Numerical and field investigations unveil the response of salt marshes to storm sediment input

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Abstract

Salt marshes are ecosystems with significant economic and environmental value. With accelerating rate in sea-level rise, it is not clear whether salt marshes will be able to retain their resilience. Field and numerical investigations have shown that storms play a significant role in marsh accretion and that they might be crucial to salt marsh survival to sea-level rise. Here we present the results from two studies (Pannozzo et al., 2021a,b; Pannozzo et al., 2022) that used numerical and field investigations to quantify the impact of storm surges on the sediment budget of salt marshes within different sea-level scenarios and to investigate how sediment transport pathways determine marsh response to storm sediment input. The Ribble Estuary, North-West England, was used as a test case. The hydrodynamic model Delft3D was used to simulate the estuary morpho-dynamics under selected storm surge and sea-level scenarios. In addition, sediment samples collected with a monthly frequency from different areas of the marsh were analysed with sediments collected from possible sources to integrate field observations with the numerical investigation of sediment transport pathways during stormy and non-stormy conditions. Results showed that, although sea-level rise threatens the estuary and marsh stability by promoting ebb dominance and triggering a net export of sediment, storm surges promote flood dominance and trigger a net import of sediment, increasing the resilience of the estuary and salt marsh to sea-level rise, with the highest surges having the potential to offset sea-level effects on sediment transport and sediment budget of the system. However, although storm sediment input resulted to be significant for the accretion of the marsh platform and particularly for the marsh interior, data showed that storms mainly remobilise sediments already present in the intertidal system and only to a minor extent transport new sediment from external sources.

References

Pannozzo N. et al., 2021. Salt marsh resilience to sea-level rise and increased storm intensity. Geomorphology, 389 (4): 107825.

Pannozzo N. et al., 2021. Dataset of results from numerical simulations of increased storm intensity in an estuarine salt marsh system. Data in Brief, 38 (6): 107336.

Pannozzo N. et al., 2022. Sediment transport pathways determine the sensitivity of salt marshes to storm sediment input. In preparation.

Abstract content goes here

Numerical and field investigations unveil the response of salt marshes to storm sediment input

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Context

- Salt marshes provide a variety of ecosystem services and act as natural, long-term, low-cost coastal defences for lowland coastal areas.
- Increasing rates of sea-level rise can threaten marsh survival as an increase in accommodation space increases the amount of sediment required for marsh stability[1].
- Storms can enhance salt marsh resilience as stronger currents and waves can resuspend and transport higher quantities of sediments over marsh platforms[2], but to what extent?

Goals

1. To investigate how storm surges affect salt marsh response to sea-level rise.

2. To investigate storm sediment contribution to salt marsh accretion and expansion.

Case study

- Ribble Estuary, North-West England (Fig 1a).
- Hypertidal, funnel-shaped estuary (Fig 1b).
- One of Europe's largest restored salt marsh systems (Fig 1c).

