lateral erosion can also contribute to vertical accretion, potentially allowing wetlands to partially adapt to rising sea levels^{53,54}. Additionally, wetland restoration efforts have contributed to slowing area decline^{3,55}. Overall, global tidal wetlands may demonstrate moderate lateral resilience to

accelerating RSL rise under the combined natural and anthropogenic forcing.”

(See tracked version, Line 417-441)

References

- Schuerch, M., Spencer, T., Temmerman, S., Kirwan, M. L., Wolff, C., Lincke, D., McOwen, C. J., Pickering, M. D., Reef, R., Vafeidis, A. T., Hinkel, J., Nicholls, R. J., & Brown, S. (2018). Future response of global coastal wetlands to sea-level rise. *Nature*, 561(7722), 231–234.
- Langston, A. K., Alexander, C. R., Alber, M., & Kirwan, M. L. (2021). Beyond 2100: Elevation capital disguises salt marsh vulnerability to sea-level rise in Georgia, USA. *Estuarine, Coastal and Shelf Science*, 249, 107093.
- Mariotti, G., & Carr, J. (2014). Dual role of salt marsh retreat: Long-term loss and short-term resilience. *Water Resources Research*, 50(4), 2963–2974.
- Murray, N. J., Worthington, T. A., Bunting, P., Duce, S., Hagger, V., Lovelock, C. E., Lucas, R., Saunders, M. I., Sheaves, M., Spalding, M., Waltham, N. J., & Lyons, M. B. (2022). High-resolution mapping of losses and gains of Earth’s tidal wetlands. *Science*, 376(6594), 744–749.
- Kemp, A. C., Horton, B. P., Donnelly, J. P., Mann, M. E., Vermeer, M., & Rahmstorf, S. (2011). Climate related sea-level variations over the past two millennia. *Proceedings of the National Academy of Sciences*, 108(27), 11017–11022.
- Mu, D., Huang, R., Yin, P., Yan, H., & Xu, T. (2025). Reconstructing sea level rise from global 945 tide gauges since 1900. *Earth System Science Data*, 17(10), 5507–5528.
- Campbell, A. D., Fatoyinbo, L., Goldberg, L., & Lagomasino, D. (2022). Global hotspots of salt marsh change and carbon emissions. *Nature*, 612(7941), 701–706.
- Chen, Y., & Kirwan, M. L. (2022). Climate-driven decoupling of wetland and upland biomass trends on the mid-Atlantic coast. *Nature Geoscience*, 15(11), 913–918.
- Raabe, E. A., & Stumpf, R. P. (2016). Expansion of Tidal Marsh in Response to Sea-Level Rise: Gulf Coast of Florida, USA. *Estuaries and Coasts*, 39(1), 145–157.
- Hou, X., Xie, D., Feng, L., Shen, F., & Nienhuis, J. H. (2024). Sustained increase in suspended sediments near global river deltas over the past two decades. *Nature Communications*, 15(1), 3319.
- FAO. (2023). The world’s mangroves 2000–2020. FAO.

Please refer to the manuscript for the references indicated by superscripts in the revised text.

Reviewer #2 (Remarks to the Author):

The study analyzes two decades of satellite observations to identify thresholds in tidal wetland loss associated with relative sea-level rise (RSLR) at the global scale. The methodological framework is generally sound and clearly described, and the authors carefully consider uncertainties throughout the manuscript. By focusing on the lateral dynamics of wetland extent, the study provides a useful complement to previous work that has primarily examined vertical wetland adjustment to sea-level rise. Overall, the manuscript offers a potentially valuable contribution to the coastal wetland literature. I recommend publication after the following issues are addressed:

1. The tidal wetland change dataset used in the analysis could be further refined. In the current framework, the authors use gross loss as the response variable (relative rate of area change, RRAC). However, RSLR is not the dominant global driver of tidal wetland loss; anthropogenic clearing remains the primary cause, particularly for mangroves (Goldberg et al., 2020). As a result, a substantial portion of the RRAC signal likely originates from non-sea-level drivers.

Because these losses are not filtered out, they may obscure the signal of RSLR, especially at lower rates of sea-level rise. This has important implications for threshold detection: losses caused by other drivers may mask the early signal of RSLR, making the RSLR effect detectable only when rates become sufficiently high. Consequently, the estimated threshold (e.g., ~9 mm/yr) may be biased upward.

I therefore suggest restricting RRAC to wetland losses that are attributable to sea-level rise. A simple approach could be to focus on wetland areas that convert to open water, which is a common outcome of inundation-driven loss. For example, intersecting the wetland-loss layer with the 2020 ocean extent layer could provide a direct estimate of tidal wetland loss associated with sea-level rise. Note that aquaculture ponds should also be excluded, as they can produce similar land-water transitions but are unrelated to RSLR. This filtering step would substantially strengthen the causal interpretation of the analysis.

Response: We sincerely thank the reviewer for this highly constructive suggestion. In response, we have implemented the proposed filtering procedure to more directly isolate wetland loss attributable to relative sea-level (RSL) rise. Specifically, we used the permanent fraction of global surface water in 2020 (Pekel et al., 2016) and removed

aquaculture-pond clusters (Wang et al., 2022) to derive a “non-aquaculture open-water” mask. The intersection of this mask with wetland-loss patches from the four tidal-wetland change datasets provides a direct estimate of inundation-driven loss. We then applied the same analytical procedure as for RRAC to compute a new metric, RROW (Relative Rate of conversion to Open Water), which is introduced in the revised **Introduction** and **Methods** sections. We have also updated the study workflow, which is now presented in **Supplementary Fig. 18**.

Analysis of RROW shows that as the RSL rise rate increases, the probability of accelerated loss (i.e., an increasing loss rate) approaches 100% (**Table 2**; **Supplementary Fig. 2**). Threshold detection further indicates that when RSL rise exceeds $\sim 8 \text{ mm yr}^{-1}$, the probability of a steep increase in inundation-driven loss also nears 100% (**Supplementary Fig. 3**; **Supplementary Table 2**). These results robustly demonstrate that rising RSL rates exert a strong, detectable influence on direct inundation loss.

At the same time, we have retained the original metric of net area change (RRAC). Within the same analytical framework, we can now compare the two metrics: RROW isolates inundation-driven loss (reflecting the lateral expression of vertical processes), whereas RRAC captures overall lateral dynamics, implicitly integrating both vertical and lateral processes. This comparison further allows us to more clearly discuss the respective roles of vertical and lateral resilience mechanisms in the revised **Discussion**.

Once again, we highly appreciate this valuable suggestion, which has not only strengthened the causal interpretation of our findings, but also clarify the comparison between lateral and vertical processes. All corresponding revisions are reflected in the **Introduction**, **Results**, **Discussion**, and **Methods** sections, along with updates to **Tables 1-2** and new supporting material in **Supplementary Figs. 2-3** and **Supplementary Table 2**.

In the Introduction As: “...To explore overall lateral dynamics and inundation-related loss in tidal wetlands, we calculate the relative rate of net area change (still referred to as RRAC hereafter) and separately for the area converted to open water (hereafter RROW).” (**See tracked version, Line 82-85**)

In the Results As: “Despite the influence of non-RSL drivers, RSL rise remains a discernible driver of tidal wetland area loss via direct inundation. In contrast to RRAC, which reflects net area change, RROW isolates inundation-driven loss and displays a greater propensity for both an overall declining trend and nonlinear

behavior, with probabilities for both two trends approaching 100% (Table 2; Supplementary Fig. 2). Applying the same threshold detection method, we identify a global threshold of $\sim 8 \text{ mm yr}^{-1}$ for RROW (Supplementary Fig. 2). Beyond this point, the slope of RROW relative to RSL rise rate steepens with 100% probability compared to preceding intervals (Supplementary Table 2), increasing from $0.0006 \% \text{ mm}^{-1}$ (0.0003 to 0.0008 , very likely range) to $0.0105 \% \text{ mm}^{-1}$ (0.0048 to 0.0185 , very likely range)—an approximately 18-fold intensification (Supplementary Fig. 3). These high probabilities indicate that as RSL rise rates exceed a critical threshold, the risk of wetland loss driven directly by RSL inundation inevitably escalates.” (See tracked version, Line 223-235)

“When considering inundation-related loss alone, abrupt acceleration in loss rate is more likely to occur at $\sim 8 \text{ mm yr}^{-1}$ (Supplementary Fig. 3d-i), with the probability of slope increase from the $0-8$ to the $>8 \text{ mm yr}^{-1}$ interval approaching 100% for both ecosystems (Supplementary Table 2). Threshold behavior is further supported by cubic fits: RRAC shows $>85\%$ probability of tail decay (i.e., accelerated net area loss) in both wetland types, and RROW indicates 100% probability of tail rise (i.e., accelerated conversion to open water) in salt marshes and 96% in mangroves (Table 2).” (See tracked version, Line 241-247)

“...Further evidence of loss acceleration in salt marshes is provided by the probability of a rising linear trend in binned median RROW: 100% versus 80% in mangroves (Table 2)...” (See tracked version, Line 325-327)

In the Discussion As: “...Among the two types of area changes we quantified, conversion to open water represents the lateral manifestation of vertical inundation processes, while net area change integrates both lateral and vertical processes. Under low-to-moderate RSL rise rates, both metrics show resilience, primarily attributable to vertical accretion: organic and mineral accumulations raise surface elevation, reducing submergence risk^{5,18,27,44} and, enable seaward progradation with sufficient external sediment supply in deltaic settings⁴⁵⁻⁴⁷, such as the eastern section of the Ganges-Brahmaputra-Meghna Delta (ref.⁴⁸; Fig. 1a) and the Changjiang Delta (ref.⁴⁹; Supplementary Fig. 4b). Our analysis on the function of SSC also corroborates this pattern (Fig. 4a-c). Notably, net change shows a higher area-based threshold ($\sim 9 \text{ mm yr}^{-1}$ versus $\sim 8 \text{ mm yr}^{-1}$) and a lower probability of decline ($>66\%$, likely) under accelerating RSL rise compared to inundation-driven loss ($>95\%$, extremely likely) (Table 2; Table 3; Supplementary

Table 2). This indicates that lateral reorganization has provided a quantifiable buffer against tidal wetland area degradation driven by high RSL rise rates.” (See tracked version, Line 414-431)

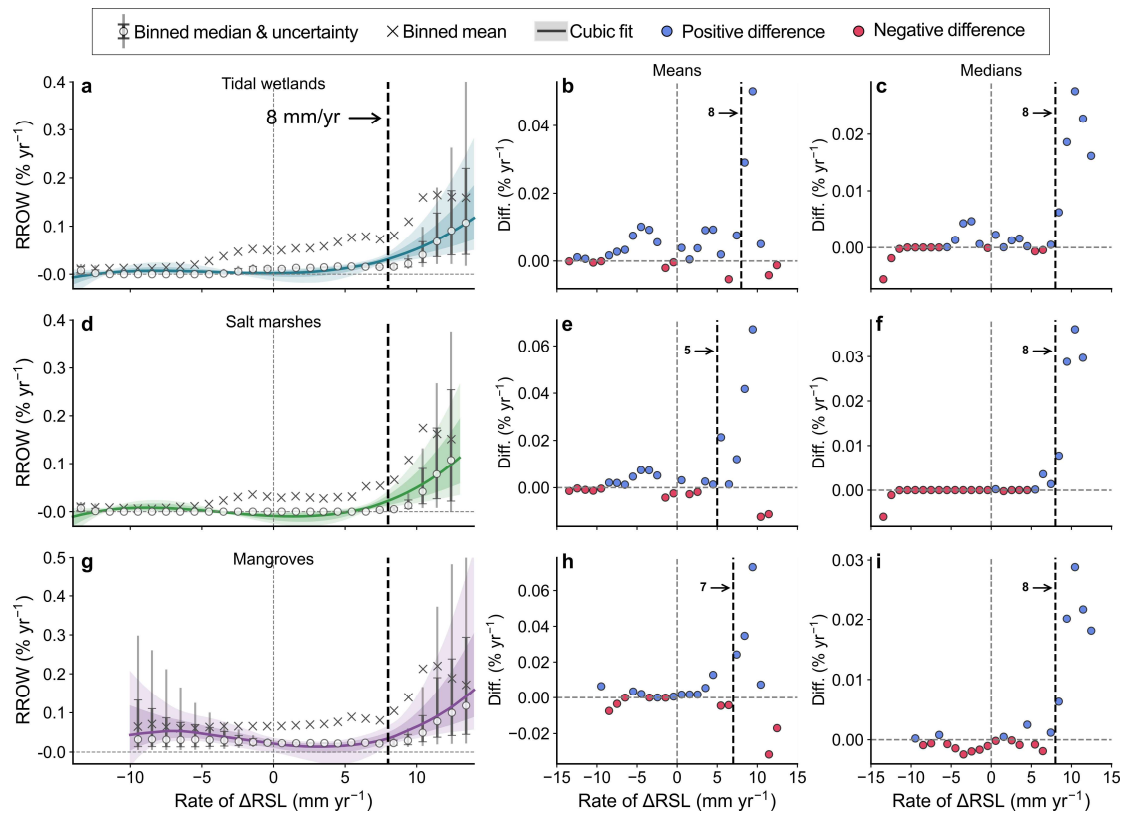
“In conclusion, we reveal a global nonlinear response in tidal wetland area change with increasing relative sea-level rise, with thresholds of apparent loss acceleration of $\sim 9 \text{ mm yr}^{-1}$ for overall lateral dynamics and $\sim 8 \text{ mm yr}^{-1}$ for inundation-related loss. ” (See tracked version, Line 628-633)

In the Methods As: “...comprising overall lateral dynamics (net change) and inundation-related loss (area directly converted to open water) ...” (See tracked version, Line 648-649)

“As a counterpart to the overall lateral dynamics, we conducted a parallel analysis of direct inundation-driven wetland loss. We first obtained the 2020 global permanent surface water distribution⁸⁷. We removed areas overlapping with the 2020 global aquaculture pond clustering⁸⁸, yielding the natural open water mask. We then intersected the loss pixels from the tidal wetland datasets with this natural open water mask to extract wetland area converted to open water. Finally, we applied the RRAC gridding procedure to calculate RROW (Relative Rate of conversion to Open Water) for each valid grid cell.” (See tracked version, Line 712-719)

Table 2 | Probability of declining trends in binned medians and means of RRAC and RROW across RSL change rate bins using different fitting methods (linear and cubic) (for grid cells with total wetland area $> 1 \text{ km}^2$). For each type, the upper and lower rows correspond to fits using binned medians and binned means, respectively. Declining RRAC and rising RROW linear trends indicate overall intensifying loss with RSL change rate; cubic fits show RRAC tail decay and RROW tail rise, suggesting nonlinear intensification and potential threshold effects.

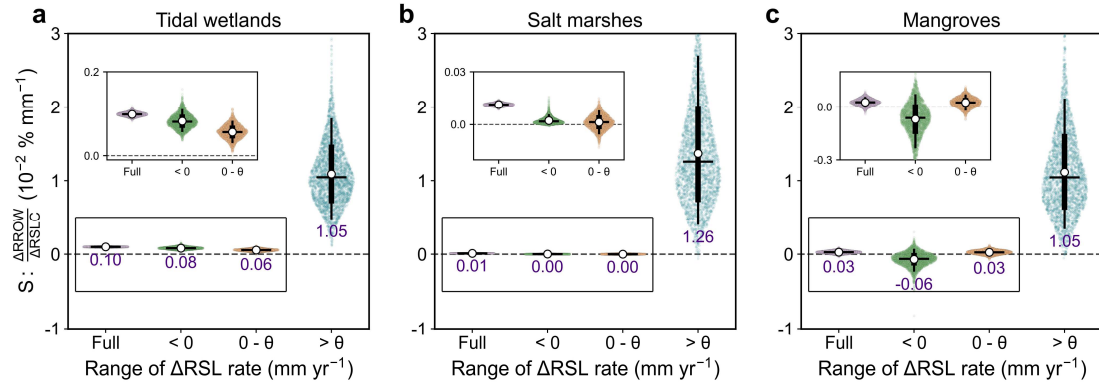
Type	RRAC (Net change)		RROW (Loss to open water)	
	Probability of a declining linear trend	Probability of tail decay in Cubic fits	Probability of a rising linear trend	Probability of tail rise in Cubic fits
Tidal wetlands	98.4%	87.6%	100.0%	99.5%
	95.7%	74.7%	100.0%	95.3%
Salt marshes	89.4%	85.2%	100.0%	100.0%
	69.7%	86.7%	100.0%	99.6%
Mangroves	67.5%	85.8%	80.0%	95.9%
	79.9%	71.7%	97.9%	88.6%



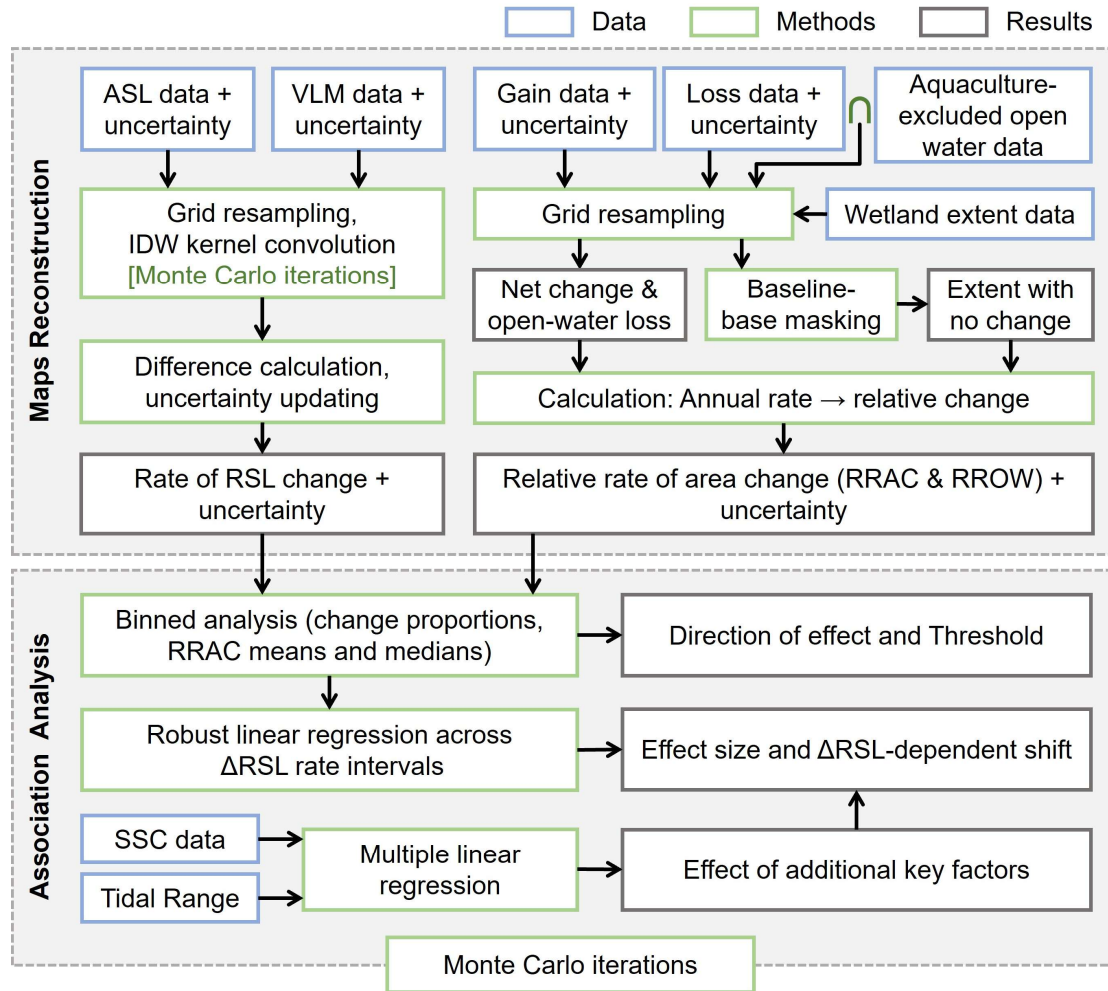
536

537 *Supplementary Fig. 2 | Effect of RSL change on wetland inundation-driven area loss.*
 538 *Trend in relative rate of conversion to open water (RROW) as a function of RSL change*
 539 *rate, along with binned means and medians, are shown for (a) all tidal wetlands, (d)*
 540 *salt marshes and (g) mangroves. Circles and crosses denote the medians of binned*
 541 *medians and binned means, respectively. The grey error bars represent the 66% and*
 542 *90% uncertainty ranges. The black vertical dashed line marks the threshold position,*
 543 *taken as the maximum of the values identified in the two right-hand panels. The colored*
 544 *curves show cubic fit to the binned medians, with darker and lighter shaded envelopes*
 545 *indicating the 66% and 90% uncertainty ranges. Only bins containing more than three*
 546 *grid cells are shown. Correspondingly, bin-to-bin differences mean RROW (b, e, h), and*
 547 *median RROW (c, f, i) across RSL change rates are shown for tidal wetlands, salt*
 548 *marshes and mangroves. Red and blue circles indicate negative and positive differences,*
 549 *respectively. The black vertical dashed lines mark the left edges (lower-boundary*
 550 *positions) of the identified bins, representing the onset points where the same wetland*
 551 *type exhibits abrupt increases in RROW (as indicated by binned means and medians).*

552



Supplementary Fig. 3 | Robust (Huber) regression slopes of RROW versus RSL change rate across different rate intervals. Results are shown for four RSL change rate intervals: full range, < 0 , $0 - \theta$ ($\theta = 8 \text{ mm yr}^{-1}$), and $> \theta$. In each violin body, the thick and thin vertical black lines represent the 66% and 90% uncertainty ranges, respectively; the white dot represents the mean, and the black horizontal line represents the median. Each colored scatter point represents the result of a single Monte Carlo simulation. Inset plot showing enlarged detail of intervals Full, < 0 and $0 - \theta$. Purple number indicates the median slope value of each group. The number of grid cells within each interval and probabilities from pairwise comparisons between intervals are reported in Supplementary Table 1.



