Conditional effects of tides and waves on sediment supply to salt marshes

Jianwei Sun[1], Bram Christiaan van Prooijen[2], Xianye Wang[3], Weiming Xie[4], Fan xu[3], Qing He[3], and Zheng Bing Wang[5]

[1]Delft University of Technology
[2]TU Delft
[3]East China Normal University
[4]State Key Laboratory of Estuarine and Coastal Research, East China Normal University
[5]Deltares

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Abstract

The survival of salt marshes, especially facing future sea-level rise, requires the supply of sediment. Sediment can be supplied to salt marshes via two routes: through marsh creeks and over marsh edges. However, the conditions of tides and waves that facilitate sediment import through these two routes remain unclear. To better understand when and how sediment import towards salt marshes occurs, measurements spanning two months were conducted in Paulina Saltmarsh. The results show that the marsh creek and the marsh edge do not import sediment simultaneously. The marsh creek tends to import sediment during neap tides with waves. A small tidal range results in weaker flow during ebb tides, reducing the export of sediment. Strong waves, particularly during this period, enhance the sediment supply from mudflats to the marsh creek. Additionally, waves can directly affect sediment re-suspension in the marsh creek during spring tides when the water level is above the marsh canopy. The marsh edge benefits from contrasting tidal and wave conditions, with sediment imported during spring tides with weak waves. Waves during spring tides re-suspend sediment, impeding the sediment deposition, and thus leading to sediment export over the marsh edge. These results highlight the potential sediment transport routes to marshes under varying conditions, shedding light on their implications for the long-term survival of salt marshes.

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Jianwei Sun[1,2], Bram van prooijen[2], Xianye Wang[1]†, Weiming Xie[1], Fan Xu[1], Qing He[1], Zhengbing Wang[2,3]

[1]State Key Laboratory of Estuarine and Coastal Research, East China Normal University, 500 Dongchuan Road, Shanghai, 200241, China

[2]Faculty of Civil Engineering and Geosciences, Delft University of Technology, Stevinweg 1, Delft, 2628 CN, The Netherlands

[3]Deltares, P.O. Box 177, Delft, 2628 CN, The Netherlands

Corresponding author: Xianye Wang (xywang@sklec.ecnu.edu.cn)

Key points:

- When and how sediment is transported to and from salt marshes was investigated.
- Sediment import through marsh creeks and over marsh edges requires opposite tidal and wave conditions.
- Waves have two different impacts on sediment transport in marsh creeks depending on tidal ranges.

Abstract

The survival of salt marshes, especially facing future sea-level rise, requires the supply of sediment. Sediment can be supplied to salt marshes via two routes: through marsh creeks and over marsh edges. However, the conditions of tides and waves that facilitate sediment import through these two routes remain unclear. To better understand when and how sediment import towards salt marshes occurs, measurements spanning two months were conducted in Paulina Saltmarsh. The results show that the marsh creek and the marsh edge do not import sediment simultaneously. The marsh creek tends to import sediment during neap tides with waves. A small tidal range results in weaker flow during ebb tides, reducing the export of sediment. Strong waves, particularly during this period, enhance the sediment supply from mudflats to the marsh creek. Additionally, waves can directly affect sediment re-suspension in the marsh creek during spring tides when the water level is above the marsh canopy. The marsh edge benefits from contrasting tidal and wave conditions, with sediment imported during spring tides with weak waves. Waves during spring tides re-suspend sediment, impeding the sediment deposition, and thus leading to sediment export over the marsh edge. These results highlight the potential sediment transport routes to marshes under varying conditions, shedding light on their implications for the long-term survival of salt marshes.

Key words: marsh creek; marsh edge; sediment transport; tidal and wave impacts; salt marsh

Plain Language Summary

The future of salt marshes greatly depends on receiving enough sediment, especially in the face of rising sea-level. This sediment can reach salt marshes via two routes: through marsh channels or over the seaside boundary of the marsh. It is not fully understood under what tidal and wave conditions sediment can be supplied to salt marshes, either along marsh channels or over the marsh boundary. Therefore, two-month data sets on hydrodynamics and sediment dynamics were collected in Paulina Saltmarsh, to investigate the optimal conditions of tides and waves for importing sediment into salt marshes. We found that sediment supply along marsh channels and over the marsh boundary requires contrasting tidal and wave conditions. Strong waves with small tidal ranges are favorable for marsh channels to bring sediment into salt marshes. Conversely, weak waves with large tidal ranges work better for marsh edges. This work highlights when and how sediment can be transported into the marsh, contributing to better salt marsh management.

Introduction

Salt marshes are coastal wetlands located in the intertidal areas which are flooded and drained by the tides. They are well-recognized for providing an array of crucial and valuable ecosystem services (Rountree & Able, 2007; Anjum et al., 2016; Kelleway et al., 2017). In the face of accelerating sea-level rise, salt marshes are confronted with a significant survival challenge (Kirwan et al., 2010). This challenge underscores the essential role of sufficient sediment supply in the vertical accretion and lateral expansion of salt marshes (Ladd et al., 2019; Fagherazzi et al., 2020).

The development of salt marshes depends on a range of complex processes (French, 2006; Cahoon et al., 2021). One of the processes involves sediment import and export between marshes and the adjacent mud flats together with channels. Waves play a crucial role in this transport and thus are one of the dynamic forces shaping salt marshes. Studies have suggested that waves can lead to scouring and damage to the marsh surface and edges (Fagherazzi et al., 2006; Feagin et al., 2009; Marani et al., 2011). However, recent observations indicate that during storms, considerable sediment can be deposited on the marsh platform (Willemsen et al., 2022; Pannozzo et al., 2023). Considering that mudflats would generally be eroded during such events (Fan et al., 2006; Xie et al., 2017), there is evidence to suggest a potential increase in sediment supply from mudflats to marshes (Schuerch et al., 2014; Rosencranz et al., 2016). These observations are credible, they present contradictory conclusions regarding the complex effects of waves on the development of salt marshes. However, how sediment is transported into or out of the marsh systems remains an enigma.