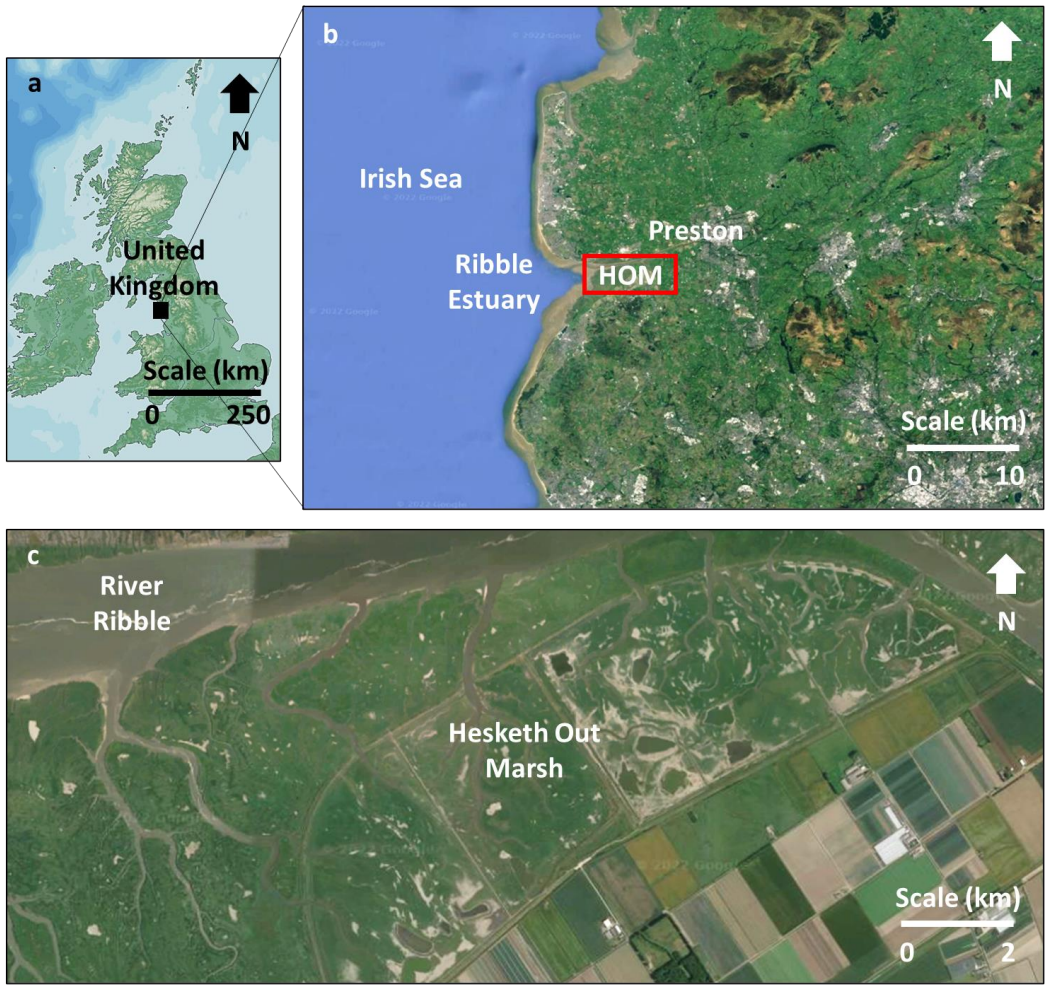

Figure 1. Location (a) and morphology (b) of the Ribble Estuary; location (b) and morphology (c) of Hesketh Out Marsh.

[1] Kirwan et al., 2010. *Geophys. Res. Lett.*, 37 (23).
[2] Castagno et al., 2018. *Geophys. Res. Lett.*, 45 (11), 5491-5500.

1. To investigate how storm surges affect salt marsh response to sea-level rise

One-month simulation run using the hydrodynamic model Delft3D, combining different sea-level and storm surge scenarios (n=250) to investigate changes in the sediment budget of the system.