Supplementary Fig. 18 | Workflow of data processing and analytical framework. The diagram summarizes the construction of RSL change and RRAC and RROW maps with uncertainty propagation, and subsequent association and attribution analyses (ASL: Absolute Sea-Level trend; VLM: Vertical Land Motion trend; RRAC: Relative Rate of net wetland Area Change; RROW: Relative Rate of conversion to Open Water). Blue boxes indicate data inputs, green boxes denote processing and analytical methods, and grey boxes represent derived results. The inverted U shape represents the intersection between datasets.

Supplementary Table 2 | Slopes and their comparison probabilities from robust linear regressions (for RROW against Δ RSL rate). Values in parentheses indicate the likely range; values in square brackets indicate the very likely range.

($\theta=8$)	Δ RSL Interval (mm/yr)	Mean number of cells and proportion	Area proportion	Slope ($\times 10^{-2}$ %/mm)	Probability of slopes comparison	
Tidal wetlands	Full	7264	—	0.10 (0.09,0.10) [0.09,0.11]	(Full) < (> θ)	99.9%
	< 0	580 (8.0%)	7.2%	0.08 (0.07,0.10) [0.06,0.11]	(<0) < (> θ)	100.0%
	0 - θ	6444 (88.7%)	88.0%	0.06 (0.04,0.07) [0.03,0.08]	(0 - θ) < (> θ)	100.0%
	> θ	240 (3.3%)	4.8%	1.05 (0.69,1.49) [0.48,1.85]	(Full) < (0 - θ)	0.1%
					(<0) < (0 - θ)	11.7%
Salt marshes	Full	3171	—	0.01 (0.01,0.01) [0.01,0.01]	(Full) < (> θ)	99.9%
	< 0	420 (13.2%)	18.6%	0.00 (0.00,0.00) [0.00,0.01]	(<0) < (> θ)	99.9%
	0 - θ	2610 (82.3%)	65.6%	0.00 (-0.00,0.01) [-0.01,0.01]	(0 - θ) < (> θ)	99.9%
	> θ	141 (4.4%)	15.8%	1.26 (0.71,2.02) [0.40,2.70]	(Full) < (0 - θ)	0.3%
					(<0) < (0 - θ)	42.0%
Mangroves	Full	4760	—	0.03 (0.01,0.05) [-0.00,0.06]	(Full) < (> θ)	99.8%
	< 0	173 (3.6%)	4.0%	-0.06 (-0.15,0.02) [-0.23,0.07]	(<0) < (> θ)	99.9%
	0 - θ	4460 (93.7%)	93.5%	0.03 (-0.00,0.05) [-0.02,0.07]	(0 - θ) < (> θ)	99.8%
	> θ	127 (2.7%)	2.5%	1.05 (0.60,1.63) [0.34,2.12]	(Full) < (0 - θ)	46.6%
					(<0) < (0 - θ)	84.8%
					(Full) < (<0)	14.0%

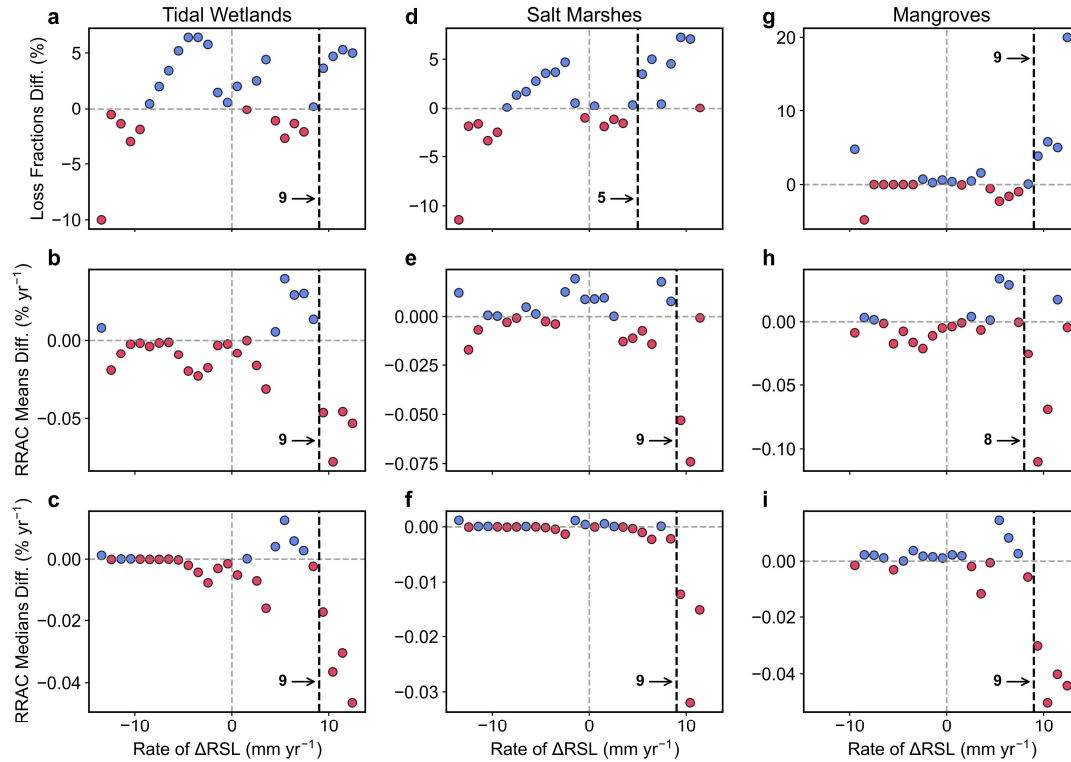
2. The identification of the RSLR threshold requires clearer and more quantitative justification. I may have overlooked it, but the manuscript does not explicitly explain how the value of 9 mm/yr was determined from the curves shown in Fig. 2.

The authors report similar thresholds (~9 mm/yr) for both salt marshes and mangroves and interpret the results as indicating that salt marshes gradually decline between 0-9 mm/yr while mangroves remain stable. However, visual inspection of Fig. 2 suggests that the breakpoint for salt marshes may occur closer to ~7.5 mm/yr, whereas mangroves indeed appear to exhibit a threshold near ~9 mm/yr. This pattern would imply that the two ecosystems may have distinct thresholds, with salt marshes reaching their tipping point at a lower RSLR rate. Prior to their respective thresholds, both ecosystems appear relatively resilient, but mangroves tolerate higher rates of sea-level rise. The manuscript would benefit from a formal breakpoint detection method (e.g., segmented regression or change-point detection) to objectively determine these thresholds.

Response: We thank the reviewer for the suggestion to clarify the threshold identification method. In the revised manuscript, we have consolidated the description into a concise and rigorous statement.

Here, the cubic curve serves only to evaluate the statistical probability of a nonlinear acceleration of loss, rather than to identify the threshold, because it cannot fully capture bin-to-bin variations. We therefore identified the change point directly from the first-order differences of the binned values. Applying this approach, the thresholds obtained for salt marshes and mangroves are similar, as shown for RRAC in Supplementary Fig.1 (9 mm yr⁻¹) and the RROW presented above in Supplementary Fig.2 (8 mm yr⁻¹). We have added the definition and identification in the Results section accordingly.

In the Results As: “We define the threshold θ as the RSL rise rate at which wetland loss abruptly accelerates. To identify θ , we examine the bin-wise first-order differences of ensemble medians for loss fraction, mean RRAC, and median RRAC. The threshold is marked by the first bin where these differences break from zero-centered oscillations to exceed all preceding magnitudes (Supplementary Fig. 1). We adopt the maximum θ across the three indicators, which represents the latest plausible onset of accelerated loss, and yields 9 mm yr⁻¹ for tidal wetlands (Fig. 2d, Supplementary Fig. 1). Beyond 9 mm yr⁻¹, loss fraction differences remain positive while RRAC differences plunge negative; below it, all differences fluctuate around zero (Supplementary Fig. 1a-c).” (See tracked version, Line 175-190)



Supplementary Fig. 1 | Bin-to-bin differences in loss fraction, mean RRAC, and median RRAC across RSL change rates. For each pair of adjacent bins, the difference (later bin minus earlier bin) is calculated and plotted at the center of the earlier bin. Red and blue circles indicate negative and positive differences, respectively. The black vertical dashed lines mark the left edges (lower-boundary positions) of the identified bins, representing the onset points where the same wetland type exhibits increased loss fraction and abrupt decreases in RRAC (as indicated by binned means and medians). The maximum of these three threshold positions is taken as the final critical threshold for abrupt area loss.

3. The section “Roles of tidal range and sediment availability” appears somewhat disconnected from the central research question of the paper. The primary objective of the study is to quantify the relationship between RSLR and tidal wetland area change, yet this section shifts the focus to examining the independent effects of tidal range and sediment availability on wetland change. A more consistent approach would be to incorporate tidal range and sediment availability as interaction terms in Eq. 3. This would allow the authors to test whether the effect of RSLR on wetland loss is modulated by tidal range or sediment supply, directly addressing how environmental context influences wetland resilience to sea-level rise.

Response: We highly appreciate your valuable suggestion. You are absolutely right. To better align with the previous context, we have incorporated the interaction terms between tidal range and RSL change rate, and between SSC and RSL change rate, respectively, as you suggested. In addition, to explore how the effects of these two factors vary across different RSL change rate ranges, we also performed multiple linear regressions over consecutive 3 mm yr⁻¹ intervals without the interaction term. This approach also allows us to visualize the changes in the effects of tidal range and SSC under different RSL change rates at fixed intervals. Based on the above, we have revised Fig. 4 (see the updated figure below). Corresponding revisions have also been made in all relevant parts of the manuscript, including Results, Discussion and Methods.

In the Results As: “...However, the interaction between tidal range and RSL change rate differs between the two ecosystems (Fig. 4a-c). In salt marshes, a larger tidal range buffers RSL-driven area loss (coefficient: 0.009 to 0.022, very likely range), whereas in mangroves it weakens this buffering effect (coefficient: -0.037 to -0.005, likely range). Multiple linear regressions, stratified by 3 mm yr⁻¹ intervals of RSL change rate, clarify this divergence. For salt marshes, the effect of tidal range is negative where RSL change rate < 0, becomes positive in the 3~6 mm yr⁻¹ interval, and remains positive at higher RSL change rates (Fig. 4e). In contrast, mangroves show a diminished positive effect across 0~9 mm yr⁻¹, which strengthens beyond the ~9 mm yr⁻¹ threshold (Fig. 4f).” (See tracked version, Line 350-362)

“...In salt marshes, SSC exhibits a consistently positive effect (0.027 to 0.036, very likely range; Fig. 4b), but negative in mangroves (-0.026 to -0.010, very likely range; Fig. 4c). Notably, the SSC-RSL change rate interaction term is likely positive in both wetland types (salt marshes: 0.009 to 0.022; mangroves: 0.006 to 0.029; likely range; Fig. 4b, c), indicating that higher SSC generally mitigates RSL-driven area loss despite the contrasting standalone effects of SSC. This pattern is further supported by stratified regressions that exclude the interaction term, in which the effect of SSC shifts from negative or near-neutral when RSL change rate < 0 to positive when RSL change rate > 0 (Fig. 4d-f).” (See tracked version, Line 369-385)

“...Moreover, both influences become more pronounced in resisting RSL-driven loss under higher RSL change rates, acting as compensatory mechanisms under accelerating RSL rise.” (See tracked version, Line 389-392)

In the Discussion As: “These processes complicate the role of sediment dynamics in large-scale wetland responses to RSL rise. However, the interaction term between SSC and RSL change rate is positive in both wetland types, suggesting increasing SSC under accelerating RSL rise could compensate for inundation risk.” (See tracked version, Line 503-506)

In the Methods As: “The final model is expressed as:

$$RRAC = \beta_0 + \beta_1 \widetilde{RSLC} + \beta_2 \widetilde{SSC} + \beta_3 \widetilde{TR} + \beta_4 \widetilde{RSLC} \times \widetilde{SSC} + \beta_5 \widetilde{RSLC} \times \widetilde{TR} + \varepsilon \quad (3)$$

where variables with a tilde ($\sim$) denote standardized values; β_0 represents the expected RRAC when all independent variables are at their mean values; β_1 - β_3 indicate the change in RRAC ($\% \text{ yr}^{-1}$) associated with a 1σ increase in each single variable, holding others constant; β_4 - β_5 are the coefficients of the interaction terms related to RSL change rate; ε is the error term. This model was then applied the model to all valid data to estimate the global contributions of each variable to RRAC.

To further examine how the effects of SSC and tidal range vary across different RSL change rate ranges, we performed multiple linear regressions without interaction terms over consecutive 3 mm yr^{-1} intervals of RSL change rate. Only intervals with over 8 valid data points were retained for reliable estimation. To enable cross-interval comparison, we rescaled the coefficients by the ratio of each factor's within-interval standard deviation to the mean of its standard deviations (σ) across all intervals. This allows every coefficient to be interpreted on a common scale. By tracking changes in these effect coefficients across rate intervals, we are able to assess how the contributions of SSC and tidal range to wetland area change vary with RSL change rates.” (See tracked version, Line 864-883)

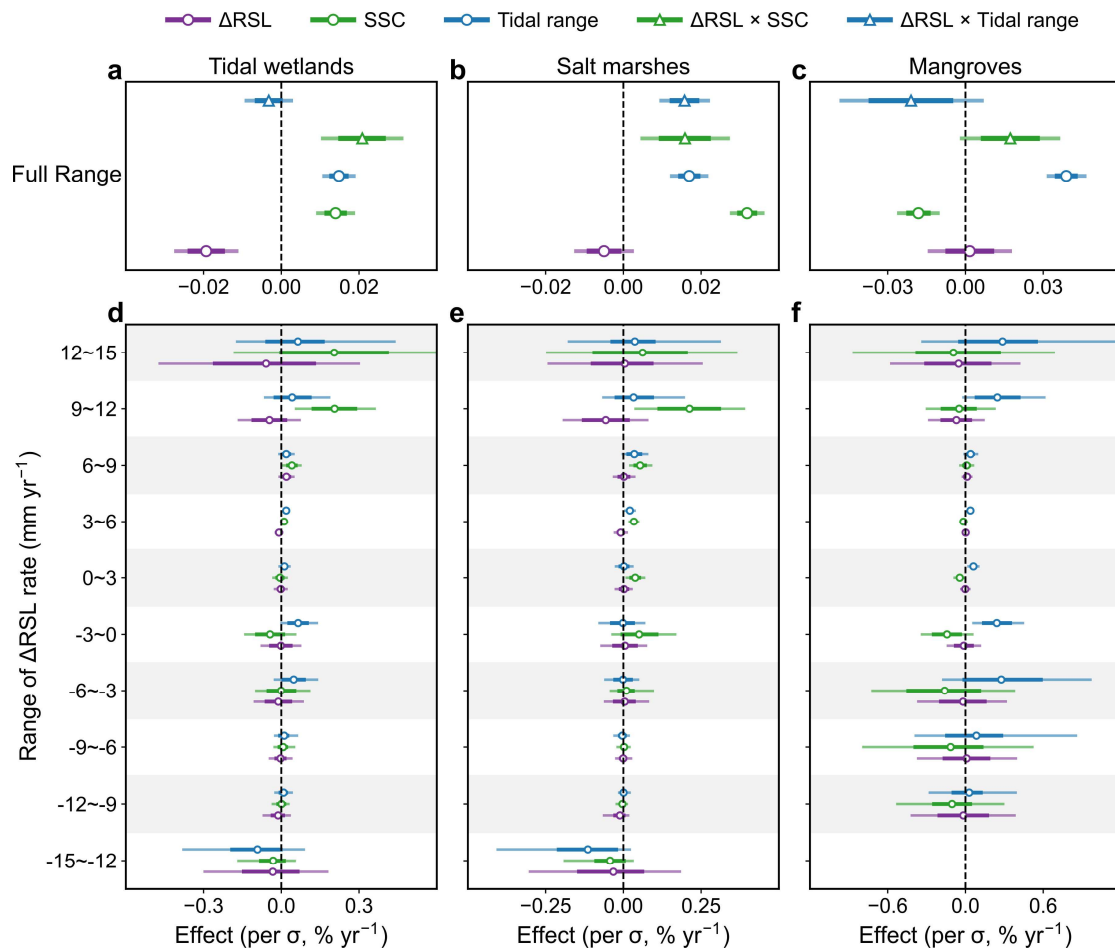


Fig. 4 | Effects estimated from multiple linear regression explaining RRAC as a function of RSL change rate, tidal range, and SSC. (a-c) Global multiple linear regressions incorporating interaction terms between RSL change rate and each of tidal range and SSC, for tidal wetlands, salt marshes, and mangroves, respectively. (d-f) Stratified multiple linear regressions excluding interaction terms, with effects estimated within 3 mm yr⁻¹ intervals of RSL change rate for tidal wetlands, salt marshes, and mangroves, respectively. Circles denote mean coefficients of independent terms; triangles denote mean coefficients of interaction terms. Horizontal thick, dark lines represent the 66% uncertainty range (aligned with the IPCC likely range), while thin, light lines represent the 90% uncertainty range (IPCC very likely range). The corresponding σ values are provided in Supplementary Table 3.

Minor comments:

1. The current title “Observed thresholds in sea-level rise induced global tidal wetland loss” is somewhat imprecise. The threshold itself does not cause wetland loss; rather, loss accelerates once sea-level rise exceeds the threshold. A clearer title might be: “Observed thresholds in sea-level rise driving global tidal wetland loss”.