The complexity for the sediment transport to salt marshes during wave events arises from the interplay on multiple scales. Temporally, the interplay between tides and waves gives rise to intricate sediment transport. Waves occurring during spring tides and neap tides have different effects on suspended sediment concentration (French, 2006; Li et al., 2019). The complexity is further increased by variations in the intensity and frequencies of wave events (Schuerch et al., 2013). Spatially, the sediment routes to salt marshes, i.e., via the marsh edge and via the marsh creek, result in more complicated sediment transport regimes (Temmerman et al., 2005a). These complexities result from the spatial heterogeneity of sediment transport processes. Yet, the contribution of marsh creeks and marsh edges to sediment delivery under varying tide and wave conditions remains not well-understood.

To address how tides and waves conditionally affect sediment transport to salt marshes, we analyzed residual sediment fluxes in the marsh creek and over the marsh edge, based on the two-month field observations in Paulina Saltmarsh. We aim to investigate (i) whether the marsh creek facilitates or impedes the sedimentation process within salt marshes during wave events, (ii) how different conditions of tides and wave may influence the sediment transport via the marsh creek and marsh edge, and (iii) what the optimal conditions are for sediment import into salt marshes. This research is crucial for better understanding the potential sediment transport routes to marshes under varying conditions, emphasizing their contribution to managing and shaping the future salt marshes.

Materials and Methods

Study site

Paulina Saltmarsh is located in the Westerschelde Estuary in the Netherlands (Figures 1a and 1b). It is perceived as a low-turbidity environment (Temmerman et al., 2003). The suspended sediment concentration (SSC) in the marsh creek remains relatively low during calm weather (less than 0.1 g/L). Storm seasons in Paulina occur during the winter. To capture storms or large wave events, measurements were conducted for two months, from January 26th to March 29th, 2023. To investigate the sediment transport to salt marshes during wave events, dynamics were measured on the mudflat (Figure 1c), in the marsh creek (Figure 1d), and also at the marsh edge (Figure 1e) simultaneously.

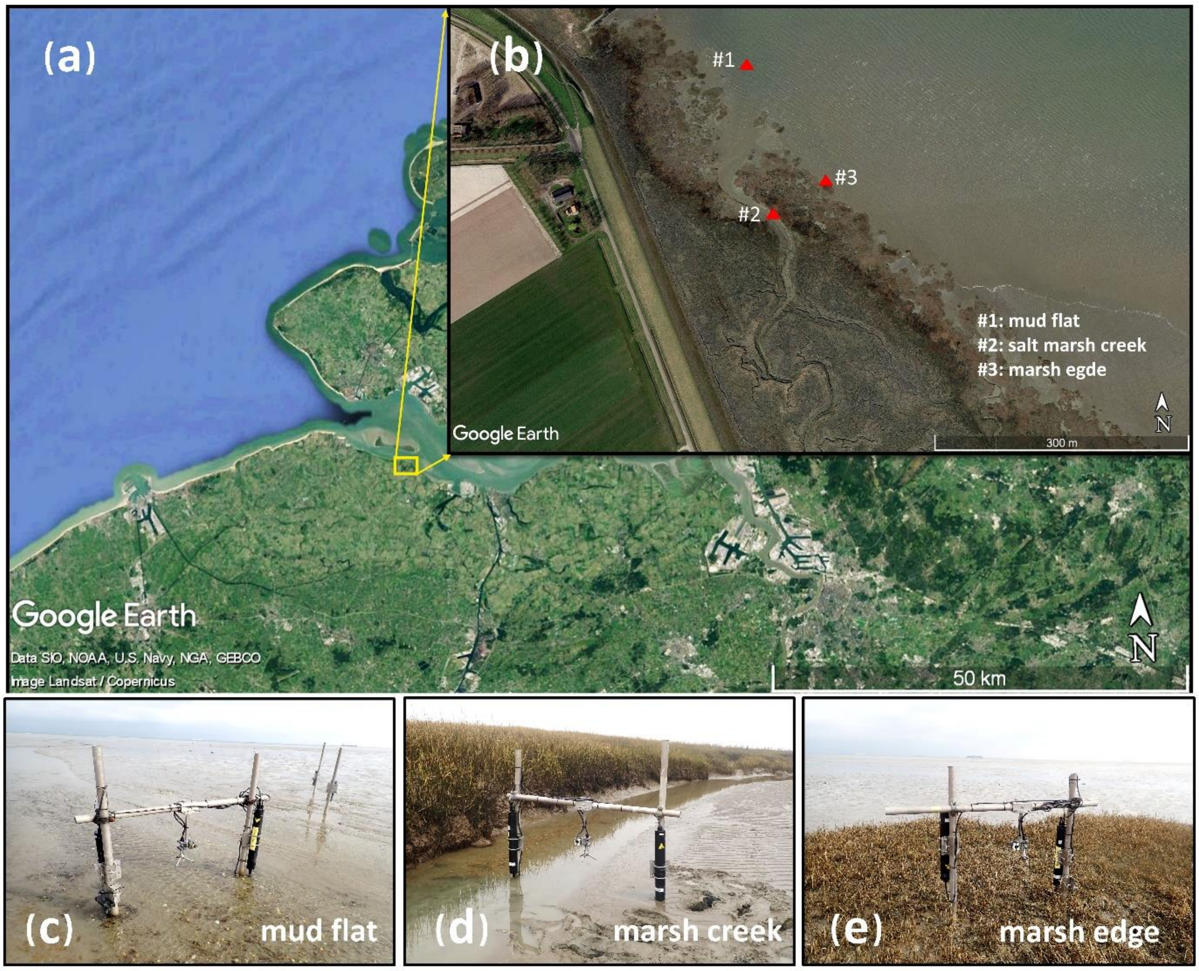

Figure 1. (a) The Westerschelde estuary in the Netherlands. (b) Measuring sites in Paulina Saltmarsh (Red triangles indicate measuring locations). Source aerial imagery: Google Earth. Photos of instruments and frames on the mudflat (c), in the marsh creek (d), and at the marsh edge (e).