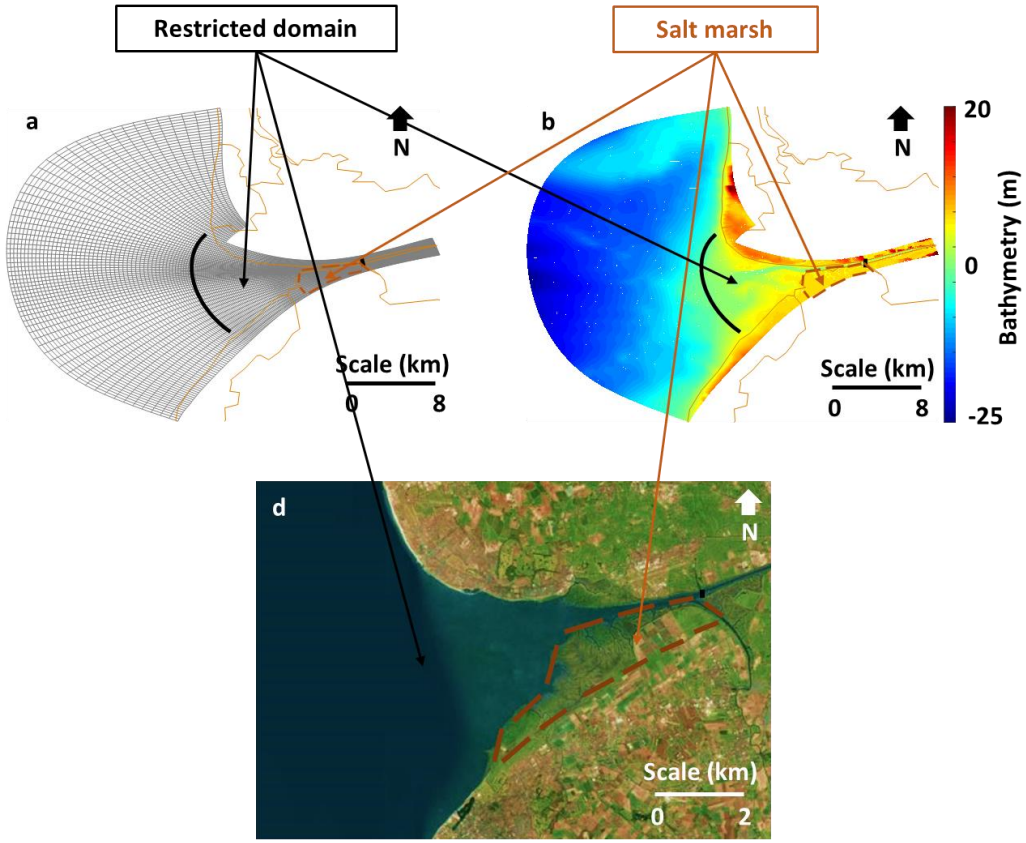

Figure 2. Grid (a), bathymetry (b) and aerial view (c) of the domain studied. The continous black lines and the brown dashed lines enclose respectively the sections of the estuary and the salt marsh used for sediment budget calculation.

Pannozzo N. et al. (2021), *Geomorphology*, 389 (4): 107825.
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2. To investigate storm sediment contribution to salt marsh accretion and extension

Sediments collected monthly (Autumn 2021 - Summer 2022) from the salt marsh platform using sediment traps to investigate storm sediment contribution to the accretion of different areas of the marsh, and compared to potential sources to understand if storms can provide an external input of sediments.