Response: Thank you for the suggestion. We fully agree. The title has been updated to “Observed thresholds in sea-level rise driving global tidal wetland loss”.

2. Line 21: Some datasets extend beyond 2000-2019 (e.g., mangrove data include observations from 1996). A broader phrase such as “the past two decades” may be more appropriate.

Response: As you suggested, this has been rephrased to “the past two decades”. (See tracked version, Line 23-24)

3. Line 27-29: This sentence is somewhat unclear. Both lateral expansion and vertical accretion can enhance wetland resilience, but this point is not directly related to the detected threshold differences.

Response: Thank you for pointing this out. Following your earlier suggestion to add the analysis of losses to open water, we subsequently compared the thresholds identified by net change and direct inundation, and found systematic differences between them. We attribute this to the effect of the overall lateral dynamics. The manuscript has been revised accordingly.

As: *“Globally, lateral wetland change exhibits a marginally higher threshold than direct inundation loss ($\sim 8 \text{ mm yr}^{-1}$), suggesting that lateral dynamics, modulated by tidal range and sediment supply, can partially buffer against rapid loss onset.”*
(See tracked version, Line 33-37)

4. Lines 93–94: The statement that 96.4% of mangrove areas experienced RSLR and 72.2% experienced net loss may be misleading. These losses are not necessarily caused by RSLR and are often driven by deforestation or land-use change. Without restricting RRAC to RSLR-related losses, the comparison may unintentionally imply causality.

Response: Many thanks for this insightful comment. As you previously suggested, we have added calculations of inundation-driven loss; please see our previous response on that matter. We also found your present remark highly valuable. In response, we have reframed the narrative by comparing the area-change fractions under positive versus negative RSL change rates, which allows us to broadly assess the potentially different roles of RSL rise and fall. The corresponding paragraph has been entirely rewritten. Our results indicate that both rising and falling RSL exert discernible effects on tidal wetlands. The text in the Results sections and Fig. 1e-g has been revised accordingly.

739 **As:** *“In terms of frequency, net loss occurs more commonly under rising RSL than under*
740 *falling RSL: 60.2% of tidal wetland grid cells experience net loss under RSL rise,*
741 *compared to 39.6% under RSL fall—a difference of 20 percentage points (Fig. 1e).*
742 *A relationship of similar magnitude is observed for individual wetland types. For*
743 *salt marshes, the proportion of net loss increases from 27.5% under RSL fall to*
744 *35.7% under RSL rise (Fig. 1f), whereas for mangroves it rises only slightly, from*
745 *67.1% to 69.3% (Fig. 1g). In contrast, the stable fraction (defined as $|RRAC| <$*
746 *$0.01\% \text{ yr}^{-1}$) is smaller under RSL rise (14.8%) than under fall (37.5%), while the*
747 *proportions of net gain differ by less than 3% (Fig. 1e). This pattern suggests a*
748 *potential shift from stable to loss states when RSL transitions from falling to rising.*
749 *In other words, although multiple factors contribute to tidal wetland loss^{2, 38-41}, the*
750 *shift from negative to positive RSL change increases the likelihood of net wetland*
751 *loss. Based on this rough estimate, and considering that over 90% of global*
752 *wetland extent currently lies in regions with rising RSL at a median rate of $\sim 4 \text{ mm}$*
753 *yr^{-1} (Fig. 1a-d), tidal wetlands have faced elevated loss risk over the past two*
754 *decades.” (See tracked version, Line 105-130)*

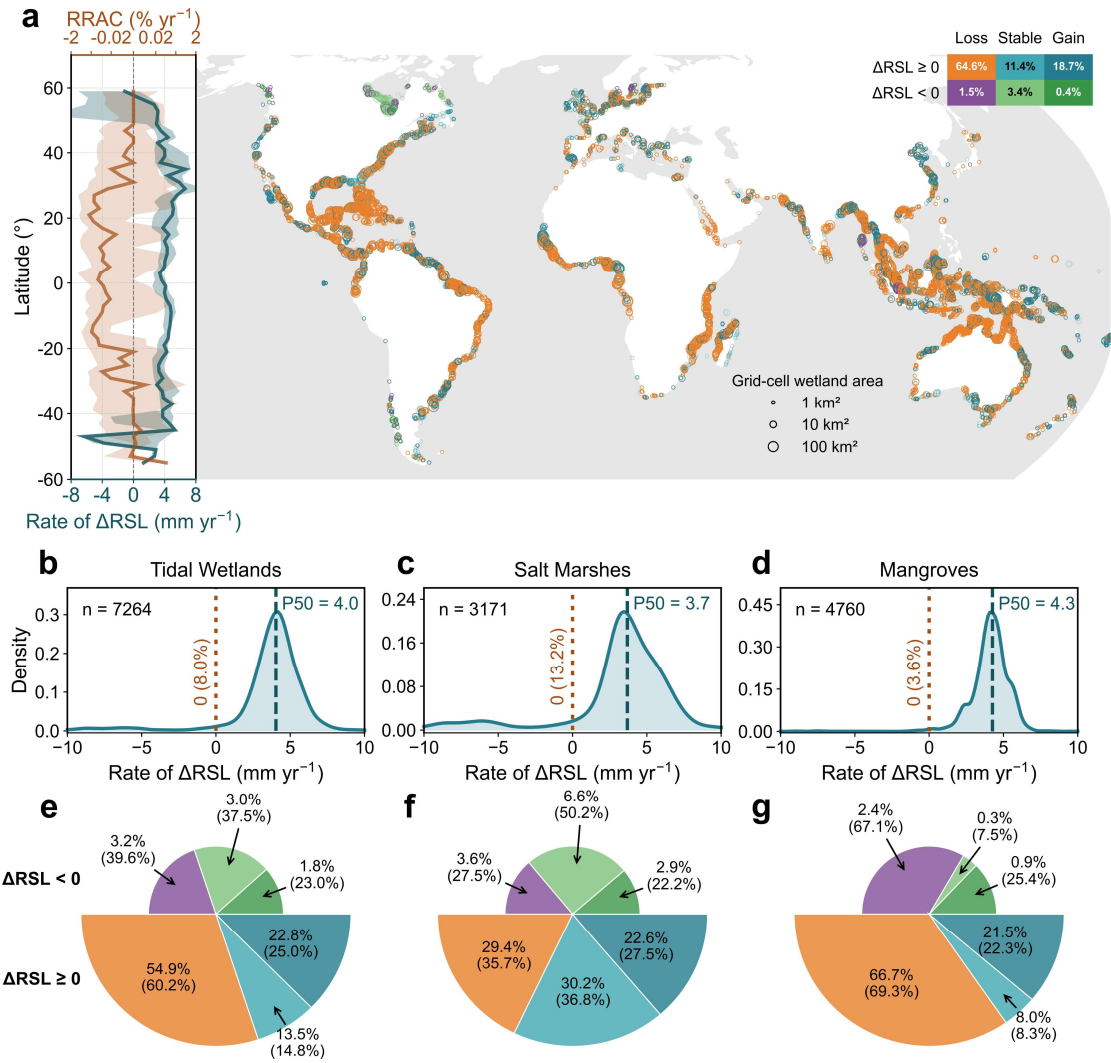


Fig. 1 | Global distribution of tidal wetland change and RSL change over the past two decades. (a) Spatial distribution of RRAC and RSL change at 0.25° resolution. Circle size indicates total tidal wetland area per grid cell and color denotes the bivariate classification of wetland change (loss, stable, gain) and RSL direction (rise or fall). The left panel shows medians (solid lines) and 66% uncertainty ranges (shaded) binned by 2° latitude (blue, RSL change; brown, RRAC). Percentages in the bivariate legend (upper right) report area-weighted proportions of the six RRAC-RSL change categories. Probability density function of RSL change for (b) all tidal wetlands, (c) salt marshes, and (d) mangroves. Orange and blue dashed lines indicate the proportion of grid cells with RSL fall and the median (P50) RSL change rate, respectively. Semi-circular pie charts (e–g) show the proportion of grid cells across the six categories for tidal wetlands (e), salt marshes (f) and mangroves (g), accounting for unequal areas under RSL fall versus rise. Upper values indicate percentages across all six categories (summing to 100%); values in parentheses show proportions within each RSL condition (fall or rise), with each side summing to 100%. Only grid cells with >1 km² of tidal wetland in both the initial and final years are included.

5. Figure 1a: The panel could be improved by reporting the percentage of global area represented by each category (e.g., $\Delta\text{RSL} > 0$ AND Loss).

Response: We have added the percentages on the bivariate color legend in the panel in Fig. 1a.

6. Line 182-183: This finding is interesting and consistent with previous studies, but it also suggests that signals from other drivers are present in the dataset. As noted above, this could be addressed by applying a simple ocean mask to isolate inundation-related losses.

Response: We have added an explanation after incorporating the analysis of inundation-related losses; please see our response to your first major comment for details.

7. Line 276: The relatively high threshold detected in this study may also be caused by spatial resolution. Because the analysis relies on 30-m wetland change data, only relatively large changes were detected, potentially leading to higher threshold estimates compared with site-based or finer-resolution studies.

Response: We agree with the limitation of observation scale, and we have added it in the Discussion section.

As: *“Our interpretation of wetland vulnerability based on these results may be conservative....our reliance on 30-m wetland change data may obscure fine-scale variations and inflate threshold estimates.”* (See tracked version, Line 536-537, 546-547)

8. Line 453: How is the “stable” category defined? When comparing two time periods, small pixel-level changes are likely inevitable. It would be helpful to clarify whether minor changes (e.g., one or two pixels) are considered "stable" or classified as "change".

Response: Thank you for your insightful comment. We defined “stable” as pixels where $|\text{RRAC}| < 0.01\% \text{ yr}^{-1}$. At this threshold, the stable category includes both previously identified no-change cells and cells with negligible pixel-level changes; over a 20-year period, this corresponds to a net change of approximately 2000 m² (~2 pixels) for a 1 km² grid cell. We have added this to the Methods section, and also briefly shown it in the Results section.

In the Results As: “...the stable fraction (defined as $|RRAC| < 0.01\% \text{ yr}^{-1}$) is smaller under RSL rise (14.8%) than under fall (37.5%)...” (See tracked version, Line 122)

In the Methods As: “We identified no-change grid cells as those with zero gain and zero loss in the baseline area datasets, and included them as valid observations. The inclusion of no-change cells is essential for assessing terrestrial ecosystem vulnerability to climate change⁸² and adaptive capacity of coastal ecosystems to RSL change²¹. To ensure consistent coverage, we excluded latitudinal segments where any of the three datasets (gain, loss, and total extent) had a discontinuity exceeding 3° . The remaining overlapping continuous ranges across all three datasets were retained as the valid latitudinal extent. These procedures were applied to tidal wetlands (combined) and separately to salt marshes and mangroves. The final dataset thus comprises all grid cells exhibiting gain, loss, or no change for each wetland type.” (See tracked version, Line 691-704)

“First, for each realization, RRAC values were classified into net gain, stable, and net loss categories using a threshold of $\pm 0.01\% \text{ yr}^{-1}$, and the relative proportions of each category were calculated, providing a frequency-based assessment of wetland response.” (See tracked version, Line 810-813)

9. Line 468: Why not use higher-resolution sea-level data? Downscaling from 2° to 0.25° represents a substantial interpolation ($64\times$). For example, the Copernicus Marine dataset provides 0.125° resolution sea-level data from 1992–2025, which may better match the spatial scale of the analysis.

Response: Thank you for your comment. We appreciate the opportunity to clarify our choice of sea-level data and evaluate the sensitivity of our findings to spatial resolution.

(1) Regarding the use of the Prandi et al. (2021) reconstruction at 2° resolution: this dataset was selected because it specifically filters out mesoscale eddy oscillations, which are considered noise for long-term sea-level trend analysis, and rigorously propagates uncertainties. When we used this geocentric sea-level trend to construct relative sea-level (RSL) change rates (by combining with VLM), the results showed good agreement with NOAA tide gauge RSL trends (Supplementary Fig. 11a), supporting the reliability of our approach.

(2) Following your suggestion, we additionally tested the 0.125° DUACS sea-level product (monthly, from CMEMS) to derive linear trends and uncertainties of geocentric sea level, and then constructed RSL change rates following the same

methodology as our original study. The DUACS-RSL trends also aligned well with NOAA tide gauge records (Supplementary Fig. 11b), but we did not observe a statistically significant improvement in the agreement compared to the Prandi-RSL results.

(3) We repeated our original analysis on the 0.125° grid using the RSL change rates derived from both data sources, recalculating the areal change rate at 0.125° resolution. All the results are very similar to our original outcomes (Supplementary Fig. 11b). This comparison also allowed us to evaluate the sensitivity of our findings to the chosen grid resolution. We find that, at least between 0.25° and 0.125°, the nonlinear trend patterns and the locations of threshold are very similar between the two resolutions. We have included this sensitivity test in the Supplementary Information (Supplementary Fig. 17).

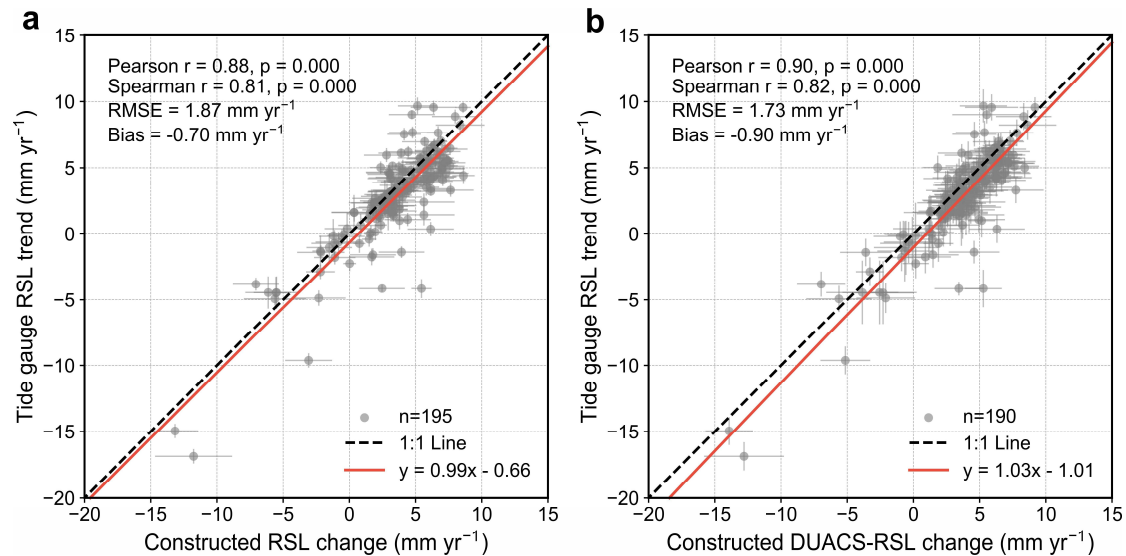
In summary, we conclude that our results are not sensitive to the spatial resolution of the sea-level rise data. We have revised the text in Discussion and Methods accordingly.

In the Discussion As: “Moreover, the key findings in Fig. 2 remain consistent when shifting the grid-cell wetland extent cutoff from 1 km² to 0.1 km² (Supplementary Fig. 16) and the analysis resolution from 0.25° to 0.125° (Supplementary Fig. 17).” (See tracked version, Line 623-625)

In the Methods As: “...after filtering out individual meso-scale eddies to remove substantial variability.” (See tracked version, Line 726-727)

“...To test the sensitivity of ASL data downscaling step, another set of RSL trends was derived by using the native 0.125° Copernicus Marine Service sea surface height product while keeping the VLM component unchanged. Both RSL trend reconstructions showed similar regressions close to the 1:1 line against tide-gauge observations with relatively high correlation (Supplementary Fig. 11), indicating that downscaling from 2° negligibly affects RSL change rate reconstruction accuracy.” (See tracked version, Line 751-756)

“...For grid-cell resolution, we refined the analysis to 0.125° for area aggregation to compare the 0.25° selection. The RSL change rates were regridded to 0.125° by assigning the original 0.25° values and uncertainties to the enclosed finer-scale cells. Another RSL change rate reconstruction, with ASL trend calculated from the native 0.125° Copernicus Marine Service product, was also used to examine its relationship with RRAC.” (See tracked version, Line 897-902)



Supplementary Fig. 11 | Comparison of grid-cell RSL change rates versus tide gauge sea level trends. ASL trends used to reconstruct RSL change rates are based on (a) the downscaled ASL trends of Prandi et al. (ref.7) and (b) the 0.125° DUACS sea surface heights from Copernicus Marine Service. Grey points represent valid paired observations where a tide gauge station falls within a wetland grid cell and provides record spanning ≥ 20 years during 1993-2020. Tide gauge sea level trends are obtained from NOAA tide gauge network. Cross symbols indicate $\pm 1\sigma$ uncertainty in both axes.

10. Lines 475–476: Please clarify the purpose of this processing step. Is it intended to fill missing values in coastal grid cells?

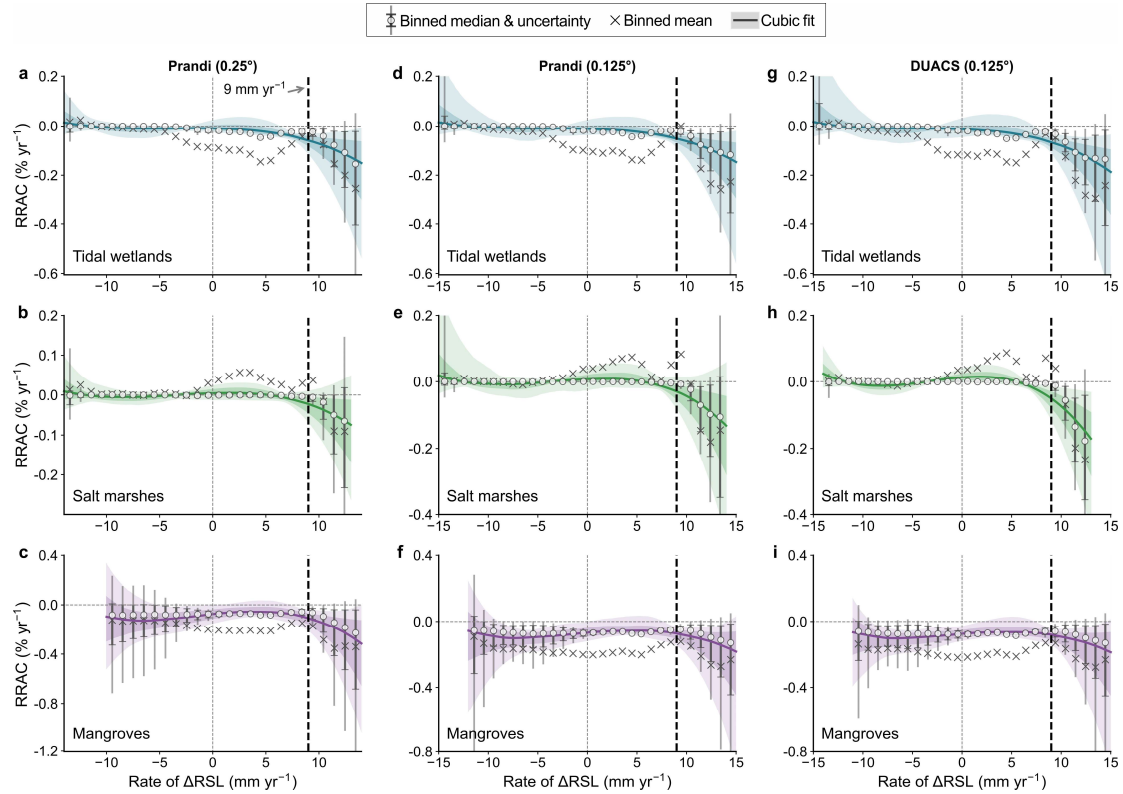
Response: Thank you for your constructive suggestion. This step is indeed intended to fill as many missing values as possible, and we have clarified this in the revised text.