Data Processing

We collected data of water depth, velocity, and bed level change at the measuring point using an ADV (Acoustic Doppler Velocimeter). To remove the invalid data from ADV, specific criteria of amplitude data (less than 100) and correlation data (less than 70) were applied (Xie et al., 2018). Amplitude data and correlation data of ADV represent signal strengths and data accuracy, respectively. Based on the methods of Goring and Nikora, (2002), a few spikes were removed. Velocities in this work were only considered the along-creek direction for the ADV located in the marsh creek and the cross-shore direction for the ADVs located on the mudflat and at the marsh edge. This allows us to investigate the exchange of water and sediment between mudflats and salt marshes.

Turbidity signals were collected with STMs (Seapoint Turbidity Meter) which were synced with ADVs. Sediment concentration data were then derived from the turbidity signals by sediment calibration experiments. The calibration curves are shown in the Appendix.

One pressure sensor OSSI (The Ocean Sensor Systems Wave Gauge Blue, Wave Sensor Company, USA) for wave measurements were deployed on the mudflat. In this work, wave shear stress measured on the mudflat serves as an indicator for assessing the intensity of wave events. Wave shear stress (τ_w [Pa]) was calculated using the same method as Zhu et al. (2016). Significant wave heights (Hs [m]), at three locations were obtained from the ADV pressure data.

The residual sediment flux per unit width, ΔF [kg/m], is obtained using the instantaneous data of velocity (v [m/s]), water depth (h [m]), and SSC (c [g/L]) , see van Weerdenburg et al. (2021). This residual sediment flux is only considered as the sediment exchange towards or away from the marsh system. Positive values of ΔF indicate sediment import into the marsh, and vice versa, negative values represent sediment export out of the marsh.

$$\Delta F = \sum_{i=1}^{n} (v_i\ h_i\ c_i)\ \Delta t \qquad (1)$$

where $\Delta t = 300$ [s], which is the measuring interval of ADVs and STMs in this work. *n* is the number of the valid data we measured for each tidal cycle.

Similar to the residual sediment flux, we also focus on the residual discharge per unit width (ΔQ [m^3/m]) towards or away from the marsh system.

$$\Delta Q = \sum_{i=1}^{n} (v_i\ h_i)\ \Delta t \qquad (2)$$

The SSC differential between flood and ebb tides (ΔC [g/L]) is calculated by subtracting the average SSC during the ebb tide from the average SSC during the flood tide (Nowacki and Ganju, 2019).

$$\Delta C = \frac{1}{n_{flood}} \sum_{i=1}^{n_{flood}} c_i - \frac{1}{n_{ebb}} \sum_{i=1}^{n_{ebb}} c_i \qquad (3)$$

Where n_{flood} and n_{ebb} are the number of SSC data for the flood tide and the ebb tide, respectively.

Results

Effects of tides and waves on sediment transport in marsh creeks and over marsh edge

To explore the conditional effects of tides and waves on the role of creeks and marsh edges in sediment transport, the relationships among the shear stress induced by waves, maximum tidal elevation per tide, and residual sediment flux have been explored (Figures 2b and 2f). The averaged wave-induced shear stress indicates wave intensity during each tidal cycle. Additionally, the maximum tidal elevation indicates the tidal range for each tidal cycle. Time-series data sets measured in the marsh creek and at the marsh edge are included in the appendix A1 and A2, respectively.

In the marsh creek, the direction of residual sediment fluxes is determined by tidal ranges, while the magnitude of sediment fluxes is influenced by wave intensities. When the maximum tidal elevation exceeds 2.74 m, the residual sediment flux is generally negative, indicating a sediment export. Conversely, when the maximum tidal elevation is less than 2.74 m, the residual sediment flux is generally positive (Figures 2a and 2b). The increase in wave shear stress ($\tau_w > 0.06\ Pa$) leads to an increase in SSC (Figure 2c). The SSC in the creek during strong wave events ($\tau_w > 0.06\ Pa$) is, on average, 4 times larger than during weak wave periods ($\tau_w < 0.06\ Pa$).

To have deeper insights into how effects of tides and waves influence residual sediment fluxes, we introduce the relative importance of asymmetries in flow (ΔQ) and in sediment concentration (ΔC), which determine the direction and magnitude of residual sediment fluxes. The SSC differential between flood and ebb tides (ΔC), which indicates the difference in suspended sediment amounts between these tidal phases, shows a good correlation with the average wave shear stress (Figure 2d). When waves are more intense, a greater difference in suspended sediment amounts between flood and ebb tides is generally observed, indicating that waves provide more sediment from mudflats to marsh creeks during flood tides. On the other hand, large tidal range causes a large negative net discharge (ΔQ) (Figure 2e), as more water from the marsh converges into the creek during ebb tides. This ebb dominant tidal current results in a higher tendency to export sediment. It is noteworthy that an evident sediment export occurs when waves intrigue substantial ebb SSC (the dark blue dot in Figure 2d). In such cases, waves may alter their function in sediment transport regimes, acting differently than merely supplying sediment to the creek.

On contrary, over the marsh edge, waves determine the direction of residual sediment fluxes, whereas tides influence the magnitude of sediment import. When the wave shear stress becomes relatively strong ($\tau_w > 0.06\ Pa$), sediment export occurs, regardless of the magnitude of tidal range (Figure 2g). However, relatively large amounts of sediment import are observed under the condition of a large tidal range and weak waves. Sediment exchange at the marsh edge was negligible when the tidal range and wave intensities are both low (Figure 2f).