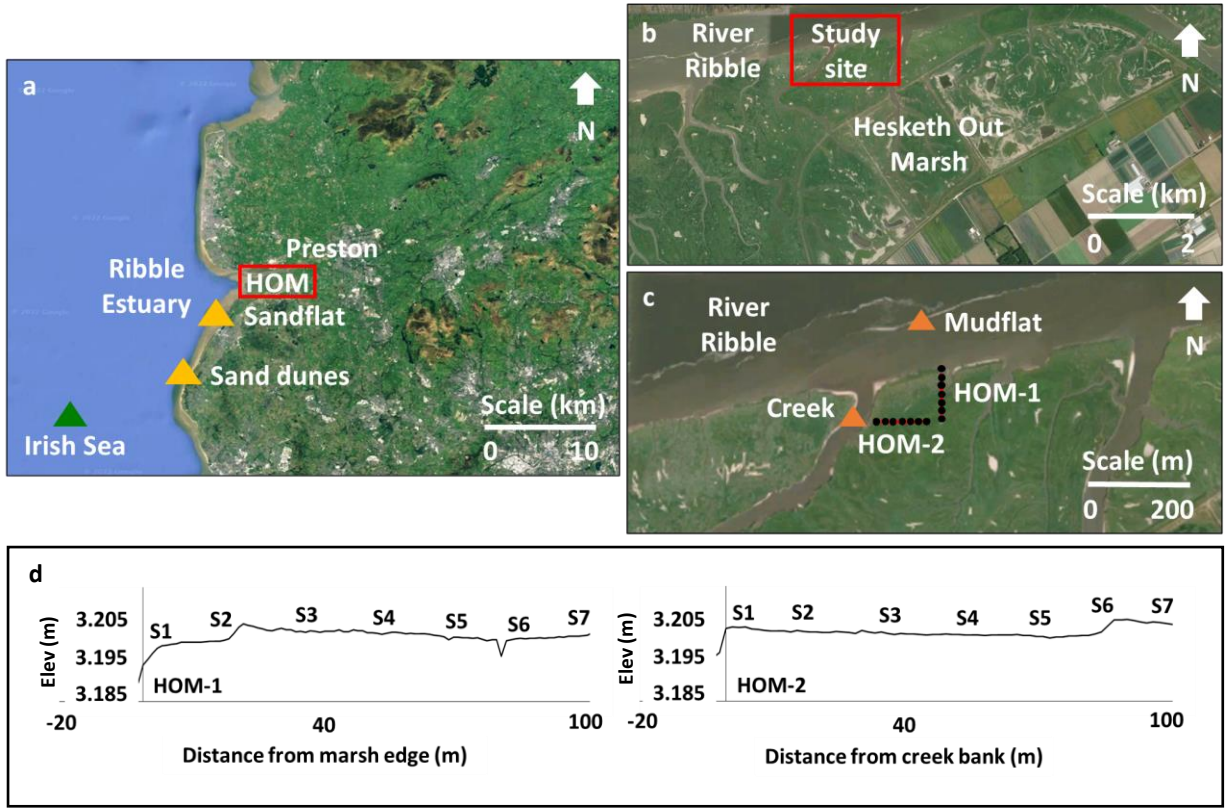

Figure 3. Location of the Irish Sea coring sites and the sand dunes and sandflat sampling sites (a); location of the study site (b); location of the mudflat and creek sampling sites and salt marsh transects (c); transects profiles and location of the sediment traps (d).

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1. To investigate how storm surges affect salt marsh response to sea-level rise

Figure 4. Sediment budget calculated for various sea-level scenarios.

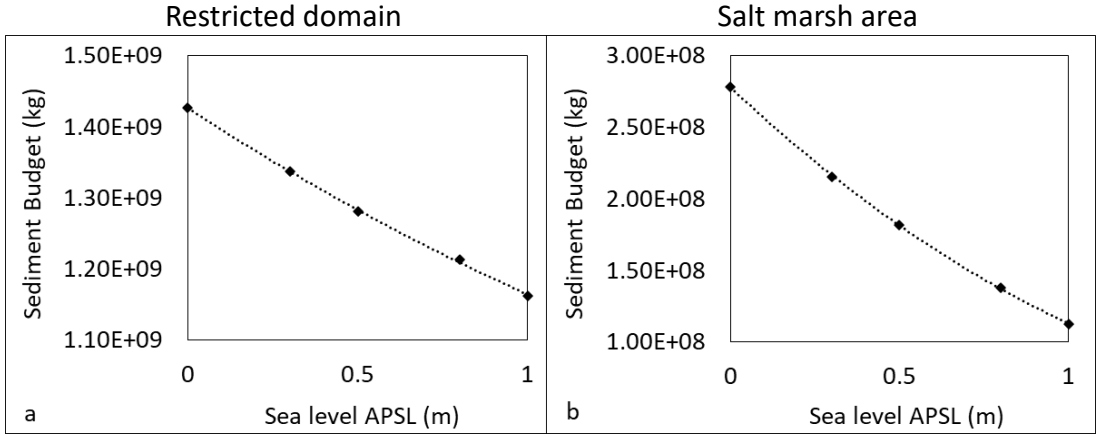


Figure 5. Sediment budget calculated for various storm surge scenarios.