As: “Subsequently, to fill as many missing values as possible in the tidal wetland grid cells.....” (See tracked version, Line 732-733)

References

- Pekel, J.-F., Cottam, A., Gorelick, N., & Belward, A. S. (2016). High-resolution mapping of global surface water and its long-term changes. *Nature*, 540(7633), 418–422.
- Wang, Z., Zhang, J., Yang, X., Huang, C., Su, F., Liu, X., Liu, Y., & Zhang, Y. (2022). Global mapping of the landside clustering of aquaculture ponds from dense time-series 10 m Sentinel-2 images on Google Earth Engine. *International Journal of Applied Earth Observation and Geoinformation*, 115, 103100.

Please refer to the manuscript for the references indicated by superscripts in the revised text.



Supplementary Fig. 17 | Sensitivity of wetland area change to RSL change across different grid-cell resolutions and ASL trend datasets. Trends in RRAC magnitude as a function of RSL change rate, along with binned means and medians, are shown for all tidal wetlands (a, d, g), salt marshes (b, e, h) and mangroves (c, f, i). The left column (a–c) shows results based on Prandi et al. (ref. 7) at 0.25° resolution; the middle column (d–f) shows results based on Prandi et al. at 0.125° resolution; and the right column (g–i) shows results based on the 0.125° DUACS sea surface heights from Copernicus Marine Service. Circles and crosses denote the medians of binned medians and binned means, respectively. The grey error bars represent the 66% and 90% uncertainty ranges. The black vertical dashed line marks the threshold position. The colored curves show cubic fit to the binned medians, with darker and lighter shaded envelopes indicating the 66% and 90% uncertainty ranges. Only bins containing more than three grid cells are shown. Only grid cells with total area > 1 km² are included.

Reviewer #3 (Remarks to the Author):

I would like to congratulate the authors with this interesting study exploring and quantifying the relationship between global tidal wetland loss and relative sea-level changes. The authors present a very thorough and sophisticated analysis of a compilation of readily available data, arriving at the unprecedented identification of relative sea-level rise thresholds for global tidal wetland loss. This work is very well written, and the analysis is supported by clear figures and extensive supporting materials. Both the methods applied and the interpretation of the results are comprehensive and convincing, and in support of the conclusions presented.

Apart from some minor suggestions and questions that I've set out below, there is one more fundamental point I would like to bring up. The presented RSL rise threshold for the lateral extent of tidal wetlands being higher than typical threshold values for wetlands' vertical extent (lines 275-276) makes me wonder if this elevated threshold comes at a loss of the elevation capital of the (remaining) wetlands. As the authors indeed argue in the discussion that lateral wetland adjustments are generally slower than vertical responses to RSL change (lines 276-277), I am afraid that the widespread assumption or application of the increased threshold that is established in this study would result in a non-linear increase of wetland (extent) loss over time, especially beyond the relatively limited timeframe (20 years) of the presented analysis. This would be in line with the increasing probability of wetland loss as RSL accelerates, observed by Saintilan et al. (2023) and quoted by the authors (lines 48-50)? Have the authors maybe looked into the wetland loss rates in relation to accelerations in the observed rates of RSL change [mm/yr²]? In this light, I suggest to elaborate and reflect more on the long-term effects and reliability of this newly established RSL rise threshold for tidal wetland loss, and to be a bit more cautious presenting this threshold to be higher than those following from studies into vertical wetland extent.

Response: We sincerely thank the reviewer for the positive assessment and for raising this crucial point regarding the long-term reliability of the lateral threshold identified in our study. In response, we have revised the manuscript to address the following aspects:

(1) Reframing the comparison between lateral and vertical dynamics

To better contextualize the observed lateral threshold, we now explicitly distinguish between two types of area-change metrics. Building on our original RRAC (Relative Rate of net wetland Area Change), we introduce RROW (Relative Rate of conversion to natural Open Water) to capture inundation-related loss. RROW is calculated by first taking the 2020 global permanent surface water dataset (Pekel et al., 2016), removing global coastal aquaculture-related water bodies (Wang et al., 2022) to isolate natural open water, then intersecting this natural water layer with the loss component of tidal wetlands, and finally normalizing the intersected area by the total wetland area within each grid cell (see **Methods** and **Supplementary Fig. 18**). RROW represents the lateral manifestation of vertical processes, whereas RRAC integrates both vertical and lateral processes. Using these two lateral metrics within the consistent framework of RSL change rate, we are able to indirectly compare vertical and lateral adjustments, instead of making direct comparisons with previously cited vertical process studies – which may be biased due to differences in their baseline references. Corresponding revisions have been made in the **Introduction**, **Results**, and **Discussion**.

(2) Testing the temporal robustness of the threshold

We performed an additional analysis using successive 3-year windows to examine whether the nonlinear loss pattern persists over shorter timescales. The results confirm that both net change and inundation-driven loss continue to exhibit comparable threshold behavior even within 3-year intervals (**Supplementary Figs. 6 & 7**), indicating that the accelerating loss signal under high RSL rise is detectable over shorter periods. However, we note that the magnitude of change does not increase indefinitely with time, likely due to lags in wetland response (Mariotti et al., 2014) and constraints in landward accommodation space (meaning that loss would not be detected where that space is exhausted) (Schuerch et al., 2018). This point is now discussed in the revised manuscript.

(3) Examining the role of sea-level change acceleration

Following the reviewer’s suggestion, we analyzed wetland loss in relation to both RSL change rate and its acceleration. The joint distribution shows that, for both salt marshes and mangroves, the proportion of area experiencing loss is higher in regions where RSL is both rising and accelerating compared to regions with RSL rise but deceleration (salt marshes: 41.9% vs. 29.2%; mangroves: 83.2% vs. 65.3%; **Supplementary Fig. 8**). While not a formal attribution, this pattern suggests that loss is more frequently associated with accelerating sea-level rise. We have incorporated this finding into the **Discussion**.

(4) Clarifying and tempering the interpretation of the lateral threshold

We agree that our original comparison with vertical thresholds may have been overly definitive. The relevant discussion has been moved to a dedicated subsection in the **Discussion**, where we explicitly acknowledge the limitations of our threshold estimates, including the potential influence of response lags and the relatively short (20-year) observation window. We now present the lateral threshold as an empirical benchmark that reflects integrated wetland dynamics over recent decades, while cautioning against its direct extrapolation to longer timescales without considering lagged responses and potential nonlinearities in RSL change rates.

All corresponding revisions are detailed in the tracked manuscript and supporting materials.

In the Introduction As: “...To explore overall lateral dynamics and inundation-related loss in tidal wetlands, we calculate the relative rate of net area change (still referred to as RRAC hereafter) and separately for the area converted to open water (hereafter RROW)...” (See tracked version, Line 82-85)

In the Results As: “Despite the influence of non-RSL drivers, RSL rise remains a discernible driver of tidal wetland area loss via direct inundation. In contrast to RRAC, which reflects net area change, RROW isolates inundation-driven loss and displays a greater propensity for both an overall declining trend and nonlinear behavior, with probabilities for both two trends approaching 100% (Table 2; Supplementary Fig. 2). Applying the same threshold detection method, we identify a global threshold of $\sim 8 \text{ mm yr}^{-1}$ for RROW (Supplementary Fig. 2).....” (See tracked version, Line 223-227)

In the Discussion As: “Our observations confirm that lateral adjustment can partially mitigate tidal wetland area loss induced by relative sea-level rise. Among the two types of area changes we quantified, conversion to open water represents the lateral manifestation of vertical inundation processes, while net area change integrates both lateral and vertical processes. Under low-to-moderate RSL rise rates, both metrics show resilience, primarily attributable to vertical accretion: organic and mineral accumulations raise surface elevation, reducing submergence risk^{5,18,27,44} and, enable seaward progradation with sufficient external sediment supply in deltaic settings⁴⁵⁻⁴⁷, such as the eastern section of the Ganges-Brahmaputra-Meghna Delta (ref.⁴⁸; Fig. 1a) and the Changjiang Delta

(ref.⁴⁹; Supplementary Fig. 4b). Our analysis on the function of SSC also corroborates this pattern (Fig. 4a-c). Notably, net change shows a higher area-based threshold ($\sim 9 \text{ mm yr}^{-1}$ versus $\sim 8 \text{ mm yr}^{-1}$) and a lower probability of decline ($>66\%$, likely) under accelerating RSL rise compared to inundation-driven loss ($>95\%$, extremely likely) (Table 2; Table 3; Supplementary Table 2). This indicates that lateral reorganization has provided a quantifiable buffer against tidal wetland area degradation driven by high RSL rise rates. ”

(See tracked version, Line 410-431)

“The loss of global tidal wetlands likely emerges as a chronic, progressive process under high rates of RSL rise. In a parallel analysis using area changes computed over successive 3-year intervals, we still detect nonlinear threshold responses in both RRAC and RROW, similar to those obtained from the two-decade analysis (Supplementary Fig. 6 & 7). This suggests that, at the global scale, degradation processes exceeding the RSL threshold emerge even at shorter timescales, rather than requiring multi-decadal observation windows to manifest. In view of the very likely existence of a secular, centennial-scale global mean sea-level rise prior to the satellite altimetry era^{56,57}, the detection of such phenomena over shorter periods is to be expected, even given potential time-lagged responses^{6,54,58}.

Wetland loss is likely to be intensify further as RSL rise rates increase⁵⁹. In recent decades, only $\sim 3\%$ of global wetland extent has experienced RSL rise rate exceeding the critical thresholds identified here, though these threshold estimates remain subject to considerable uncertainty (Fig. 2 & 3; Table 3). In a supplementary analysis, we find that tidal wetlands experiencing both RSL rise and acceleration show higher loss proportions than those with RSL rise but deceleration (salt marshes: 41.9% vs. 29.2% ; mangroves: 83.2% vs. 65.3% ; Supplementary Fig. 8), underscoring heightened risk for wetlands under accelerating RSL rise over the past two decades. Under SSP3-7.0, globally averaged geocentric rates of 8 mm yr^{-1} are expected as early as 2060 (ref.⁶⁰), implying that an increasing fraction of tidal wetlands may face nonlinear abrupt collapse. Yet this projection likely represents a lower bound for deltaic regions, where anthropogenic subsidence increasingly dominates relative sea-level rise and amplifies compound coastal flooding⁶¹. ” (See tracked version, Line 442-469)

“Our interpretation of wetland vulnerability based on these results may be conservative..... Second, the thresholds observed here exceed most reported vertical thresholds from SET-MH sites (Table 1). Although vertical accretion and

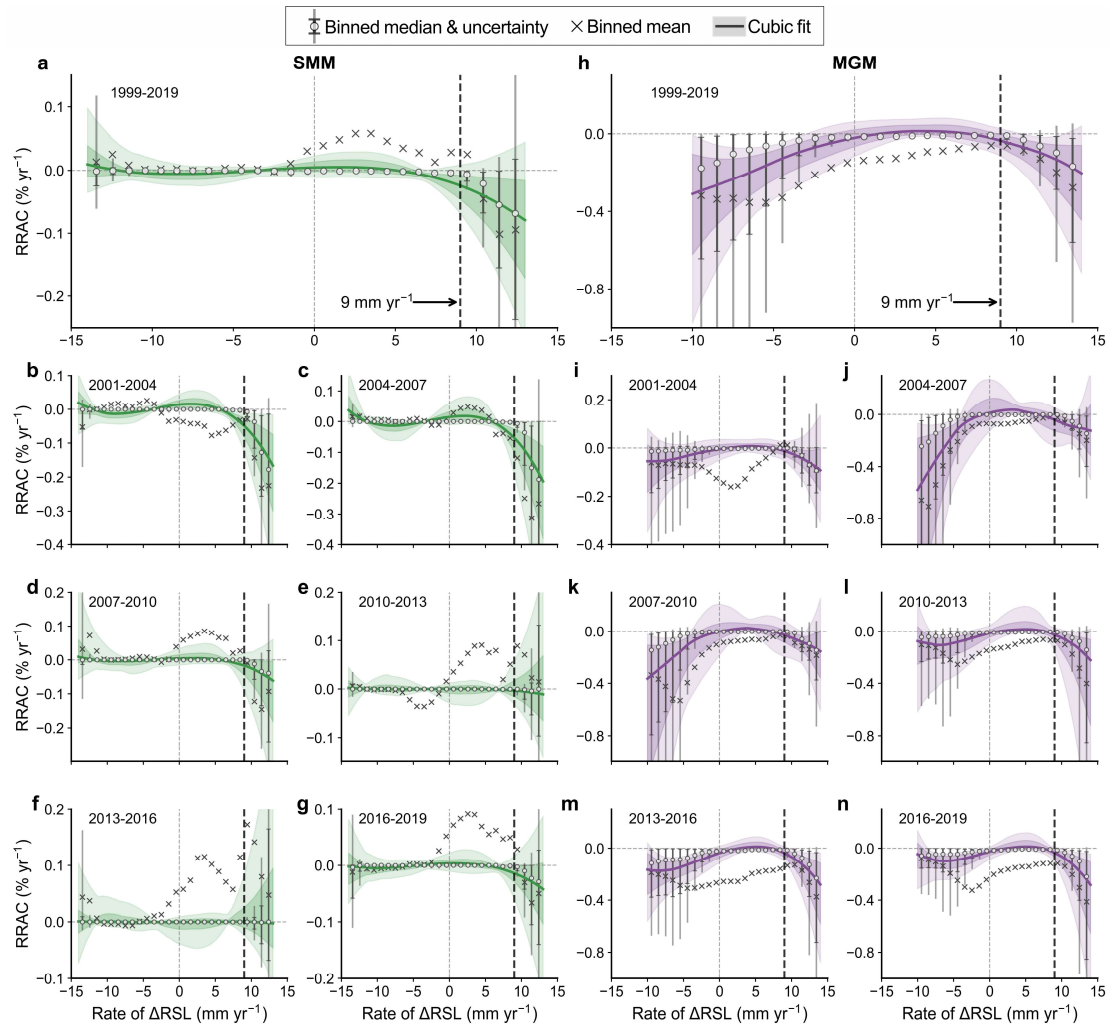
lateral area change show a modest correlation (Pearson's $r = 0.20$, $p = 0.014$; Supplementary Fig. 10), our reliance on 30-m wetland change data may obscure fine-scale variations and inflate threshold estimates. Furthermore, area change is an inherently lagged indicator relative to vertical processes: high-elevation wetlands require time to become inundated once vertical accretion falls behind RSL rise^{6,58,76}. Discrepancies in the RSL data benchmarks between this study and prior observations may also introduce additional bias⁷⁷. Third, the relatively short observation period (~20 years) and the use of linear trend estimation may mask ongoing accelerated losses that is not yet apparent⁵⁸, especially given that the global sea-level rise rate has doubled over the past three decades⁷⁸ ...” (See tracked version, Line 536-537, 543-554)

“In conclusion, we reveal a global nonlinear response in tidal wetland area change with increasing relative sea-level rise, with thresholds of apparent loss acceleration of $\sim 9 \text{ mm yr}^{-1}$ for overall lateral dynamics and $\sim 8 \text{ mm yr}^{-1}$ for inundation-related loss.” (See tracked version, Line 628-633)

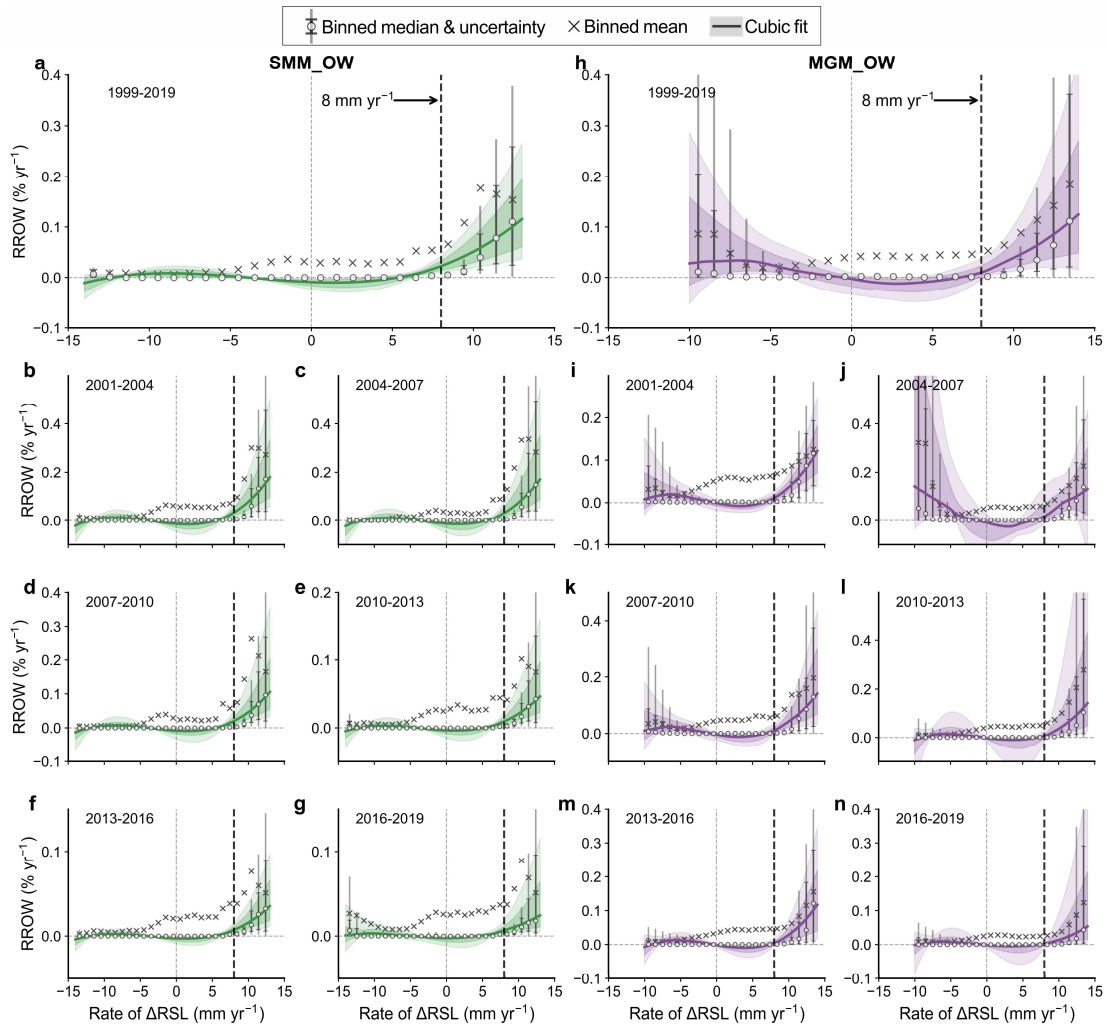
In the Methods As: “As a counterpart to the overall lateral dynamics, we conducted a parallel analysis of direct inundation-driven wetland loss. We first obtained the 2020 global permanent surface water distribution⁸³. We removed areas overlapping with the 2020 global aquaculture pond distribution⁸⁴, yielding the natural open water mask. We then intersected the loss pixels from the tidal wetland datasets with this natural open water mask to extract wetland area converted to open water. Finally, we applied the RRAC gridding procedure to calculate RROW (Relative Rate of conversion to Open Water) for each valid grid cell.” (See tracked version, Line 712-719)

“To test the robustness of our main findings across selections of temporal and spatial scales and wetland datasets, we repeated the same methodological framework under alternative configurations.