We further investigate why strong waves consistently lead to sediment export over the marsh edge. As shown in Figure 2h, an increase in wave intensity is associated with a larger negative ΔC, indicating that waves cause a larger ebb SSC. This large ebb SSC results in the export of sediment over the marsh edge. Waves lead to the erosion of marsh edge, causing the sediment resuspension and thereby an increase in SSC. The reason behind the occurrence of the larger ebb SSC induced by waves will be discussed in the following section. Furthermore, there is no linear relationship between tidal ranges and the net discharge (ΔQ) over the marsh edge (Figure 2i). However, the positive ΔQ generally appears with weak waves, whereas negative ΔQ occurs with strong waves. It is crucial to point out that the net discharge over the marsh edge is relatively small comparing with that in the marsh creek. Consequently, the impacts of ΔQ on residual sediment fluxes are less significant than the impacts of ΔC over the marsh edge.

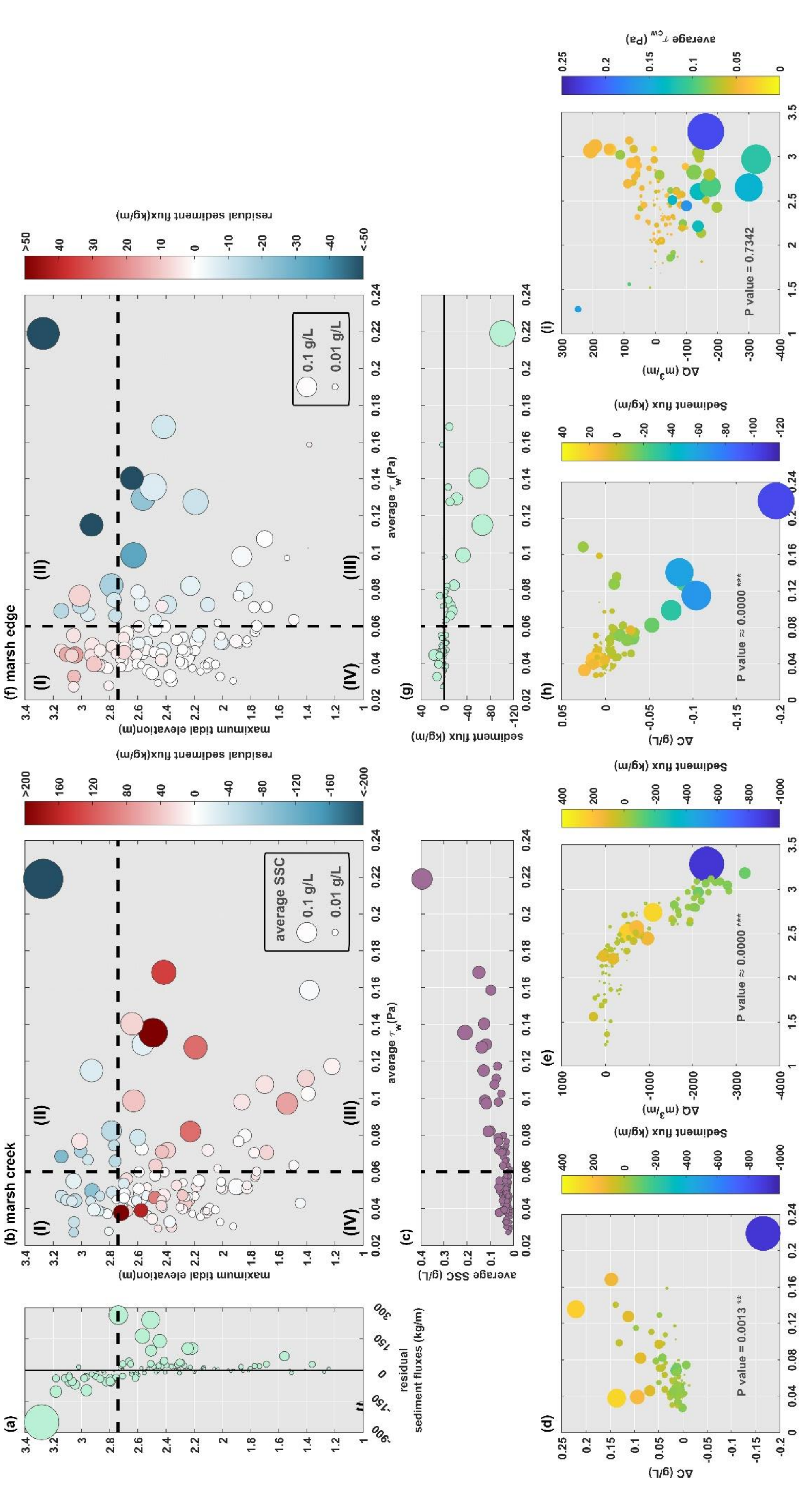
(a)
residual sediment fluxes (kg/m)
(b) marsh creek
(f) marsh edge
(I)
(II)
(III)
(IV)
maximum tidal elevation(m)
average τw(Pa)
average SSC
0.1 g/L
0.01 g/L
residual sediment flux(kg/m)
(c)
average SSC (g/L)
(g)
sediment flux (kg/m)
(d)
P value = 0.0013 **
ΔC (g/L)
average τcw (Pa)
Sediment flux (kg/m)
(e)
P value ≈ 0.0000 ***
ΔQ (m3/m)
maximum tidal elevation (m)
(h)
P value ≈ 0.0000 ***
(i)
P value = 0.7342
average τcw (Pa)

Figure 2. Residual sediment fluxes under varying tidal and wave conditions in the marsh creek (a-e) and over the marsh edge (f-i). Effects of tides and waves on residual sediment fluxes in the marsh creek and over the marsh edge, respectively (b and f). The size of the circle shows the tidally-averaged SSC. The color of the circle represents the residual sediment flux, where the warm color indicates sediment import and the cold color indicates sediment export. The relationship between the maximum tidal elevation and residual sediment flux in the marsh creek (a), between tidally-averaged wave shear stress and residual sediment flux over the marsh edge (g), and between tidally-averaged SSC and wave shear stress in the marsh creek (c). The size of each circle represents the magnitude of the residual sediment flux in subfigures (a) and (g) and the magnitude of tidally-averaged SSC in subfigure (c), respectively. The relationship among the average wave shear stress, the SSC differential between flood and ebb tides (ΔC) and residual sediment flux in the marsh creek and over the marsh edge, respectively (d and h). The relationship among the maximum tidal elevation, net discharge (ΔQ), and residual sediment flux in the marsh creek (e) and over the marsh edge with introducing the wave impacts (i). The size and color for circles in subfigures (d), (e) and (h) indicate the magnitude and the direction of residual sediment flux, respectively. The size and color for circles in the subfigure (i) indicate the magnitude of sediment fluxes and average wave shear stress, respectively.