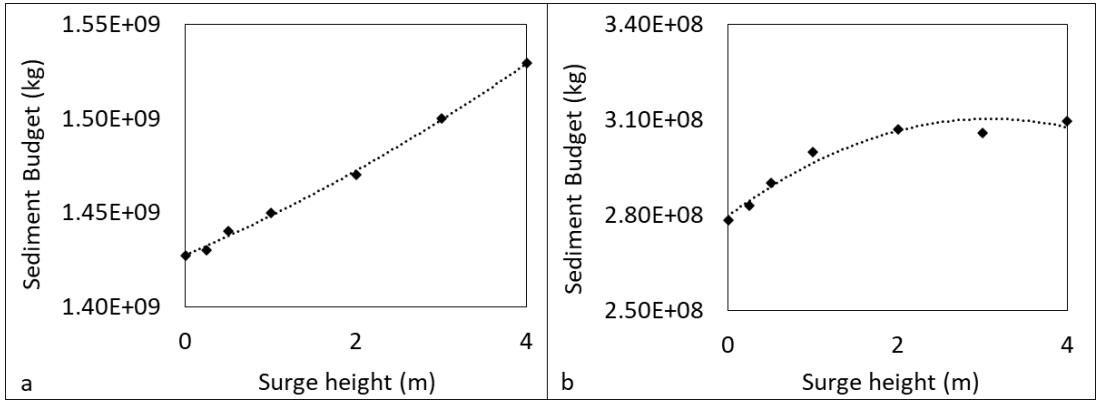
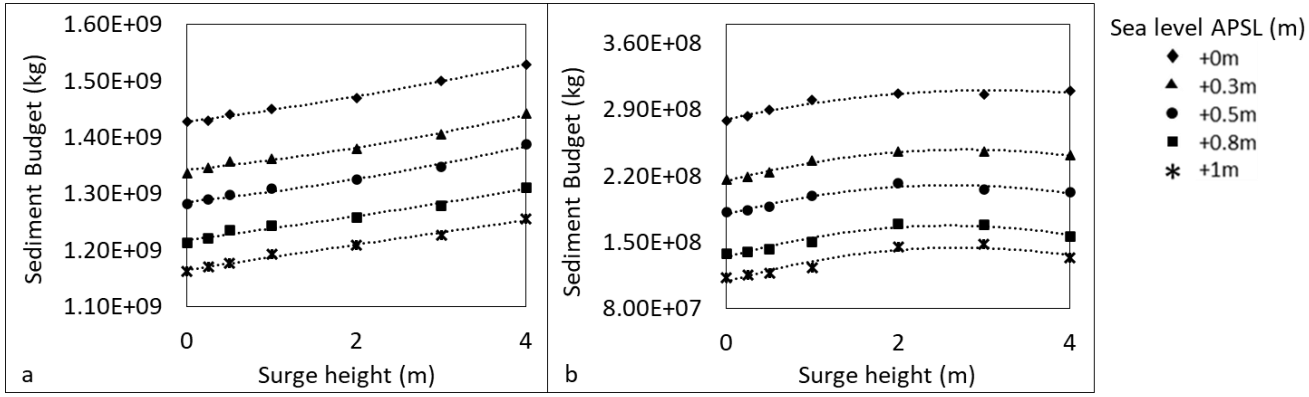


Figure 6. Sediment budget calculated for combined sea-level and storm surge scenarios.



- An increase in sea-level can also change the resonance properties of the basin promoting nearshore ebb dominance, thus triggering sediment export (Fig. 4).
- An increase in storm intensity also increases the propagation speed of the incoming tide promoting nearshore flood dominance, thus further enhancing sediment import (Fig. 5).
- Intense storms (>3 m) can offset the effects of sea-level rise on the sediment budget of the system (Fig. 6).
- But the increase in sediment budget caused by storm surges is more significant for the marsh platform (up to 65%) than it is for the restricted domain (up to 7%) (Fig. 6).

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2. Storm sediment contribution to salt marsh accretion and expansion

Figure 7. Traps used for the collection of sediment samples over the salt marsh platform.