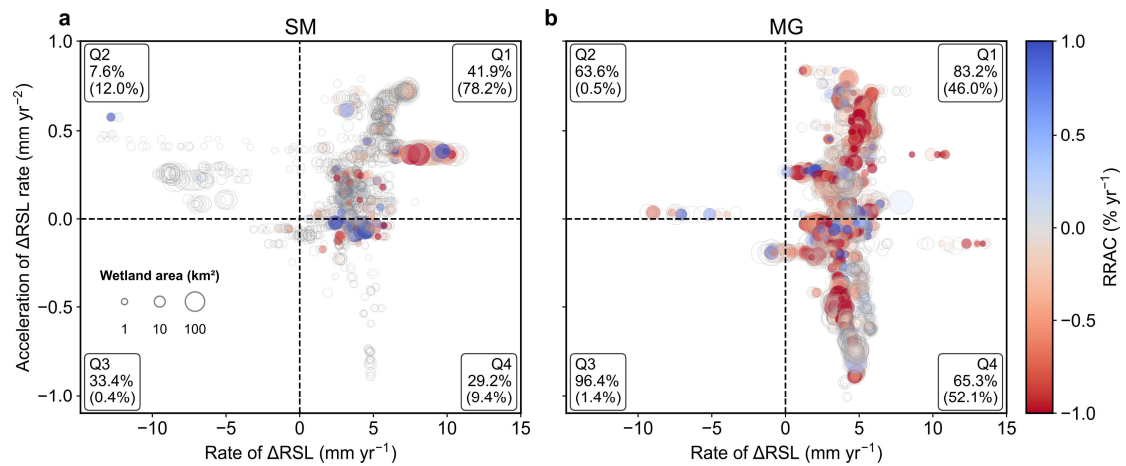
Temporal coverage. To test whether our main findings depend on long-term monitoring, we applied an identical analytical framework to Murray et al.'s data (ref.³), which provides continuous 3-year change intervals (2001-2004, 2004-2007, 2007-2010, 2010-2013, 2013-2016, 2016-2019), paralleling the 20-year span analysis. Consistency between the two temporal scales was evaluated to assess sensitivity to monitoring duration.” (See tracked version, Line 885-893)



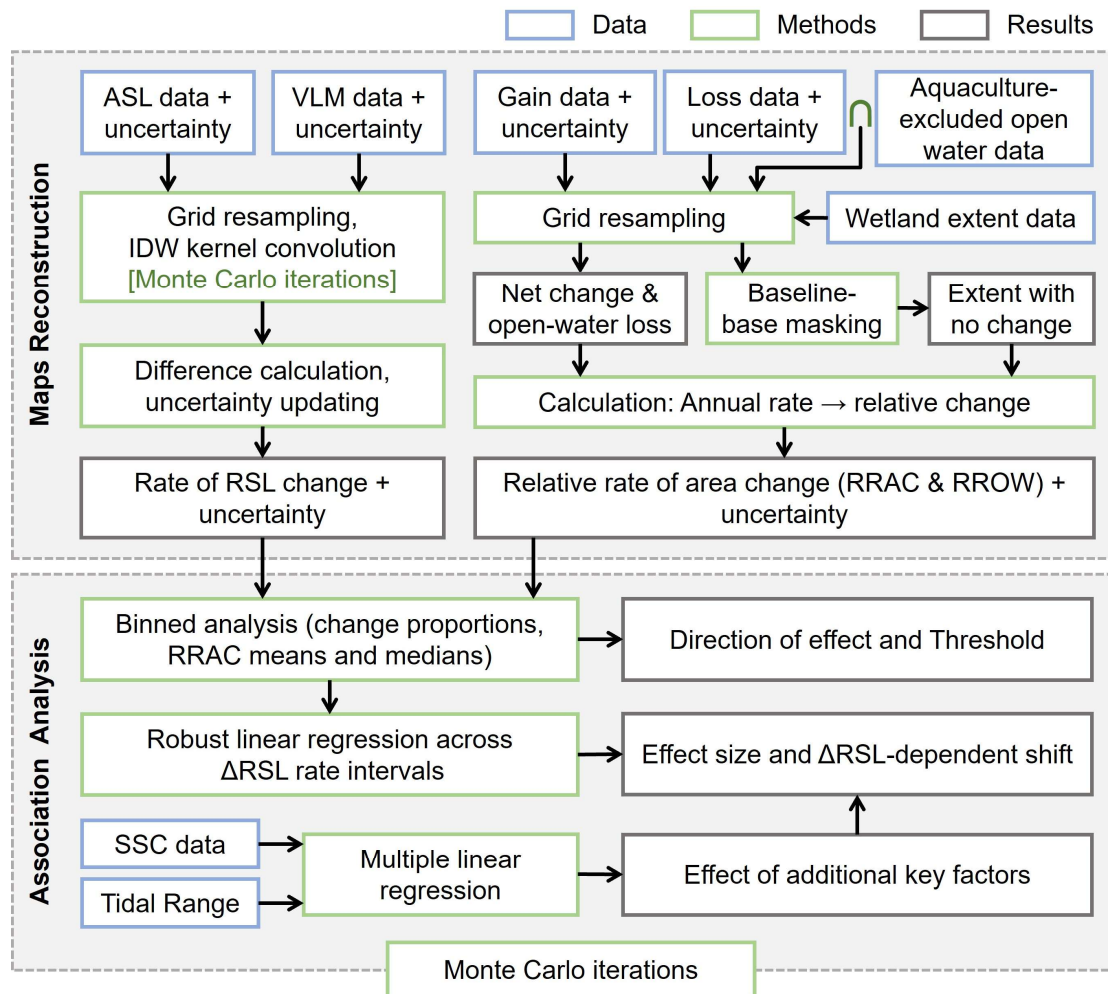
Supplementary Fig. 6 | Comparison of RRAC trends across rates of RSL change calculated over 20-year and 3-year periods. (a) and (h) show trends for salt marshes and mangroves, respectively, across the entire 1999-2019 period from the Murray et al. (2022) dataset. The panels below present trends for RRAC calculated in the same manner over successive 3-year intervals, with (b-g) corresponding to salt marshes and (i-n) to mangroves. The time span of the data used is indicated in the upper-left corner of each panel. Circles and crosses denote the medians of binned medians and binned means, respectively. Grey error bars represent the 66% and 90% uncertainty ranges. The black vertical dashed line marks the threshold position. The colored curves show cubic fits to the binned medians, with darker and lighter shaded envelopes indicating the 66% and 90% uncertainty ranges, respectively.



Supplementary Fig. 7 | Comparison of RROW trends across rates of RSL change calculated over 20-year and 3-year periods. (a) and (h) show trends for salt marshes and mangroves, respectively, across the entire 1999-2019 period from the Murray et al. (2022) dataset. The panels below present trends for RROW calculated in the same manner over successive 3-year intervals, with (b-g) corresponding to salt marshes and (i-n) to mangroves. The time span of the data used is indicated in the upper-left corner of each panel. Circles and crosses denote the medians of binned medians and binned means, respectively. Grey error bars represent the 66% and 90% uncertainty ranges. The black vertical dashed line marks the threshold position. The colored curves show cubic fits to the binned medians, with darker and lighter shaded envelopes indicating the 66% and 90% uncertainty ranges, respectively. RROW: relative rate of conversion to open water.



Supplementary Fig. 8 | RRAC in the RSL change rate-acceleration space. (a) and (b) show salt marshes (SM) and mangroves (MG), respectively. Each circle represents a grid cell, with circle size proportional to total wetland area and color indicating RRAC magnitude (red for negative values, blue for positive values). The four quadrants are divided by dashed lines at zero RSL change rate and zero acceleration. Quadrant labels display two areal proportions: the upper value (outside parentheses) indicates the proportion of wetland area within that quadrant exhibiting $RRAC < -0.01\% \text{ yr}^{-1}$ (defined as “loss”) relative to the quadrant’s total wetland area; the bracketed lower value indicates that quadrant’s share of total wetland area across all quadrants (summing to 100%). Comparison of loss percentages across quadrants, particularly between the upper-right quadrant (Q1, positive rate and acceleration) and the lower-right quadrant (Q4, positive rate but negative acceleration), highlights the potential role of acceleration in modulating inundation risk under rising RSL. The sea-level acceleration data are derived from Prandi et al. (2021).



Supplementary Fig. 18 | Workflow of data processing and analytical framework. The diagram summarizes the construction of RSL change and RRAC and RROW maps with uncertainty propagation, and subsequent association and attribution analyses (ASL: Absolute Sea-Level trend; VLM: Vertical Land Motion trend; RRAC: Relative Rate of net wetland Area Change; RROW: Relative Rate of conversion to Open Water). Blue boxes indicate data inputs, green boxes denote processing and analytical methods, and grey boxes represent derived results. The inverted U shape represents the intersection between datasets.

Detailed comments:

28-29 (line numbers): It would be interesting to provide a bit more context to this notion that lateral expansion can enhance wetland resilience, by including a very brief reflection on the observed impact of tidal range and SSC in accommodating this resilience.

1132 **Response:** Thank you for your suggestion. We have added a sentence as:

1133 “Globally, lateral wetland change exhibits a marginally higher threshold than direct
 1134 inundation loss ($\sim 8 \text{ mm yr}^{-1}$), suggesting that lateral dynamics, modulated by tidal
 1135 range and sediment supply, can partially buffer against rapid loss onset.” (See
 1136 tracked version, Line 33-37)

1137 46-47: There are some words missing in the sentence ‘These contrasting...that accrete’.

1138 **Response:** We revised it as:

1139 “These contrasting findings stem from a key limitation: point-based sedimentary
 1140 archives, embedded in local settings, are biased to places that accrete²⁰, and may
 1141 not represent broader trends in wetland area^{5,12,18}” (See tracked version, Line 56-
 1142 59)

1143 50: Please remove the article ‘a’ before ‘global investigations’.

1144 **Response:** We have removed this. (See tracked version, Line 61)

1145 52: For clarity, please specify that the ‘divergent response thresholds’ concern wetlands’
 1146 response to accelerated RSL rise.

1147 **Response:** Thanks. We have revised it as:

1148 “...with studies reporting divergent response thresholds to RSL rise...” (See tracked
 1149 version, Line 63)

1150 58: It is unclear to me what is meant by ‘lateral processes remain poorly constrained’.
 1151 Could the authors please elaborate, in relation to the field data and models that have
 1152 been addressed in the previous sentences?

1153 **Response:** We have updated it as:

1154 “Yet due to limited global observations, lateral processes in these models remain poorly
 1155 constrained, and validation of projected responses is still lacking^{21,33}. ” (See
 1156 tracked version, Line 69-71)

1157 69-70: The presented definition of the RRAC seems incorrect. Here, the yearly wetland
 1158 gain in a cell is related to the global total extent in the reference year. However, in lines
 1159 457-460 the RRAC is expressed as the RAC in cell k as a fraction of the wetland area
 1160 in the reference year in that same cell k. Please correct accordingly.

Response: Thank you for pointing this out. We have revised it as:

“...an RRAC of $+1\% \text{ yr}^{-1}$ indicates a yearly wetland gain in a cell corresponding to 1% of the cell’s total wetland extent in the reference year of observation...” (See tracked version, Line 81-82)

82-83: With the statement that ‘RSL (is) decreasing and RRAC increasing toward the poles’, I would suggest to specify that this observed increase in RRAC is observed over a much smaller latitudinal range than the much higher latitudes associated with the decrease of RSL. The present statement is confusing as the phrase ‘toward the poles’ suggests similar latitudinal ranges for both trends.

Response: This statement has been revised to:

“Latitudinally, RSL change and RRAC exhibit approximately symmetric patterns about the zero line, with RSL change rate decreasing and RRAC increasing from lower to higher latitudes (Fig. 1a). This mirror-image pattern is also reflected in some local peaks and troughs of both components (Fig. 1a).” (See tracked version, Line 100-104)

86: The abbreviation RSLR is not defined or used elsewhere in the manuscript. For consistency, I would suggest replacing it with ‘RSL rise’.

Response: We have revised it accordingly. And we have made the corresponding changes throughout the manuscript.

114-116: I struggle a bit with references to the rate of RSL in integers, whereas the labels in Figure 2 are positioned right between the bins. What bins have actually been used in this analysis? And if the bins are indeed aligned with the labels in Figure 2 (i.e. separated at integers rather than centred around integers), shouldn’t the references to these bins in the text mention their ranges (e.g. 12-13 mm/yr) rather than the lower limit of these bins?

Response: Yes, the bins are aligned with the labels in Figure 2. Following your suggestion, we have revised the references to use range notation (e.g., low~high) instead of single values.

As: *“The overall decline is reflected by an increasing proportion of loss, rising from 41% (21-61%, 66% uncertainty range, i.e. IPCC likely range⁴²) at the bin of -14~-13 mm yr⁻¹ to 82% (57-100%, likely range) at 13~14 mm yr⁻¹ (Fig. 2a). In contrast,*

the stable fraction holds a higher proportion under RSL fall than under RSL rise, peaking at 60% (53-67%, likely range) at bin of -9~-8 mm yr⁻¹, then dropping to 17% (14%-19%, likely range) at 0~1 mm yr⁻¹ and falling to zero at 12~13 mm yr⁻¹ (Fig. 2a).” (See tracked version, Line 159-166)

116-117: The statement that ‘the stable fraction maintains a relatively high mean portion of 24% under RSL-fall conditions’ is incorrect for the largest RSL-fall rates in Figure 2a. Please correct this statement accordingly.

Response: We have checked all the data in the text against the figure and revised them. For the new version, please refer to our previous response.

146: The threshold value θ has not been defined prior to this mention (as the methods are presented afterwards). Please provide a proper definition of this threshold here, in the results section.

Response: Thank you for your insightful suggestion. We have provided a definition here, and rewritten part of this section.

As: “We define the threshold θ as the RSL rise rate at which wetland loss abruptly accelerates. To identify θ , we examine the bin-wise first-order differences of ensemble medians for loss fraction, mean RRAC, and median RRAC. The threshold is marked by the first bin where these differences break from zero-centered oscillations to exceed all preceding magnitudes (Supplementary Fig. 1). We adopt the maximum θ across the three indicators, which represents the latest plausible onset of accelerated loss, and yields 9 mm yr⁻¹ for tidal wetlands (Fig. 2d, Supplementary Fig. 1).” (See tracked version, Line 175-186)

160-161: Please correct references to the blue dashed line (not solid) for the 50% proportion and darker/lighter error bars (not solid/dashed) for the different likelihood intervals.

Response: Thank you for your careful review. We have corrected the figure captions. (See tracked version, Line 254)

Fig. 3: I think the results presented in this figure could benefit from a violin-plot presentation rather than showing the scattered points in the background.

Response: Thank you. We have updated Fig. 3 accordingly.

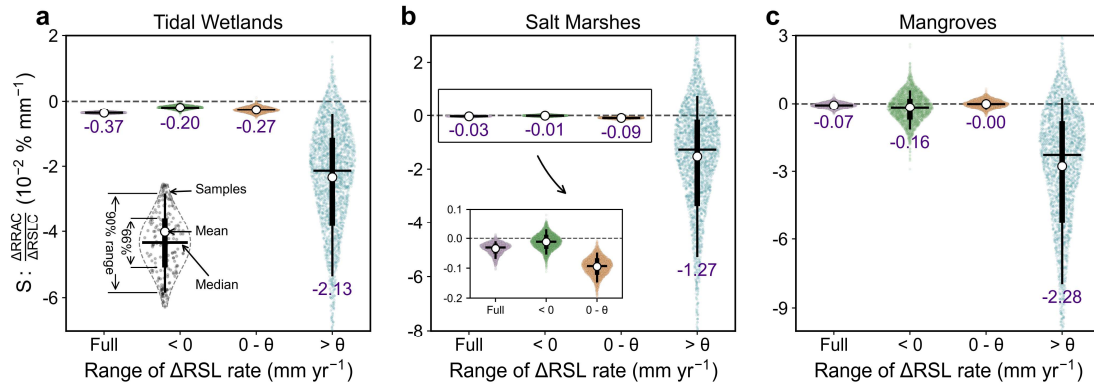


Fig. 3 | Robust (Huber) regression slopes of RRAC versus RSL change rate across different rate intervals. Results are shown for four RSL change rate intervals: full range, < 0 , $0-\theta$ ($\theta=9 \text{ mm yr}^{-1}$), and $>\theta$. In each violin body, the thick and thin vertical black lines represent the 66% and 90% uncertainty ranges, respectively; the white dot represents the mean, and the black horizontal line represents the median. Each colored scatter point represents the result of a single Monte Carlo simulation. Inset plot showing enlarged detail of intervals Full, < 0 and $0-\theta$. Purple number indicates the median slope value of each group. The number of grid cells within each interval and probabilities from pairwise comparisons between intervals are reported in Table 3.

174-175: The numbers printed in purple are wrongly referred to as purple markers. The actual markers of the medians (the purple centrelines of the boxplots) are not purple.

Response: We have corrected this, please refer to the previous response.

184-186: To this point, it is not clear from the main text what the original cutoff was for the minimum wetland area in grid cells to be included in the analysis, hence I cannot quite comprehend how this compares to the new cutoff of 0.1 km^2 that is introduced here. Please provide the original value here, for comparison.

Response: Thank you for pointing this out. We first added a sentence in the Introduction section stating the cutoff area we used.

In the Introduction section As: “To balance data coverage with the inclusion of sufficient wetland area per grid for reliable RRAC calculation, a cutoff of 1 km^2 per grid cell is applied (see Methods). This results in 7264 valid grid cells for tidal wetlands (Supplementary Table 1).” (See tracked version, Line 85-88)

The analysis based on the 0.1 km^2 cutoff was originally part of our sensitivity analysis. Because we performed multiple spatiotemporal sensitivity analyses in the revised manuscript and want to maintain the readability of the main text, we have removed the

results of the 0.1 km² analysis from the main text and moved them to the Supplementary Information, together with the other sensitivity analyses.

In the Discussion As: “Moreover, the key findings in Fig. 2 remain consistent when shifting the grid-cell wetland extent cutoff from 1 km² to 0.1 km² (Supplementary Fig. 16) and the analysis resolution from 0.25° to 0.125° (Supplementary Fig. 17). These analyses support the robustness of our main conclusions despite multi-source uncertainties.” (See tracked version, Line 623-627)

195: Please correct ‘RSL rate threshold’ to ‘RSL change rate threshold’.

Response: We have corrected this and revised similar expressions throughout the text.

213-214: The statement in this sentence that ‘are loss in salt marshes is more certain than in mangroves under low-to-moderate RSL-rise rates’ is contradictory to the numbers presented in the next two sentences and the associated data in Figure 2. Please correct accordingly.

Response: Thank you for this insightful comment. We have deleted the potentially misleading sentence (“area loss in salt marshes is more certain than in mangroves”) and now report the changes in loss proportions under low-to-moderate RSL rise rates (increase for salt marshes, decrease for mangroves).

As: “Moreover, salt marsh loss proportion increases by 5 percentage points (from 37% to 42%) from the 0~1 to the 8~9 mm yr⁻¹ bin, while mangrove loss proportion decreases by 3 percentage points (from 68% to 65%) over the same interval (Fig. 2b, c).” (See tracked version, Line 318-325)

Figure 4: I find it confusing that the data are binned here in 10% bins of the RSL change rate, rather than bins of e.g. 2 mm/yr. The total range of the RSL change rates is different for salt marshes and mangroves and since panels e and f present data for all 10% bins for both salt marshes and mangroves, this would imply that the actual RSL change rate ranges of these bins vary between the wetland types and, more importantly, don’t match with the RSL change rate ranges of the 10% bins of the merged results in panel d. I would suggest to use actual RSL rate change values for binning these results (e.g. bins of 2 or 3 mm/yr), rather than 10% intervals of the different ranges of these values. This will allow for better comparison between the wetland types and also for direct linking to the three different RSL change regimes that are distinguished in Figures 2 and 3.