Discussions

Different wave impacts on sediment transport regimes

The impacts of waves on the marsh edge and the marsh creek can be evident. Firstly, we found that significant wave heights at the marsh edge exhibited comparable magnitudes and patterns as those at mudflats (Figures 3b and 3d). This observation aligns well with the findings that waves can cause the re-suspension of sediment and the erosion of the marsh edge, occasionally contributing to the collapse of the marsh edge and lateral erosion (Callaghan et al., 2010; Finotello et al., 2020; Choi et al., 2021).

In addition, waves can indirectly increase the SSC in marsh creeks by eroding mudflats and directly erode marsh creeks during high tidal range tidal cycles. The indirect effects of waves, observed in Figure 3b, led to an increased sediment import of 105 kg/m during small inundation tidal cycles (compared to the sediment import of 36 kg/m in Figure 3a), as waves have the potential to erode mudflats (Schuerch et al., 2019), consequently enhancing sediment supply to marsh creeks. On the other hand, direct wave effects on the marsh creek became evident when the water level exceeds the marsh canopy (Figure 3d). Large significant wave heights were observed in the marsh creek. This indicates that waves can directly contribute to the erosion of the marsh creek bed. Although the erosion of mudflat caused by waves supplied a large amount of sediment to the creek during flood tides, the dual impacts of tides and waves resulted in sediment suspension, impeding the sediment deposition and ultimately leading to sediment export. Therefore, the substantial sediment export of approximately 900 kg/m in the marsh creek, represented by the dark blue dot in Figure 2d, was contributed by both tides and waves in such case. Conversely, when the water level was below the marsh canopy, the creek was minimally affected by waves (Figure 3b), potentially due to the sheltering effects of elevated marshes.

To further explore the mechanisms behind sediment export over the marsh edge during wave events, several tidal cycles shown in Figure 4 were selected. The impacts of waves on the export of sediment over the marsh edge can be delineated into two aspects: (i) The presence of waves leads to a significant increase in SSC especially during ebb tide, which is caused by the fact that the occurrence of strong waves was primarily during the late flood tide and the ebb tide (Figures 4a and 4c), consequently, the average SSC during ebb tides was considerably higher than that during flood tides over the marsh edge; (ii) due to the energy-dissipating effect of vegetation (Leonardi et al., 2018), flow velocities over the marsh edge remained generally low, even during high tide, typically below 0.1 m/s. Therefore, the velocities exhibited fluctuations due to the wave generated flow (Figures 4a and 4c). This also resulted in relatively minor negative net discharge. Consequently, the combination of the higher ebb SSC and slight outflow contributed to the export of sediment over the marsh edge.

Without the impacts of strong waves, relatively higher velocities and SSC peaks were observed during flood tides (Figures 4b and 4d), leading to the import of sediment over the marsh edge.

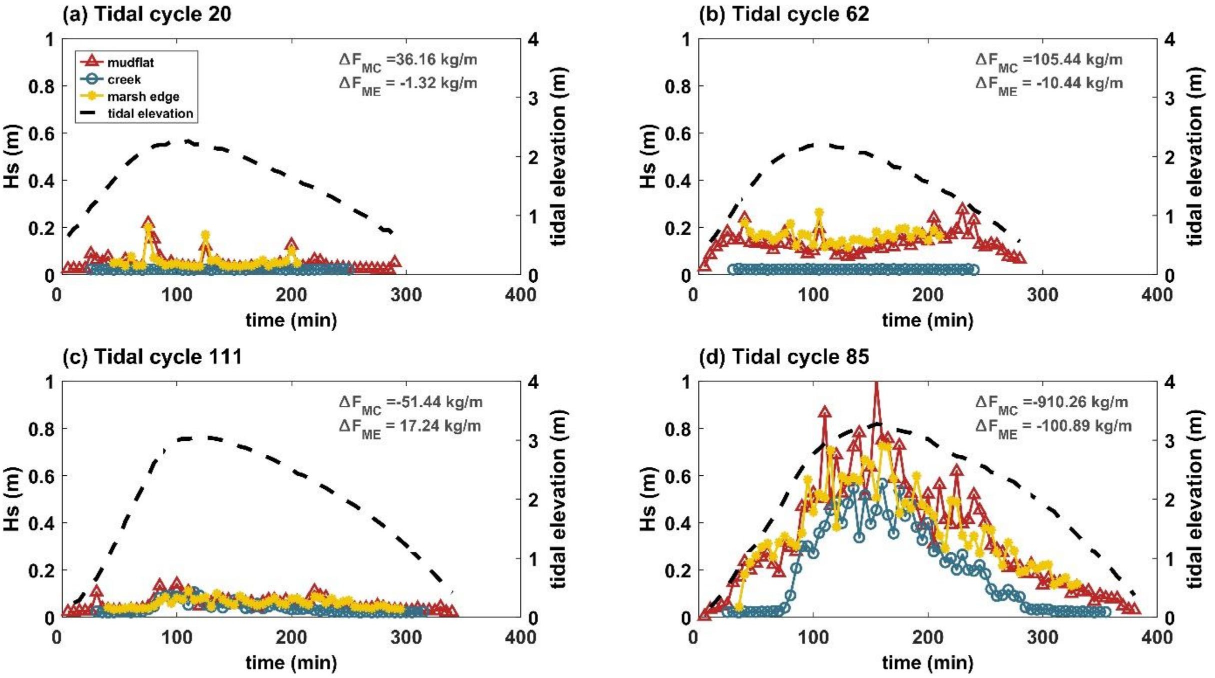

Figure 3. Time series of different significant wave heights during small inundation tidal cycles (a and b) and during large inundation tidal cycles (c and d). ΔF_{MC} is the residual sediment flux in the marsh creek, and ΔF_{ME} is the residual sediment flux at the marsh edge. Positive values indicate sediment import and negative values indicate sediment export.