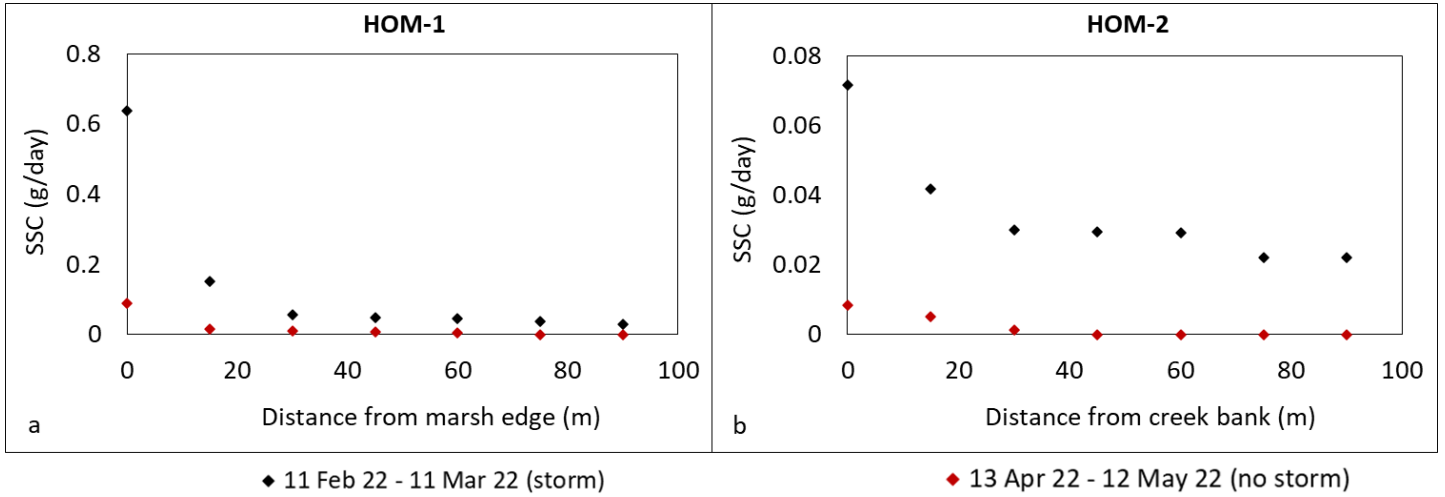

Figure 8. SSC profile across the marsh platform relative to a stormy and a non-stormy period.

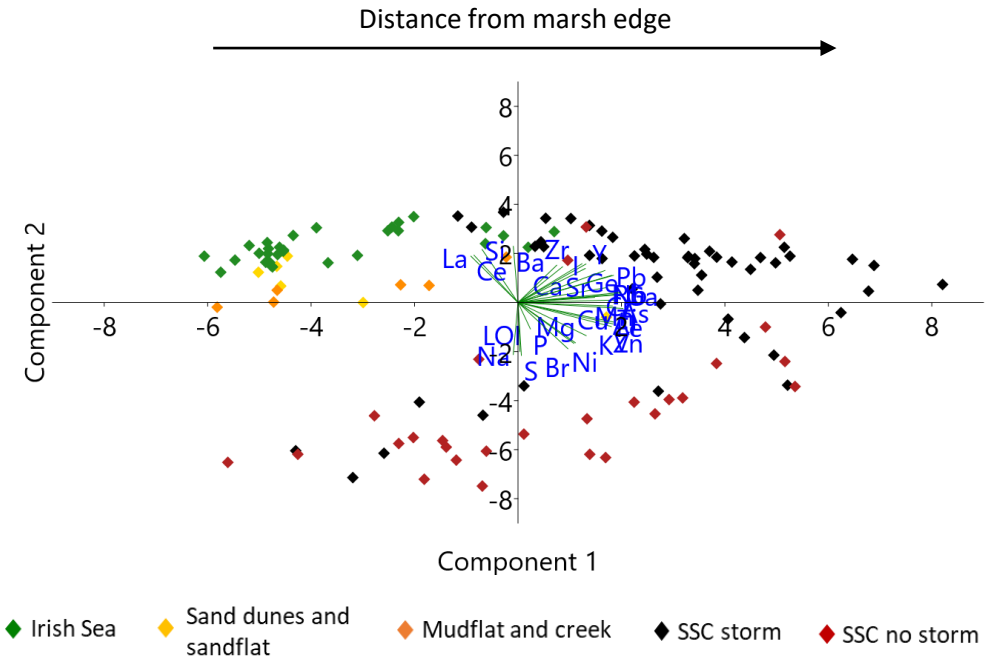

Figure 9. Principal component analysis between the geochemistry of the samples collected from the marsh platform and the geochemistry of the samples collected from the potential sources.

- Sediment supply decreases non-linearly from the marsh edge (to a major extent) and from the creek bank (to a minor extent) both in stormy and fair-weather conditions, as it correlates with cross-marsh variations of current velocities and wave energy[3] (Fig. 8).
- As expected, sediment supply is overall higher during stormy conditions compared to fair-weather conditions, in agreement with the model results (Fig. 8).
- But the increase in sediment supply during stormy periods is more significant for the inner marsh areas (up to 600%), which is rarely inundated, than it is at the marsh edge (up to 250%), which is regularly inundated.
- Sediment supply to the marsh edge is always marine in provenance, while the rest of the marsh only receives marine sediment supply during storm events (Fig. 9).