Response: Thank you. Following your suggestion, we have changed the interval of the RSL change rate in this figure to 3 mm yr⁻¹, to better align with the perspective described earlier, as shown in the figure below. Subsequently, we revised the corresponding text in the **Results, Discussion and Methods** section.

In the Results As: “Multiple linear regressions, stratified by 3 mm yr⁻¹ intervals of RSL change rate, clarify this divergence. For salt marshes, the effect of tidal range is negative where RSL change rate < 0, becomes positive in the 3~6 mm yr⁻¹ interval, and remains positive at higher RSL change rates (Fig. 4e). In contrast, mangroves show a diminished positive effect across 0~9 mm yr⁻¹, which strengthens beyond the ~9 mm yr⁻¹ threshold (Fig. 4f).” (See tracked version, Line 357-362)

“...This pattern is further supported by stratified regressions that exclude the interaction term, in which the effect of SSC shifts from negative or near-neutral when RSL change rate < 0 to positive when RSL change rate > 0 (Fig. 4d-f).” (See tracked version, Line 382-385)

In the Discussion As: “Across most ranges of RSL rise rates (from the -12~-9 to the 3~6 mm yr⁻¹ intervals), both types of tidal wetlands exhibit a general neutral response (Fig. 4d-f), likely reflecting the intrinsic adaptive capacity of vegetation^{24,28}.” (See tracked version, Line 508-513)

In the Methods As: “To further examine how the effects of SSC and tidal range vary across different RSL change rate ranges, we performed multiple linear regressions without interaction terms over consecutive 3 mm yr⁻¹ intervals of RSL change rate. Only intervals with over 8 valid data points were retained for reliable estimation. To enable cross-interval comparison, we rescaled the coefficients by the ratio of each factor’s within-interval standard deviation to the mean of its standard deviations (σ) across all intervals. This allows every coefficient to be interpreted on a common scale. By tracking changes in these effect coefficients across rate intervals, we are able to assess how the contributions of SSC and tidal range to wetland area change vary with RSL change rates.” (See tracked version, Line 872-883)

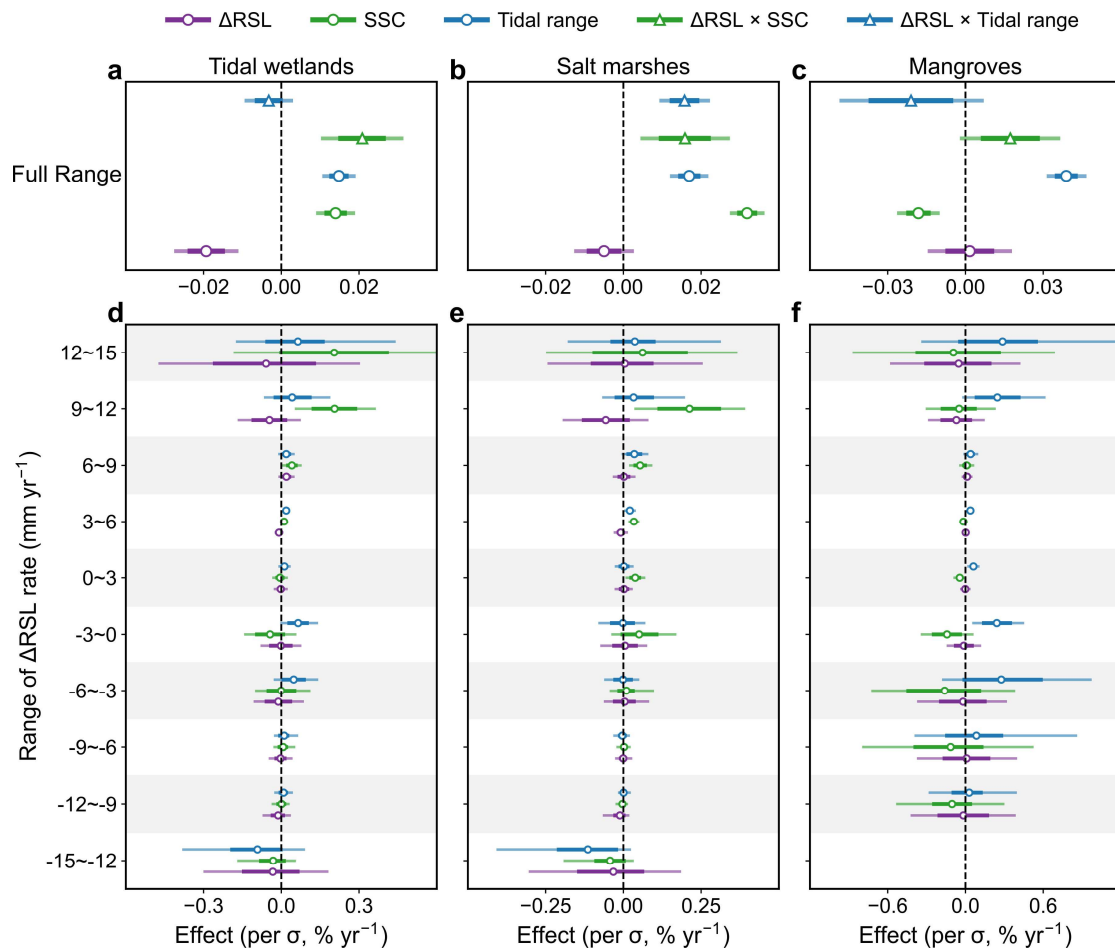


Fig. 4 | Effects estimated from multiple linear regression explaining RRAC as a function of RSL change rate, tidal range, and SSC. (a-c) Global multiple linear regressions incorporating interaction terms between RSL change rate and each of tidal range and SSC, for tidal wetlands, salt marshes, and mangroves, respectively. (d-f) Stratified multiple linear regressions excluding interaction terms, with effects estimated within 3 mm yr⁻¹ intervals of RSL change rate for tidal wetlands, salt marshes, and mangroves, respectively. Circles denote mean coefficients of independent terms; triangles denote mean coefficients of interaction terms. Horizontal thick, dark lines represent the 66% uncertainty range (aligned with the IPCC likely range), while thin, light lines represent the 90% uncertainty range (IPCC very likely range). The corresponding σ values are provided in Supplementary Table 3.

~341-344: The first part of this sentence addresses the ‘counteracting of sea-level-driven coastal erosion through modifications of environmental drivers’. It seems to me that this statement refers to the observed positive impacts of tidal range and SSC at higher RSL change rates. However, tidal range can’t really be considered an

environmental driver that can be modified by human intervention. Please revise this statement.

Response: We have revised this.

As: *“Given that tidal range cannot be actively modified, safeguarding existing vegetation remains critical for coastal protection, while managing anthropogenic sediment supply offers an additional actionable strategy where feasible.”* (See tracked version, Line 521-526)

354-357: The pixel-based RSLR shown in Supplementary Figure 7.b appears much less variable/sensitive (varying between 0-15 mm/yr) than the regional RSLR values from the field (varying between -5-20 mm/yr). Instead of mentioning the significant and positive correlation between these two, I would expect a reflection on the fact that the range of the RSLR values used in this study is only half the range of the observed RSLR rates in the field. Could the authors please elaborate on why they believe their reconstructed RSLR data is accurate and on the implications of this deviation?

Response: Thank you for your comment. We have re-examined the RSL change rates used for validation, which were directly sourced from Jankowski et al. (2017) and Saintilan et al. (2023). However, their RSLR records were aligned with SET-MH measurement periods (generally <10 years) and derived from point-based measurements and nearest tide gauges, respectively. Merging these may introduce substantial uncertainty and temporal misalignment with our data (~20 years).

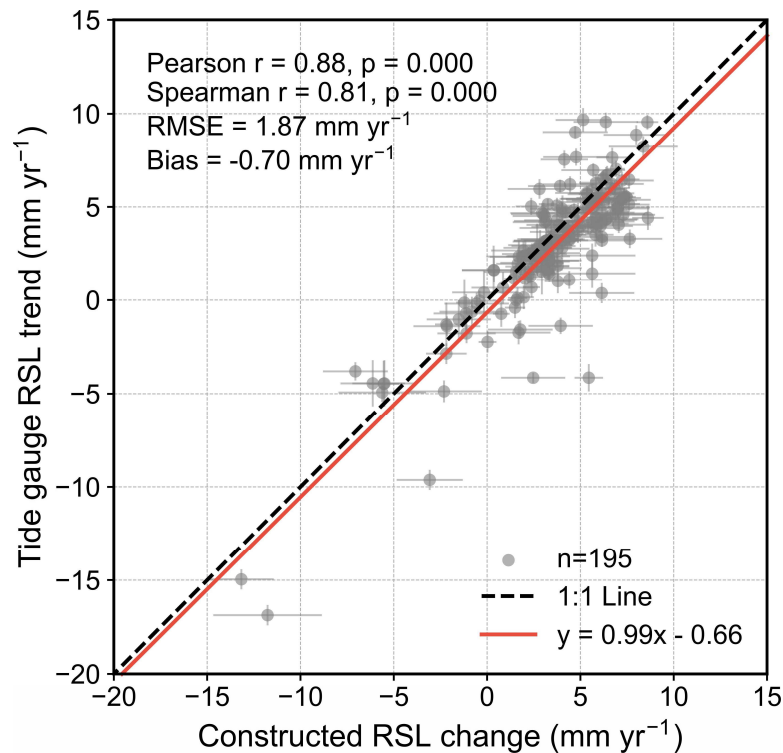
For these reasons, we have removed this figure and instead collected NOAA tide gauge RSL trends with measurement records exceeding 20 years between 1993 and 2020 for validation. These data correlate well with our reconstructed gridded dataset (*Pearson's $r=0.88$, $p=0.000$*), with a slope close to 1 despite a systematic negative bias (likely due to GNSS-tide gauge benchmark discrepancies). This indicates that our RSL change data are reliable. We have noted in the Discussion that this bias may contribute to threshold overestimation.

We greatly appreciate your careful observation, which prompted us to undertake this important revision. Revised texts are in the Discussion and Methods sections.

In the Discussion As: “...Discrepancies in the RSL data benchmarks between this study and prior observations may also introduce additional bias⁷⁷...” (See tracked version, Line 550-551)

“Several methodological uncertainties warrant consideration. Although our grid-cell RSL change rates correlate strongly with tide-gauge trends (Pearson’s $r=0.88$, $p<0.001$, slope ≈ 1 ; Supplementary Fig. 11) ...” (See tracked version, Line 565-569)

In the Methods As: “We validated our grid-cell RSL change rates against tide gauge RSL trends compiled by NOAA (Supplementary Fig. 11). For alignment, gauges with at least 20 years of valid data during the period of 1993-2020 were retained and spatially matched to the respective grid cells.” (See tracked version, Line 748-751)



Supplementary Fig. 11a | Comparison of grid-cell RSL change rates versus tide gauge sea level trends ($n = 195$). Grey points represent valid paired observations where a tide gauge station falls within a wetland grid cell and provides record spanning ≥ 20 years during 1993-2020. Tide gauge sea level trends are obtained from NOAA tide gauge network. Cross symbols indicate $\pm 1\sigma$ uncertainty in both axes.

394: Please correct ‘validate’ to ‘valid’.

Response: We have corrected this and revised similar expressions throughout the text.

399: Please correct ‘increase’ to ‘increases’.

Response: We have corrected this and revised similar expressions throughout the text.

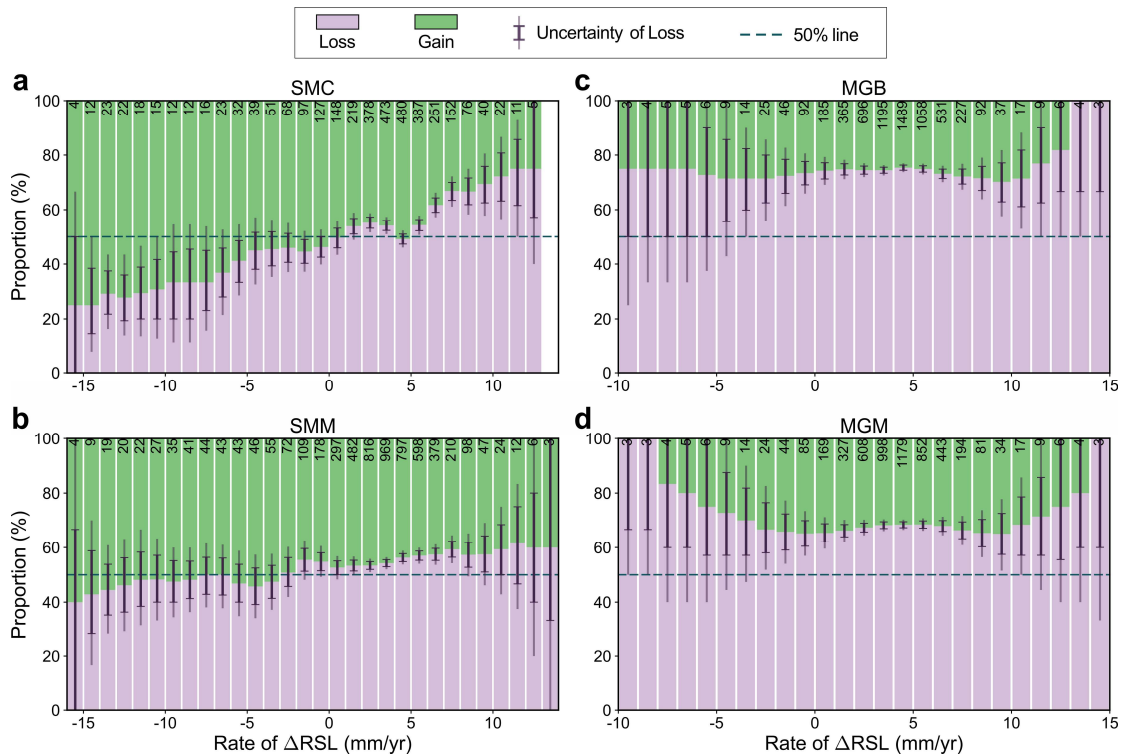
438-445: The MGB dataset is selected to map mangrove area change rates, but at the same time the data in Supplementary Figure 11.b shows a much greater variation of the rates of area change for the MGB dataset than for the MGM dataset (corroborated by the 1.20 slope of the linear fit). To what extent could the focus on the MGB data for determining the RAC estimates have affected the results of this study? The mangrove rates of area change obtained from the MGM dataset seem much more in line with the salt marsh rates of change from the SMM dataset. Would the use of the MGM dataset have reduced the greater sensitivity of mangroves to RSL changes in comparison to salt marshes?

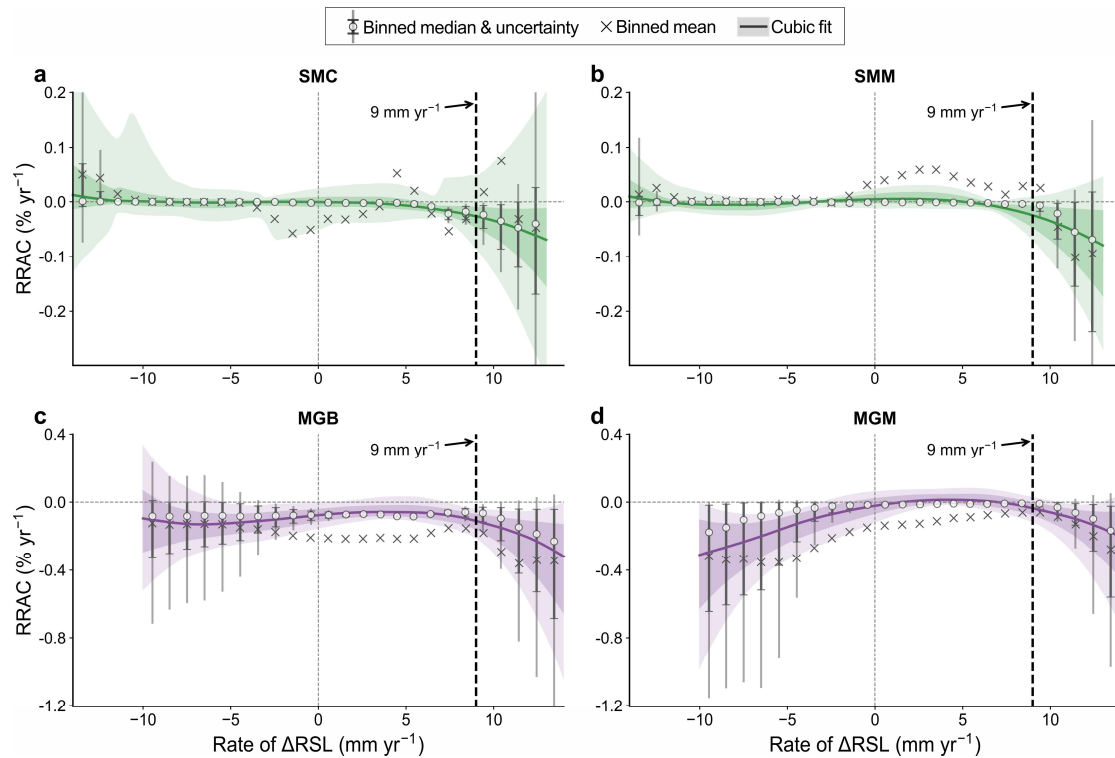
Response: This discrepancy likely reflects greater mangrove losses in the late twentieth century, which have since slowed due to conservation and restoration efforts. The longer MGB record (1996-2019) therefore captures more of this early decline, producing a steeper linear trend than MGM (1999-2019) (Bunting et al., 2022). As part of our sensitivity analyses, we have conducted separate trend analyses for each dataset. Although the two mangrove datasets diverge somewhat under falling RSL conditions, both display similar nonlinear threshold responses under high RSL change rates (Supplementary Fig. 9 & 15). To maximize temporal coverage, we therefore retain the MGB and SMM combination as our primary analysis. We have added relevant clarifications to the manuscript, in the Discussion and Methods sections.

In the Discussion As: “Incorporating no-change areas introduces noise from cross-source delineation discrepancies, and incomplete temporal overlap further compounds rate estimation uncertainty. Additionally, the choice of grid-cell wetland extent cutoff and analysis resolution introduces uncertainty. To evaluate these effects, several parallel analyses were performed. Binary gain-loss analysis on individual datasets (ignoring wetland extent cutoff to exclude biases from total-extent datasets) reproduces the increasing loss proportions under RSL rise rates shown in Fig. 2b-c (Supplementary Fig. 9). Repeating the Fig. 2f-g analyses across

individual datasets further validates the nonlinear RRAC threshold trends (Supplementary Fig.15).” (See tracked version, Line 603-623)

In the Methods As: “Individual datasets. For each individual area-change dataset, we performed a binned loss-gain analysis based on the corresponding RSL change rates, without introducing uncertainties associated with total extent estimates or the identification of no-change areas. Additionally, we calculated RRAC for individual datasets, to assess consistency across different area-change products.” (See tracked version, Line 913-917)





Supplementary Fig. 15 | RRAC trends across RSL change rates from individual wetland area change datasets. Each panel corresponds to an individual wetland area change dataset analyzed as a function of RSL change (SMC: salt marshes from ref.⁸; SMM: salt marshes from ref.⁹; MGB: mangroves from ref.¹⁰; MGM: mangroves from ref.⁹). Circles and crosses denote the medians of binned medians and binned means, respectively. Grey error bars represent the 66% and 90% uncertainty ranges. The black vertical dashed line marks the threshold position. The colored curves show cubic fits to the binned medians, with darker and lighter shaded envelopes indicating the 66% and 90% uncertainty ranges, respectively.

453: Please explain or include a reference to the ‘existing global benchmark’ for the latitude range used to identify stable regions.