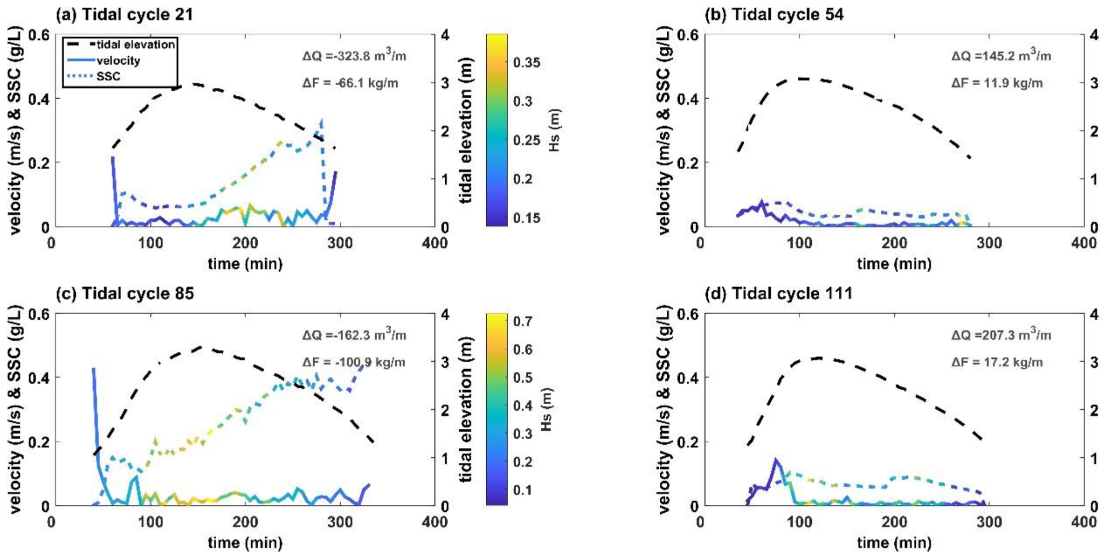

Figure 4. Wave impacts on velocities and SSC during large inundation tidal cycles at the marsh edge: (a) and (c) capture the effects of relatively strong waves, while (b) and (d) show the conditions during relatively weak wave events. ΔQ and ΔF indicate the net discharge and residual sediment flux, respectively.

effects of tides and waves on sediment transport in Chongming saltmarsh creeks

To investigate whether the effects of tides and waves on sediment transport in Paulina Saltmarsh remain consistent in other systems, we take Chongming Saltmarsh as an example. Chongming Saltmarsh, which is located in the Yangtze Estuary, is perceived as a turbid system (Shi et al., 2014). We compared the data between during calm weather and during two successive storm events in the main creek in Chongming. These data sets are obtained from Fan et al, (2019).

Even in the turbid system, the conditional effects of tides and waves still play an important role in the function of marsh creeks in transporting sediment. During calm weather, creeks tend to slightly import sediment during neap tides (maximum water depth less than 2 *m*) but export sediment during spring tides (water depth larger than 2 *m*) (Figure 5). During storm events, waves enhance both processes of sediment import and export. Specifically, waves increase the resilience against the export of water during tides with large tidal ranges (larger than 2 m), by supplying additional sediment from mudflats to marsh creeks during flood tides. Yet, in the scenarios with larger tidal ranges and strong waves, creeks tend to export sediment, potentially due to the combined effects of large tidal ranges and strong waves on marsh creeks erosion. This is consistent with our findings in Paulina Saltmarsh.

Apparently, with this additional data measured in the Yangtze Estuary, our analysis does not cover all possible scenarios. However, the underlying patterns observed, such as the interaction between tidal ranges, waves, and sediment dynamics, appear to be broadly applicable. This is because the consistent patterns of sediment transport under varying tidal and wave conditions can actually be explained by the relative importance of the asymmetries in flow and in sediment concentration between flood and ebb tides (Sun et al., 2024). The Asymmetry in flow is determined by tidal ranges. A large tidal range leads to a net water export in the marsh creeks, as water from the marsh can be concentrated into marsh creeks during ebb tides. On the other hand, waves trigger mudflat erosion, thereby supplying more sediment to marsh creeks during flood. The net import or export of sediment under varying tidal and wave conditions depends on the extent to which sediment brought in during flood tides due to waves can counteract the tendency of water export due to large tidal ranges. However, local variations, such as local morphology, vegetation impacts, and reginal climate conditions, might influence sediment transport regimes (Poirier et al., 2017; Ortals et al., 2021; Zhu and Wiberg, 2022). Future research is essential for further verifying these findings to enrich our knowledge of these complex ecosystems.