[3] Zhang et al., 2020. *Geophys. Res. Lett.*, 47 (13).
Pannozzo N. et al. (2022), *Geomorphology*, In Review.

2. Storm sediment contribution to salt marsh accretion and expansion

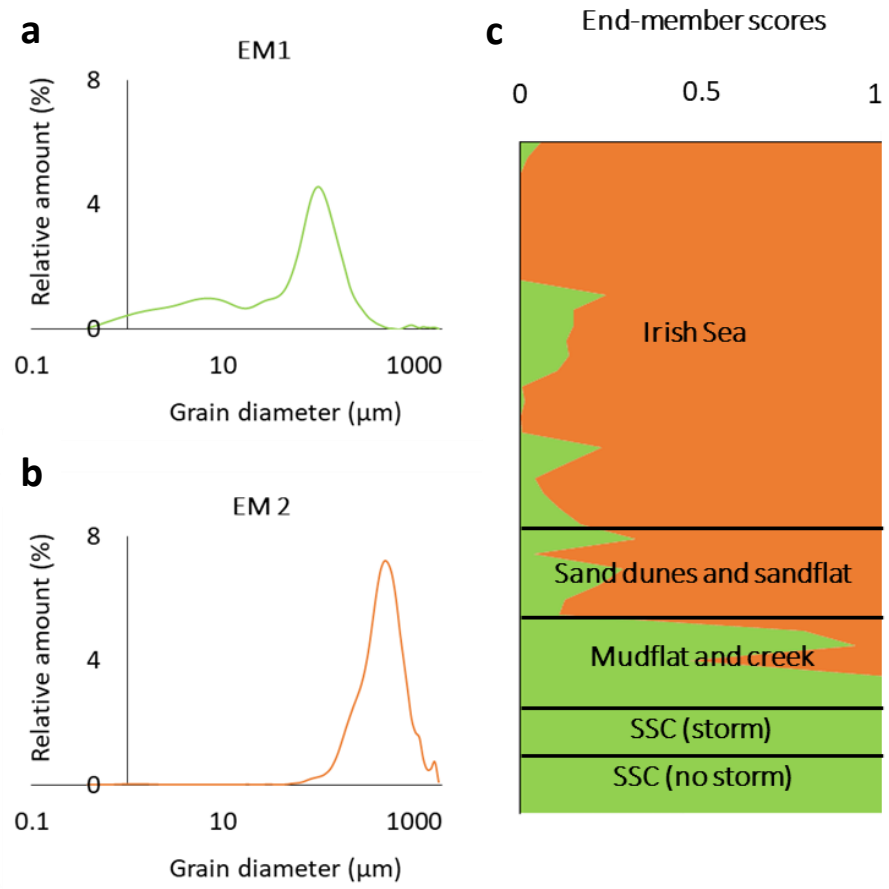

Figure 10. End-member analysis of the PSDs of the samples collected from the marsh platform and from the potential sources.

- At the marsh edge, both stormy and non-stormy samples are characterised by fine sediments and have similar PSDs (Fig. 10).
- This means that, at least for medium-intensity storms, the mode of deposition doesn't change significantly compared to fair-weather conditions[4].
- This suggests that the sediments deposited over the marsh platform during stormy conditions are unlikely to be transported from further sources than usual and very likely to be mostly resuspended from the mudflat/creek area.
- This resembles what we saw in the model: storm surges, even those with the highest intensities, increase the sediment budget of the marsh platform significantly but only benefit the restricted domain minimally.
- The enhanced excavation of the mudflat, however, while promoting marsh vertical accretion, can limit salt marsh expansion on a horizontal scale[5].

[4] Rahman and Plater, 2014. *Geomorphology*, 213, 139-152.
[5] Roner et al., 2021. *Front. Mar. Sci.*, 8.
Pannozzo N. et al. (2022), *Geomorphology*, In Review.

Key findings

Storms enhance salt marsh resilience to sea-level rise by increasing the overall marsh sediment budget.

However, this comes from supporting mostly vertical accretion while limiting horizontal expansion.

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