Response: We have revised this sentence to clear explain the data erase as: “To ensure consistent coverage, we excluded latitudinal segments where any of the three datasets (gain, loss, and total extent) had a discontinuity exceeding 3°. The remaining overlapping continuous ranges across all three datasets were retained as the valid latitudinal extent.” (See tracked version, Line 695-700)

459-490: Am I correct in assuming that this reference year (ref) is 2020? Or does the reference year still vary based on the temporal coverage of the base data? Please clarify.

Response: We have clarified the definition of the reference year (using the initial year of the base data) to better explain the physical meaning of RRAC.

1447 **As:** “...where $A_{ref,k}$ denotes the tidal wetland area in the reference year (i.e., the
1448 initial year of each dataset) for the k -th grid cell. The reference-year area was
1449 back-calculated from the 2020 extent by subtracting the cumulative area change
1450 over the observation period.” (See tracked version, Line 707-710)

1451 479: Indices j and n remain undefined here.

1452 **Response:** We have revised the formula and added definitions for the subscripts.

1453 **As:** “

$$w_i = \frac{d_i^{-p}}{\sum_{i=1}^n d_i^{-p}} \quad (2)$$

1454 where d_i denotes the distance between the target grid cell and the i -th neighboring
1455 cell, n is the total number of cells the neighborhood, and p is the distance-decay
1456 exponent...” (See tracked version, Line 738-740)

1457 483: Please update the reference to the next section to ‘Uncertainty quantification’.

1458 **Response:** We have updated this. (See tracked version, Line 744)

1459 932: Please correct ‘tidal wetland’ to plural.

1460 **Response:** We have corrected this. (See tracked version, Line 1284)

1461 **Supplementary Information:**

1462 **Figure 6:** I assume the date ranges in the legend for gains and losses (2019-2019) is
1463 incorrect. Please correct.

1464 **Response:** Thank you for your careful reminder. We have corrected it and renumbered
1465 it as **Supplementary Fig. 4** based on the revised manuscript.

1466 **Figure 7:** Is the ‘surface gain/loss’ on the vertical axis in panel as the same as the RRAC?
1467 If so, please clarify in the figure or caption.

1468 **Response:** Yes, to align with the main text, we have specified it as “RRAC” in the
1469 caption. We have renumbered it as **Supplementary Fig. 10**.

1470 **Figure 13:** Instead of the input of ‘SLR data’ (top left corner), I would say ‘RSL data’
1471 as sea levels can also drop. In addition, I’m wondering if the bottom two boxes of the

maps reconstruction (RSL rate change and RRAC) should be considered results (grey box) instead of data (blue box), as these maps in themselves are an important output of this work.

Response: You are absolutely correct. To clarify the two components driving RSL (relative sea level) change, we now use ‘ASL’ (absolute sea level change) and ‘VLM’ (vertical land motion) in the revised version. In addition, we have recolored the boxes based on the processing type. (See Supplementary Fig. 18)

References

- Pekel, J.-F., Cottam, A., Gorelick, N., & Belward, A. S. (2016). High-resolution mapping of global surface water and its long-term changes. *Nature*, 540(7633), 418–422.
- Wang, Z., Zhang, J., Yang, X., Huang, C., Su, F., Liu, X., Liu, Y., & Zhang, Y. (2022). Global mapping of the landside clustering of aquaculture ponds from dense time-series 10 m Sentinel-2 images on Google Earth Engine. *International Journal of Applied Earth Observation and Geoinformation*, 115, 103100.
- Mariotti, G., & Carr, J. (2014). Dual role of salt marsh retreat: Long-term loss and short-term resilience. *Water Resources Research*, 50(4), 2963–2974.
- Schuerch, M., Spencer, T., Temmerman, S., Kirwan, M. L., Wolff, C., Lincke, D., McOwen, C. J., Pickering, M. D., Reef, R., Vafeidis, A. T., Hinkel, J., Nicholls, R. J., & Brown, S. (2018). Future response of global coastal wetlands to sea-level rise. *Nature*, 561(7722), 231–234.
- Jankowski, K. L., Törnqvist, T. E., & Fernandes, A. M. (2017). Vulnerability of Louisiana’s coastal wetlands to present-day rates of relative sea-level rise. *Nature Communications*, 8(1), 14792.
- Saintilan, N., Horton, B., Törnqvist, T. E., Ashe, E. L., Khan, N. S., Schuerch, M., Perry, C., Kopp, R. E., Garner, G. G., Murray, N., Rogers, K., Albert, S., Kelleway, J., Shaw, T. A., Woodroffe, C. D., Lovelock, C. E., Goddard, M. M., Hutley, L. B., Kovalenko, K., ... Guntenspergen, G. (2023). Widespread retreat of coastal habitat is likely at warming levels above 1.5 °C. *Nature*, 621(7977), 112–119.
- Bunting, P., Rosenqvist, A., Hilarides, L., Lucas, R. M., Thomas, N., Tadono, T., Worthington, T. A., Spalding, M., Murray, N. J., & Rebelo, L.-M. (2022). Global Mangrove Extent Change 1996–2020: Global Mangrove Watch Version 3.0. *Remote Sensing*, 14(15), 3657.

Please refer to the manuscript for the references indicated by superscripts in the revised text.

1 *Reviewer comments are shown in black, author responses in blue, and*
2 *revised manuscript text in grey italic.*

3 Previous manuscript ID: NCOMMS-26-009208A

4 Title: Observed thresholds in sea-level rise driving global tidal wetland loss

5

6 Contents

7 *Reviewer #1 (Remarks to the Author):* 1

8 *Reviewer #2 (Remarks to the Author):* 6

9 *Reviewer #3 (Remarks to the Author):* 12

10

11 We thank all the reviewers for their invaluable comments, which have substantially
12 improved our manuscript. Below are point-by-point responses to the remaining
13 concerns.

14 **Reviewer #1 (Remarks to the Author):**

15 I thought the original manuscript was quite strong but raised 4 concerns that the
16 reviewers have now addressed. Below, I walk through the author responses to each of
17 these concerns, and have only suggested a few more minor edits.

18 **Response:** We appreciate your affirmation of our original manuscript and subsequent
19 revisions. We have made further modifications based on the comments you provided.
20 Please see below.

21

22 1. The authors have admirably added text near the end of the discussion acknowledging
23 that their metrics could be lagging indicators. But I would like the authors to
24 additionally add the elevation capital argument to the first paragraph of the discussion,
25 as I believe this is the primary reason for the higher threshold rates of sea level rise.
26 They should explicitly use the “elevation capital” terminology as requested by another

reviewer. I'm also left wondering if the area-based lateral thresholds (9 mm/yr) are really meaningfully higher than vertical thresholds (8mm/yr).

Response: Thank you for your positive feedback on our revisions regarding the lagged indicator. In response to your suggestion to incorporate the 'elevation capital' argument, we have referenced the relevant literature (Cahoon et al., 2019; Barksdale et al., 2025) and revised the relevant section of the Discussion accordingly.

In the Discussion As: "...Under low-to-moderate RSL rise rates, both metrics show resilience, primarily attributable to maintenance or increase of elevation capital^{44,45}: organic and mineral accumulations raise surface elevation, thereby offsetting RSL rise and reduce submergence risk^{5,13,27,46}..." (See tracked version, Line 314-317)

"...A key buffering behavior occurs when RSL rise outpaces surface elevation gain and depletes elevation capital, yet wetland area may not immediately decline if landward migration is possible..." (See tracked version, Line 338-341)

"...A larger tidal range prolongs inundation duration and increases water depth, thereby facilitating vertical sediment deposition in low-lying zones⁷¹ and promoting the maintenance of elevation capital⁴⁴..." (See tracked version, Line 392-395)

"...Furthermore, area change is an inherently lagged indicator relative to vertical processes: even after vertical accretion falls behind RSL rise, high-elevation wetlands require time to become inundated before elevation capital is exhausted^{6,60,79}..." (See tracked version, Line 461-464)

We appreciate your question about whether the area-based lateral threshold (9 mm yr⁻¹) is meaningfully higher than the vertical threshold (8 mm yr⁻¹). We address this from three perspectives:

First, **regarding the comparability of these thresholds**. We have softened the interpretation of RROW as a proxy for vertical processes, instead describing it as "lateral changes driven by the cumulative effects of inundation". This clarification emphasizes that both RRAC and RROW represent lateral changes, allowing us to shift focus from a vertical-vs-lateral comparison to differences between distinct lateral processes. Using the same RSLR map, we compare these two metrics (RRAC vs. RROW): one reflects conversion to open water only, while the other encompasses all

changes. This allows us to assess whether the net effect of all changes (including gains and other losses beyond direct inundation) is less severe than RSLR-driven losses alone under accelerating RSLR. The 1 mm yr⁻¹ lag suggests that over the past two decades, the combined effect of gains and other losses has likely moderated the impact of accelerated sea-level rise.

In the Discussion As: “...Of the two area-change metrics we quantified, conversion to open water represents the lateral cumulative effects of inundation processes, whereas net area change integrates overall lateral processes...” (See tracked version, Line 311-314)

Second, **regarding the presentations of comparison.** Besides threshold identification, we also compared the overall linear and nonlinear trends of both area metrics with RSLR rate (Table 2), as well as the magnitude and probability of enhanced loss rates before and after the RSLR thresholds (Fig. 3; Table 3; Supplementary Fig. 3; Supplementary Table 2). The consistent finding is that RROW exceeds a lower threshold (8 mm yr⁻¹) with extremely likelihood (≈100%), whereas RRAC exceeds its higher threshold (9 mm yr⁻¹) with lower likelihood (>66%, likely to very likely). This contrast supports the distinction between these two metrics.

Third, **regarding the practical significance.** As noted above, RROW (open-water loss) exceeds its threshold with higher likelihood than RRAC (total lateral change), indicating that direct inundation is more tightly coupled to RSLR than the net effect of all changes. Following Reviewer 2’s suggestion, we further assessed the compensatory effect of gross gains on open-water losses (denoted as RRAC’). We found that RRAC’ exhibits greater uncertainty than both RRAC and RROW in its response to increasing RSLR, whether in linear or nonlinear trends, and its threshold effect is indistinguishable due to high uncertainty (Supplementary Fig. 4; Supplementary Table 4). This implies that when non-inundation losses (e.g., human deforestation) are excluded, various gains (landward migration, natural expansion, restoration) could potentially offset RSLR-driven inundation losses, thereby raising the threshold value. In other words, the comparison suggests that reducing anthropogenic and other non-SLR losses at regional scales offers a feasible pathway to enhance the areal resilience of tidal wetlands under accelerating RSLR.

In the Discussion As: “...To further elucidate this buffering capacity, we introduce a refined area-change metric, RRAC’, defined as relative rate of gross wetland gain

minus loss to open water. RRAC' directly quantifies the extent to which wetland gain offsets inundation-relative loss. The relationship between RRAC' and RSL change rate reveals a relatively inconspicuous threshold effect at high RSL rise rates (Supplementary Fig. 4d-f), with probability assessments differing between linear and nonlinear loss trajectories (Supplementary Table 4). This suggests that the RSL rise rate threshold for accelerated wetland loss may become obscured or shift to higher values if non-RSL-driven losses are effectively constrained." (See tracked version, Line 329-338)

2. The authors have done a nice job addressing my concern about needing longer time series data by adding an analysis with higher temporal resolution, and also by acknowledging the issue. No further edits requested.

Response: We appreciate your positive feedback and are glad that the added analysis and acknowledgment address your concern.

3. The concern about data quality as it relates to marsh migration can't really be addressed without substantial reworking of the input data, but the authors now acknowledge the issue, and give the Chesapeake Bay and Florida Gulf Coasts as examples. No further edits requested.

Response: Thank you for recognizing our acknowledgment of the data limitation and the examples we provided.

4. The authors have addressed my concern about wetland progradation near river deltas adequately by listing the various processes that could cause wetland gains.

Response: Thank you for confirming that our discussion of the various processes adequately resolves your concern.

I have one final requests.

1. Incorporate the following reference to the discussion of how tidal range and SSC influence wetland vulnerability: Coleman et al., 2022. Limnology and Oceanography. <https://aslopubs.onlinelibrary.wiley.com/doi/abs/10.1002/lol2.10230>. It's an important paper about marsh vulnerability thresholds at the global scale, and particularly the role of SSC and tidal range.

Matt Kirwan

Response: We appreciate you bringing this valuable reference to our attention. We have now incorporated the important paper by Coleman et al. (2022) into our introduction, discussion and method of how tidal range and suspended sediment concentration (SSC) influence wetland vulnerability. (See tracked version, Line 61, 441, 546, 706)

References

Cahoon, D. R., Lynch, J. C., Roman, C. T., Schmit, J. P. & Skidds, D. E. Evaluating the relationship among wetland vertical development, elevation capital, sea-level rise and tidal marsh sustainability. *Estuaries and Coasts* 42, 1–15 (2019).

Barksdale, M. B., Valentine, K., Hein, C. J. & Kirwan, M. L. Tradeoffs between vertical and lateral resilience in a salt marsh restoration model. *J. Geophys. Res. Biogeosci.* 130, e2025JG009145 (2025).

Coleman, D. J. et al. Reconciling models and measurements of marsh vulnerability to sea level rise. *Limnol. Oceanogr. Lett.* 7, 140–149 (2022).

Please refer to the manuscript for the references indicated by superscripts in the revised text.

Reviewer #2 (Remarks to the Author):

I sincerely appreciate the authors' substantial efforts in this round of revision. The manuscript has been substantially improved and is now more robust and insightful, particularly through the comparison of different datasets and the newly added Relative Rate of conversion to Open Water (RROW) metric. I recommend publication, subject to the authors addressing a few remaining concerns before acceptance.

Response: We appreciate your thorough review and positive assessment of our revised manuscript. Below, we provide point-by-point responses to your remaining comments.

1. The comparison between the relative rate of area change (RRAC) and RROW is a very interesting and useful addition. RROW represents wetland loss caused by inundation and therefore provides a more direct measure of how relative sea-level rise (RSLR) contributes to wetland loss. In contrast, RRAC is based on net area change, and thus describes the extent to which RSLR-induced wetland loss may be offset by wetland expansion. For this reason, I think the calculation of net area change in RRAC should also exclude losses caused by deforestation. Specifically, net area change should be calculated as gross gain minus wetland loss caused by inundation, rather than gross gain minus total gross loss, because gross loss includes substantial areas of human-driven deforestation that are not related to RSLR. For example, the wetland loss shown in Supplementary Fig. 5b is explicitly identified by the authors as deforestation associated with aquaculture ponds. Such areas are not related to RSLR and therefore should not be included in an analysis designed to assess wetland responses to sea-level rise. The authors should either provide a clear justification for including human-driven deforestation in the calculation of net area change in a sea-level-rise-focused study, or update the analysis so that RRAC more directly reflects the extent to which wetland expansion offsets inundation-driven wetland loss.

Response: We thank the reviewer for the positive assessment of the RRAC-RROW comparison. Below, we provide clarifications and additional explanations regarding the design logic of RRAC and the supplementary analyses prompted by your constructive suggestion.

1. Rationale for using total gross loss in RRAC. We intentionally calculated RRAC as gross gain minus total gross loss to avoid a priori exclusion of any loss processes.

This metric is designed to examine, from a system-level perspective, the historical relationship between global tidal wetland area change and RSL change rates without pre-filtering individual drivers. In other words, RRAC addresses the question: when all gain and loss processes are considered, does increasing RSL change rate produce a discernible signal in net area change? As shown in [Fig. 1](#), the effects of both RSL fall and rise are clearly reflected in the overall proportion of gains versus losses, while [Fig. 2](#) further resolves these relationships by revealing the proportional and magnitude changes in area change across refined RSL change rate bins. In general, the standalone RRAC analysis is not intended to quantify the degree to which gains offset inundation-driven losses; rather, it provides a top-down, unfiltered view of the global tidal wetland system.

2. The complementary role of RROW and its contrast with RRAC. Following your valuable suggestion from the previous round, we introduced the RROW analysis to directly isolate the inundation signal and test whether increasing RSL change rates unambiguously accelerate wetland submergence losses. The results clearly show an association with extremely high likelihood: higher RSLR rates drive accelerated conversion of tidal wetlands to open water ([Table 2](#); [Supplementary Table 2](#)). In comparison, RROW exceeds a lower threshold (8 mm yr⁻¹) with *extreme likelihood* ($\approx 100\%$), whereas RRAC exceeds a higher threshold (9 mm yr⁻¹) with lower likelihood ($>66\%$, i.e., *likely to very likely*). The larger threshold and lower loss likelihood in RRAC indicate that, over the past two decades, aggregate lateral gains, including landward migration, natural expansion, and anthropogenic restoration, have provided partial buffering against direct inundation losses.

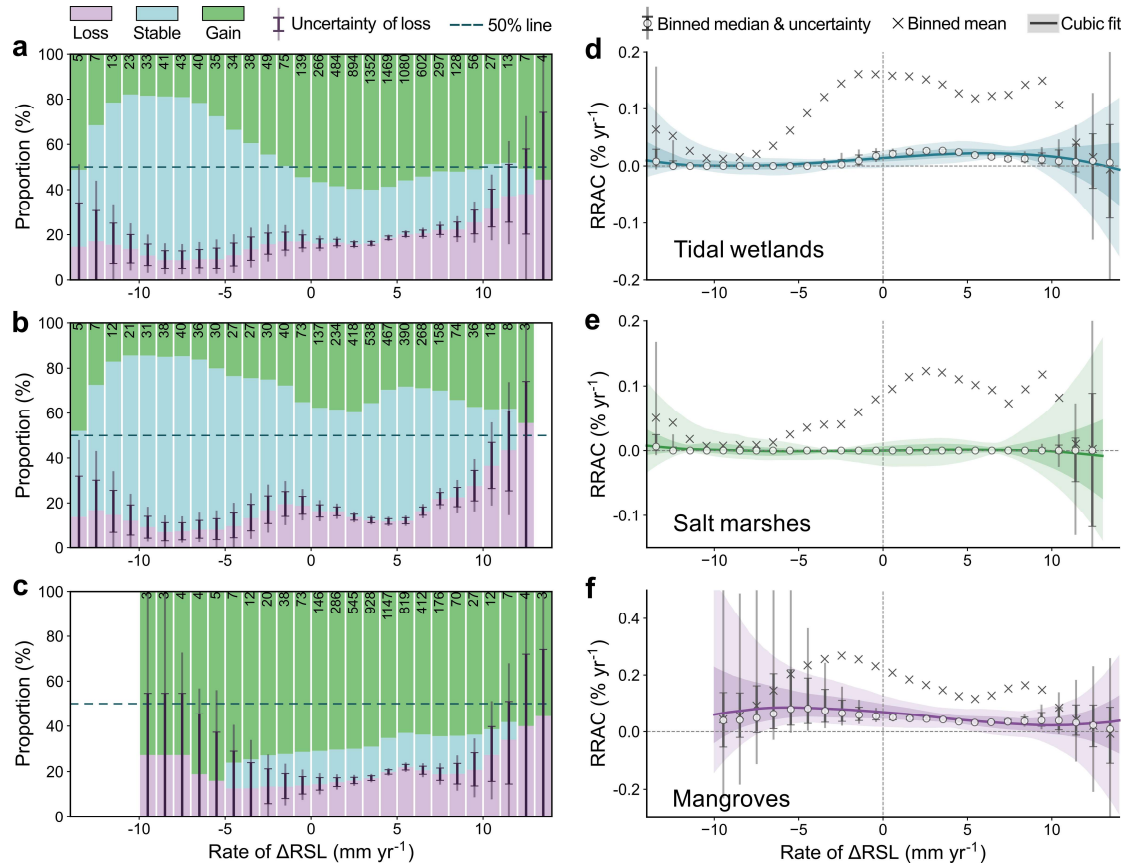
3. Supplementary analysis: RRAC' (gross gain minus loss to open water). To further address your suggestion, we introduce RRAC' in the supplementary materials, calculated as gross gain minus loss to open water. By excluding non-inundation losses (e.g., deforestation and aquaculture conversion), RRAC' isolates the theoretical capacity of gross gains to buffer inundation-related losses. Theoretically, RRAC' should exhibit an even stronger buffering effect, and this expectation is confirmed by our results: the RRAC'-RSLR relationship is comparatively stable, with a weaker threshold effect ([Supplementary Fig. 4d-f](#)) and the trend of accelerated loss carries greater uncertainty ([Supplementary Table 4](#)). This indicates that controlling non-RSL-driven losses would allow gross gains to substantially offset RSLR-induced inundation, effectively raising the threshold for loss acceleration. Nevertheless, the loss proportion

still increases non-linearly at higher RSLR rates, signaling persistent degradation risk under high-end scenarios not yet widely observed (Supplementary Fig. 4a-c).