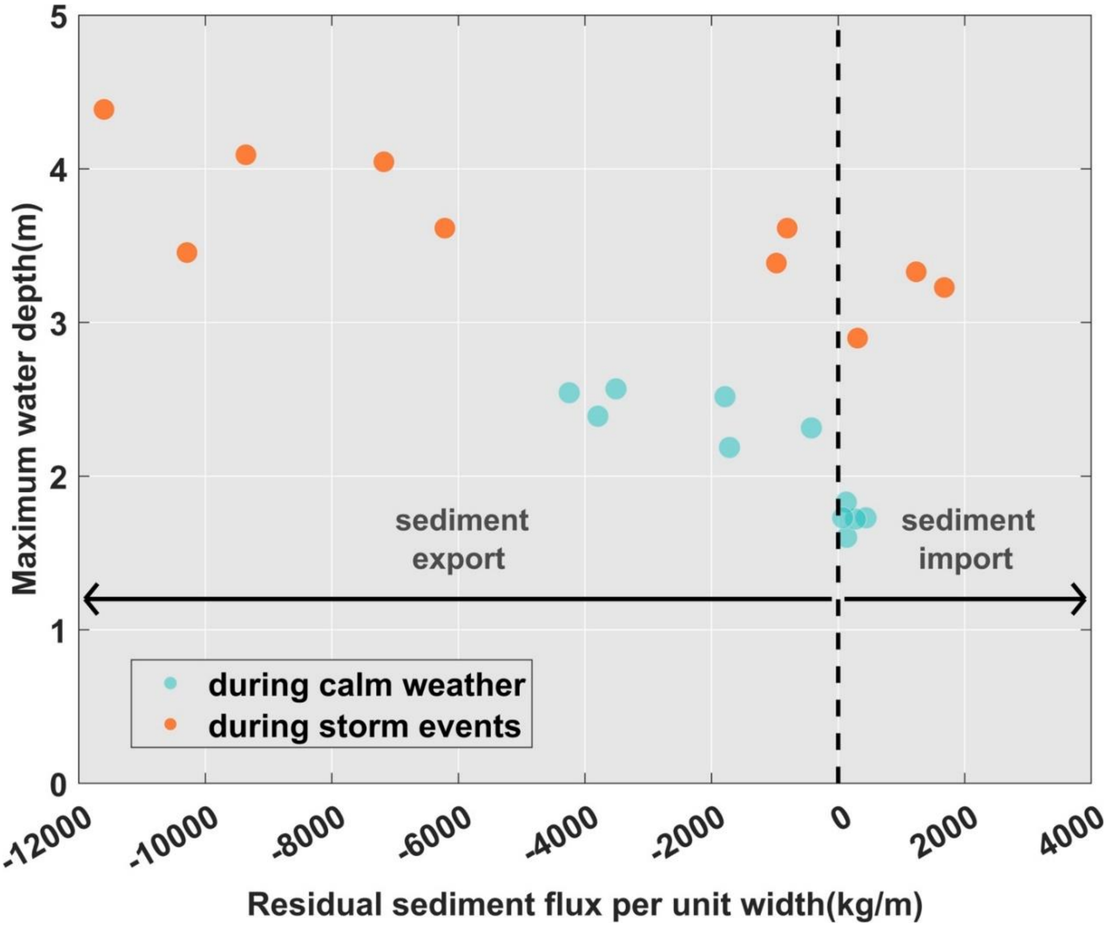

Figure 5. Residual sediment fluxes per unit width under various tidal conditions during calm weather (blue circles) and during storm events (orange circles) in Chongming (Data adapted from the tables and figures of Fan et al. (2019)).

Potential sediment transport regimes in salt marshes

Marsh creeks are recognized as highly dynamic channels that convey water and sediment to the marsh systems (Ortals et al., 2021), especially during small inundation tidal cycles when more water being supplied through the marsh creek than the marsh edge (Temmerman et al., 2005b). However, due to the low tidal elevation, limited sediment is exchanged between creeks and marshes. Consequently, sediment primarily accumulates in marsh creeks (Figure 6a). Waves enhance this sediment accumulation in the marsh creek but erode the marsh edge(Figure 6c).

During large inundation tidal cycles, a substantial amount of water and sediment can be delivered directly through the marsh edge as well (Temmerman et al., 2005b). This allows marsh edges to receive an increased supply of water and sediment through the marsh edge under weak wave conditions, but to experience erosion and export more sediment under strong wave conditions (Figures 6b and 6d). For the marsh creek, due to overbank flow, sediment that has deposited in the creek during the previous small inundation tidal cycles has the potential to be transported to the marsh. However, an ebb-dominant current appears because water from the marsh would be concentrated into the creek during ebb tides, resulting in net sediment export in the creek (Figure 6b). Strong waves intensify the erosion of marsh creek beds (Howes et al., 2010; Mariotti and Fagherazzi, 2013; Ma et al., 2018), and potentially cause erosion of the marsh creek bank, which may enhance the sediment exchange between creek and marsh platform (Figure 6d).

Considering the wider expanse of marsh edges, the amount of sediment transported via the marsh edge could exceed that which was transported through the marsh creek. This suggests that the role of marsh creeks in exchanging sediment might be overestimated during large inundation tidal cycles. Nevertheless, due to the impact of plants hindering energy flow, sediment tends to be deposited near the marsh edge (Temmerman et al., 2003), and cannot reach the inner marsh easily through the marsh edge. As a result, the contribution of marsh creeks to vertical accretion, especially for the inner marsh, is important.

During large inundation tidal cycles with strong waves, both marsh creeks and marsh edges transport more sediment out of the marsh system, which reduces the resistance of salt marshes to accelerated SLR. Sea-level rise prolongs inundation periods and promotes ebb dominance, and thus more scenarios of Figure 6b can occur, leading to fewer occurrence of small inundation tidal cycles (scenarios of Figures 6a and 6c) and more erosion in creeks. Consequently, sediment that should have been accumulated in the marsh creek during the small inundation tidal cycles cannot be replenished in time. Therefore, limited sediment can be supplied to the marsh from creeks. When sea-level rise combined with strong wave events (the scenario of Figure 6d), the risk of the substantial sediment export increases, making salt marshes even more vulnerable.

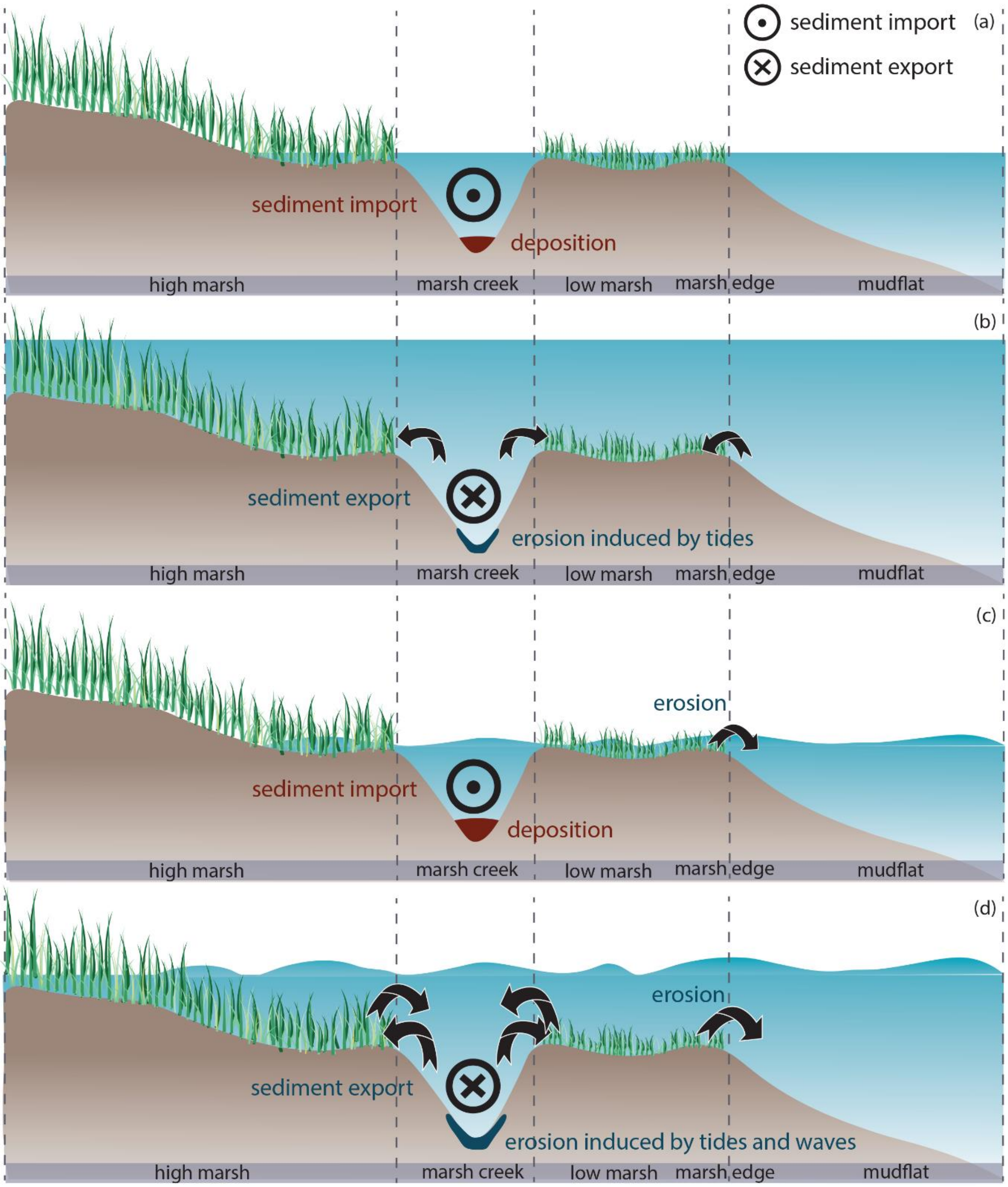

Figure 6. Conceptualized schemes for the potential sediment transport regimes in salt marshes under different conditions of tides and waves: (a) a scenario of small inundation tidal cycles with weak waves; (b) a scenario of large inundation tidal cycles with weak waves; (c) a scenario of small inundation tidal cycles with strong waves; and (d) a scenario of large inundation tidal cycles with strong waves.

Conclusions

Sediment fluxes in the marsh creek and over the marsh edge vary depending on different tidal and wave conditions. In the creek, the direction of sediment flux is determined by the tidal range, and magnitude is influenced by wave action. Marsh creeks tend to export sediment during tidal cycles with high tidal ranges and import sediment during tidal cycles with small tidal ranges. Larger tidal ranges facilitate a more ebb-dominant asymmetry in flow within the marsh creek, where more water from the marsh can be concentrated and larger ebb velocities occur during ebb tides. This likely results in the erosion of marsh creeks during ebb tides, causing the export of sediment. During tidal cycles with small tidal ranges, when tides are less ebb-dominant, marsh creeks function as conduits for importing sediment. The occurrence of waves enhances both sediment import and export processes. Waves contribute to sediment supply to the marsh creek by transporting sediment from mudflats, leading to an increase in SSC in the marsh creek. However, strong waves, coupled with high tidal ranges, can also intensify the erosion of marsh creek beds, resulting in sediment export.

Sediment flux on marsh edges is determined by contrasting conditions, where sediment flux direction is governed by wave action, while magnitude is influenced by the tidal range. Sediment import over the marsh edge exclusively occurs under the conditions of high tidal ranges and weak waves. Waves govern the export of sediment over the marsh edge, by causing sediment re-suspension especially during ebb tides. Therefore, sediment import over the marsh edge only occurs during relatively calm conditions. During the small tidal inundation tidal cycles, weak hydrodynamics limit sediment transport over marsh edges, while high tidal ranges allow the marsh edge to receive greater amounts of sediment.

These findings offer deeper insights into the sediment routes through marsh creeks and marsh edges under varying tidal and wave conditions. This is crucial for effectively managing salt marshes, enabling better-informed decisions related to sediment nourishment and conservation strategies in the face of sea-level rise, limited sediment supply, and storm events.

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This article has been partially grammar checked by ChatGPT, an OpenAI language model based in San Francisco, CA, USA.

Open Research

Field data collected in Paulina Saltmarsh on the mudflat, in the marsh creek, and at the marsh edge between 26 January and 29 March 2023 were used in this manuscript. These velocities, pressure, bed level change at measuring points, suspended sediment concentration data sets are available at https://doi.org/10.4121/f369d289-c89f-4750-9ce0-5dc35b68ac07. Field data processing and visualization were performed using MATLAB R2023a.

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