In the Discussion As: “An additional buffering mechanism operates under high RSL rise rates through integrative lateral reorganization. Although both metrics exhibit nonlinear responses, RRAC shows a higher area-based threshold ($\sim 9 \text{ mm yr}^{-1}$ versus $\sim 8 \text{ mm yr}^{-1}$) and a lower probability of decline ($>66\%$, likely) under accelerating RSL rise compared to RROW ($>95\%$, extremely likely) (Table 2; Table 3; Supplementary Table 2). This indicates that lateral reorganization, despite encompassing non-RSL-driven losses, has provided a quantifiable buffer against tidal wetland degradation over the past two decades. To further elucidate this buffering capacity, we introduce a refined area-change metric, RRAC', defined as relative rate of gross wetland gain minus loss to open water. RRAC' directly quantifies the extent to which wetland gain offsets inundation-relative loss. The relationship between RRAC' and RSL change rate reveals a relatively inconspicuous threshold effect at high RSL rise rates (Supplementary Fig. 4d-f), with probability assessments differing between linear and nonlinear loss trajectories (Supplementary Table 4). This suggests that the RSL rise rate threshold for accelerated wetland loss may become obscured or shift to higher values if non-RSL-driven losses are effectively constrained. A key buffering behavior occurs when RSL rise outpaces surface elevation gain and depletes elevation capital, yet wetland area may not immediately decline if landward migration is possible (refs.^{4,52-54}; Supplementary Fig. 5c, Supplementary Fig. 6b), and area gains can occasionally exceed losses¹⁸. Lateral erosion can also reallocate sediment to vertical accretion, potentially allowing wetlands to adapt to rising sea levels^{45,55,56}. Additionally, wetland restoration efforts have contributed to decelerating area decline^{3,57}. Collectively, global tidal wetlands may demonstrate moderate lateral resilience to accelerating RSL rise under the combined natural and anthropogenic forcing.” (See tracked version, Line 322-349)

“Wetland loss is likely to intensify further as RSL rise rates increase⁶¹.....Loss proportions increase under both the RRAC and RRAC' metrics as RSL rise rates accelerate, indicating escalating submergence risk despite their lateral buffering capacities (Fig. 2a-c; Supplementary Fig. 4a-c).” (See tracked version, Line 364-367)

We are grateful for your insightful comments and constructive suggestions, which have helped us clarify the core logic of our analyses and motivated us to conduct more comprehensive supplementary validations.



Supplementary Fig. 4 | Effect of RSL change on RRAC'. RRAC': relative rate of area change calculated as: gross gain minus loss into open water (inundation-related loss). Proportions of loss, stable and gain per rate of RSL change are shown for (a) all tidal wetlands, (b) salt marshes, and (c) mangroves. Number of grid cells within each RSL change rate bin is indicated above each bin. The blue dashed line denotes the 50% proportion. Darker and lighter error bars denote the uncertainty range of 66% (likely range) and 90% (very likely range), respectively. Trends in RRAC' magnitude as a function of RSL change rate, along with binned means and medians, are shown for (d) all tidal wetlands, (e) salt marshes and (f) mangroves. Circles and crosses denote the medians of binned medians and binned means, respectively. The grey error bars represent the 66% and 90% uncertainty ranges of binned medians. The colored curves show cubic fits to the binned medians, with darker and lighter shaded envelopes indicating the 66% and 90% uncertainty ranges. Only bins containing more than three grid cells are shown. Only grid cells with total area $> 1 \text{ km}^2$ are included. Calculations are performed on 0.25° grid cells.

Supplementary Table 4 | Probability of loss intensification in binned medians and means of RRAC' across RSL change rate bins using different fitting methods (for grid cells with total wetland area > 1 km²). RRAC': relative rate of area change calculated as gross gain minus loss into open water. For each wetland type, the upper and lower rows show fits to binned medians and binned means, respectively.

RRAC' (Gain minus OW)	Probability of a declining linear trend	Probability of tail decay in Cubic fits
Tidal wetlands	31.9%	76.4%
	32.8%	87.6%
Salt marshes	63.2%	60.8%
	21.6%	83.6%
Mangroves	82.9%	40.7%
	84.1%	45.7%

2. I do not think that RRAC and RROW reflect different dimensions of wetland response in the way currently described. Both metrics primarily capture lateral wetland area dynamics rather than vertical processes. The statement that RROW reflects lateral change whereas RRAC captures both lateral and vertical processes does not seem well supported. In my view, RRAC mainly indicates the degree to which wetland expansion can compensate for RSLR-induced wetland loss, rather than providing direct information on vertical wetland adjustment.

Response: We agree with your assessment and have revised the relevant statements accordingly. We clarify as follows:

RROW does not directly represent vertical processes; rather, it serves as a lateral retreat signal that reflects the cumulative outcome of inundation processes. In other words, whether vertical accretion keeps pace with RSL rise is ultimately manifested as the lateral conversion of wetlands to open water. RRAC, by contrast, characterizes net lateral change, indicating whether a region can maintain relatively stable total wetland area. Both metrics are therefore fundamentally lateral area-change indicators.

Thus, our comparison between RROW and RRAC is not between lateral and vertical dimensions. Instead, it asks whether the aggregated response (RRAC, which

282 incorporates gains and non-RSL-driven losses) is more sensitive or more damped than
283 the inundation-specific response (RROW) under increasing RSL rise.

284 ***In the Discussion As:** "...Of the two area-change metrics we quantified, conversion to*
285 *open water represents the lateral cumulative effects of inundation processes, whereas*
286 *net area change integrates overall lateral processes...."* (See tracked version, Line 311-
287 314)

288 3. In line 61 of the change-tracked version of the main text, "but" should be replaced
289 with "however".

290 ***Response:*** Thank you, we have updated it. (See tracked version, Line 53)

291

Reviewer #3 (Remarks to the Author):

I would like to thank the authors for their elaborate responses and revisions following the feedback of myself and the other reviewers. Both the responses as well as the revised manuscript are now convincingly presenting some highly relevant findings regarding the impacts of relative sea-level rise on global tidal wetlands.

Response: We thank you for your thorough review and positive assessment of our revised manuscript.

Upon reading the revised manuscript, I have one question remaining in relation to the negative association between RRAC and SSC observed for mangroves. In the discussion (lines 372-372) it is stated that the underlying mechanisms remain unknown. Yet, I'm wondering whether this effect is related to dynamics at the fringe (drowning) or losses at the landward side of the mangroves. Have the authors considered to perform a similar multiple linear regression for RROW? My guess would be that the association between RROW and SSC is negative (i.e. seaward expansion for higher SSC), so that the losses are somehow related to different anthropogenic impacts (possibly on the landward side). If the association between RROW and SSC is positive, a possible explanation would be that in highly turbid estuaries mangroves are actively removed from mudflats to maintain open water (this happens in for instance New Zealand).

Response: We thank you for this insightful suggestion. Following your recommendation, we performed the same multiple linear regression analysis for RROW as we did for RRAC. The results show that RROW is positively correlated with SSC for both mangroves and salt marshes ([Supplementary Fig. 11](#)).

We agree that this finding calls for careful interpretation. One plausible explanation, as you proposed, is that in highly turbid estuaries, coastal vegetation may be actively removed to maintain navigable channels or open tidal flats (e.g., mangroves in New Zealand; Xie et al., 2023), or to eradicate fast-growing invasive species for ecological safety (e.g., *Spartina alterniflora* in the Yangtze Estuary; Zhang et al., 2020). This anthropogenic mechanism would manifest as a positive association between RROW (loss to open water) and SSC at the seaward fringe.

Alternatively, the positive RROW–SSC relationship could reflect sedimentary signatures of retreating wetland margins: extensive inundation-related loss may elevate

local turbidity through enhanced resuspension from exposed substrates (Ganju et al., 2015). These resuspended sediments can then be redistributed landward to support elevation gain, thereby maintaining high-marsh positions (Barksdale et al., 2025). This compensatory mechanism may also explain why salt-marsh RRAC remains positively correlated with SSC. For mangroves, however, anthropogenic disturbance likely remains the dominant driver of loss (Goldberg et al., 2020), thereby masking this compensatory signal in the RRAC metric.

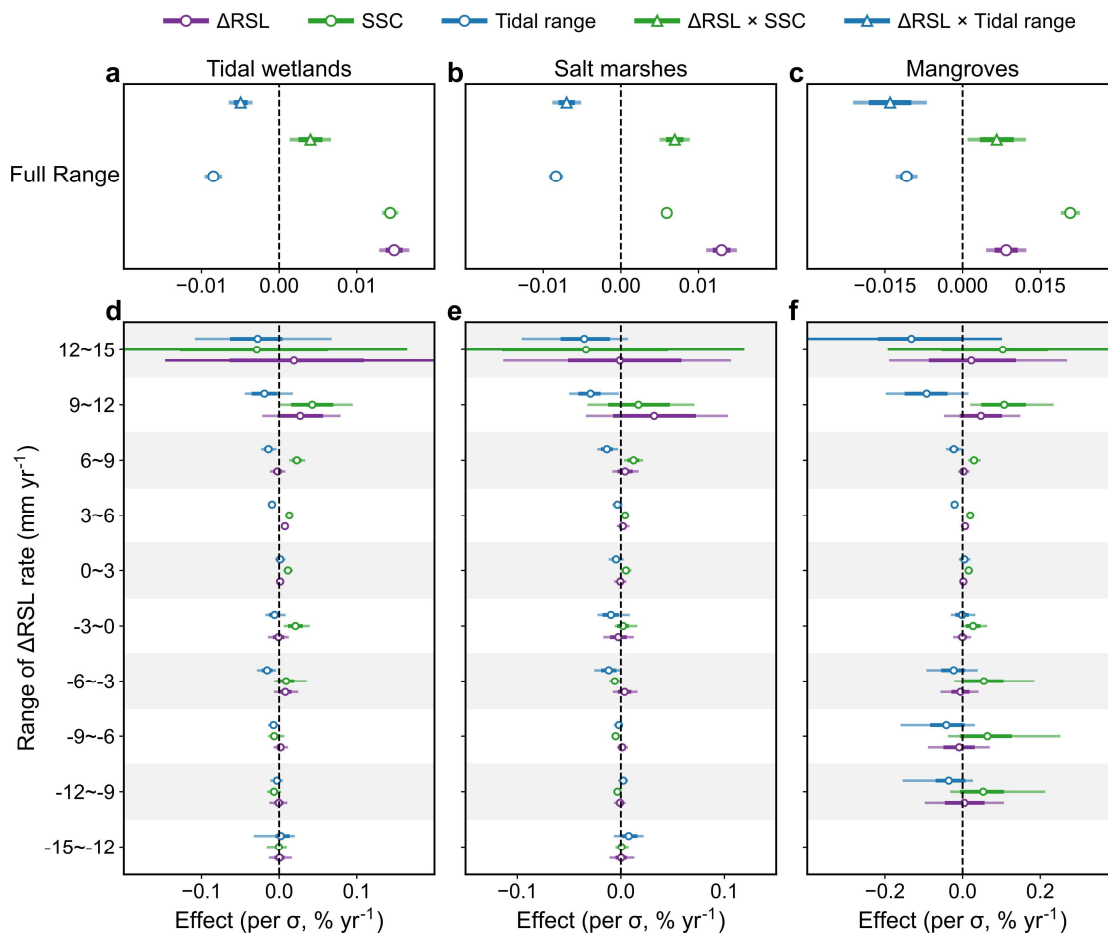
We have incorporated this discussion into the revised manuscript, explicitly noting that the current dataset cannot fully discriminate natural drowning processes from anthropogenic disturbances, and that regression analysis alone cannot establish causality. This limitation is now acknowledged as a caveat of our study.

In the Discussion As: “Natural factors such as tidal range and SSC can partially mitigate the threat posed by accelerating RSL rise. For RRAC, our observed positive effect of tidal range is consistent with previous findings (Fig. 4; refs.^{17,68-70}). A larger tidal range prolongs inundation duration and increases water depth, thereby facilitating vertical sediment deposition in low-lying zones⁷¹ and promoting the maintenance of elevation capital⁴⁴. It also provides broader accommodation space for sediment accumulation and vegetation establishment^{4,13}. In salt marshes, SSC exerts a similarly positive influence, enhancing vertical accretion and lateral expansion^{9,68,72}.

By contrast, the negative RRAC–SSC association observed in mangroves is counterintuitive. To isolate this effect from confounding lateral processes, we conduct an analogous multiple linear regression on RROW. Notably, both wetland types exhibit a positive RROW–SSC relationship (Supplementary Fig. 11b,c), indicating that inundation-related loss actually accelerates under high-SSC settings. This apparent paradox may arise from several mechanisms. First, in highly turbid estuaries, coastal vegetation has been actively removed to maintain navigable channels or open tidal flats (e.g., mangroves in New Zealand⁷³), or to eradicate fast-growing invasive species for ecological safety (e.g., *Spartina alterniflora* in Changjiang estuary⁷⁴). Second, excessive sediment deposition under high SSC can suppress plant growth or even induce mortality through hypoxic stress⁷⁵⁻⁷⁷. Alternatively, if viewed from a sedimentary perspective, the positive RROW–SSC relationship could reflect sedimentary signatures of

retreating wetland margins: extensive inundation-related wetland loss elevates local turbidity via resuspension from exposed substrates⁷⁸, and landward reallocation of this sediment promotes elevation gain⁴⁵—which would explain why RRAC in salt marshes remains positively correlated with SSC. For mangroves, however, anthropogenic disturbance likely remains the dominant driver of loss⁴¹, thereby masking this compensatory signal. Collectively, the current dataset cannot fully discriminate natural drowning from anthropogenic disturbances, and regression analysis alone cannot establish causality. Despite this limitation, our findings provide strong correlational evidence that the buffering capacity of lateral reorganization is mediated by both physical setting (tidal range, SSC) and local human activities, underscoring the need for site-specific risk assessments.”

(See tracked version, Line 390-433)



Supplementary Fig. 11 | Effects estimated from multiple linear regression explaining RROW as a function of RSL change rate, tidal range, and SSC. (a-c) Global multiple linear regressions incorporating interaction terms between RSL change rate and each of tidal range and SSC, for tidal wetlands, salt marshes, and mangroves, respectively.

(d-f) Stratified multiple linear regressions excluding interaction terms, with effects estimated within 3 mm yr⁻¹ intervals of RSL change rate for tidal wetlands, salt marshes, and mangroves, respectively. Circles denote mean coefficients of independent terms; triangles denote mean coefficients of interaction terms. Horizontal thick, dark lines represent the 66% uncertainty range (aligned with the IPCC likely range), while thin, light lines represent the 90% uncertainty range (IPCC very likely range).

Otherwise, the manuscript reads very well and I only have a few very minor comments left.

Response: We thank the reviewer for the positive feedback. Below we provide our point-by-point responses to the remaining minor comments.

Minor comments

75-77 (line numbers): The line ‘we calculate the relative rate of net area change (still referred to as RRAC hereafter) and separately for the area converted to open water (hereafter RROW)’ doesn’t provide a very clear explanation of the RROW. I would suggest to revise the second half of the sentence to ‘and, separately, for the relative rate of area converted to open water’.

Response: Thank you, we have revised this sentence, as “...we calculate the relative rate of net area change (still referred to as RRAC hereafter) and, separately, for the relative rate of area converted to open water (hereafter RROW)”. (See tracked version, Line 76-77)

210: Please remove either ‘behaviors’ or ‘responses’, these words are doubling.

Response: We have deleted ‘responses’. (See tracked version, Line 210)

223: ‘cubic fit’ should be plural.

Response: We have corrected this. (See tracked version, Line 223)

Figure 3: The unit on the vertical axis uses Δ RSLC. RSLC is not defined in the manuscript up to here, but I believe it to be RSL change? In that case, does it make sense to also have the Δ in front?

Response: We thank the reviewer for raising this point. We have now explicitly defined RSLC in the Figure 3 caption. Regarding the Δ notation, Δ RRAC and Δ RSLC denote

the increments of the two variables along the regression line (standard slope notation: $S = \Delta y / \Delta x$). Therefore, we believe that the Δ notation in the figure is appropriate and does not require any correction. Besides, as the time units (yr^{-1}) cancel out, S represents the percentage wetland area change per millimetre of sea-level rise, making the physical interpretation more direct. We have clarified this in the revised caption.

As: “RRAC denotes relative rate of wetland area change ($\% \text{ yr}^{-1}$); RSLC denotes relative sea-level change rate (mm yr^{-1}). The slope $S = \Delta \text{RRAC} / \Delta \text{RSLC}$ is the ratio of increments of the two variables along the regression line; as the time units (yr^{-1}) cancel out, S represents the percentage change in wetland area per millimeter rise in relative sea level.” (See tracked version, Line 231-234)

239: Please correct ‘an negative’.

Response: We have corrected this. (See tracked version, Line 242)

262-263: Please add the unit after ‘an increase in RRAC of 0.015’, otherwise this could be confused with a percentage/relative increase.

Response: We have added the unit here. (See tracked version, Line 266)

340: Please remove ‘be’ in ‘to be intensify’.

Response: We have removed ‘be’. (See tracked version, Line 361)

341: Please correct ‘only ~3% of global wetland extent has experienced RSL rise rates’.

Response: We have corrected it. (See tracked version, Line 362)

400: Please insert the article in ‘at a preceding point’. Also please correct ‘mean RROW increases’.

Response: We have corrected them. (See tracked version, Line 452)

414: ‘losses that is’ should read ‘losses that are’

Response: We have corrected it. (See tracked version, Line 467)

678: Please see my comment re Figure 3; RSLC is not clearly defined.

Response: We have added the abbreviation reference in Line 723.

682: Please remove ‘the model’ from ‘This model was then applied the model’.

Response: We have deleted ‘the model’ . (See tracked version, Line 737)

References

Xie, D., Schwarz, C., Kleinhans, M. G. et al. Mangrove removal exacerbates estuarine infilling through landscape-scale bio-morphodynamic feedbacks. *Nat. Commun.* 14, 7310 (2023).

Zhang, X. et al. Quantifying expansion and removal of *Spartina alterniflora* on Chongming island, China, using time series Landsat images during 1995–2018. *Remote Sens. Environ.* 247, 111916 (2020).

Ganju, N. K. et al. Sediment transport-based metrics of wetland stability. *Geophys. Res. Lett.* 42, 7992–8000 (2015).

Barksdale, M. B., Valentine, K., Hein, C. J. & Kirwan, M. L. Tradeoffs between vertical and lateral resilience in a salt marsh restoration model. *J. Geophys. Res. Biogeosci.* 130, e2025JG009145 (2025).

Goldberg, L., Lagomasino, D., Thomas, N. & Fatoyinbo, T. Global declines in human-driven mangrove loss. *Global Change Biology* 26, 5844–5855 (2020).

Please refer to the manuscript for the references indicated by superscripts in the revised text.