

Global coastal wetland expansion under accelerated sea-level rise is unlikely

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Schuerch et al. (2018)¹ deserve credit for compiling a wide range of disparate, global datasets that will be instrumental in predicting future coastal wetland change. However, we challenge their projections that range from modest losses to substantial gains worldwide by the end of this century. Their modeling does not adequately capture the role of sediment supply which must be treated volumetrically, with profound implications for their projections. We anticipate that an appropriate modification will result in substantially different projections, with rates of coastal wetland loss that generally increase as a function of relative sea-level rise (RSLR), regardless of the human adaptation scenario. This is also in line with the findings from a precursor study² by a subset of the Schuerch et al. group.

Schuerch et al. claim that if landward migration due to RSLR can occur largely uninhibited, coastal wetlands have the ability to expand by as much as 60% by the end of this century, even under pessimistic (RCP8.5) sea-level scenarios. They contend that the business as usual human adaptation scenario (i.e., with essentially no room for landward migration) leads to coastal wetland loss of <30% by 2100 CE, while nature-based adaptation scenarios generally lead to wetland expansion, regardless of the sea-level scenario. These surprising results are illustrated, for example, by the fact that some of the highest wetland gains are projected to occur in coastal Louisiana (their Fig.

2, ED Fig. 3), one of the largest coastal wetland areas in the world that has seen exceptionally high rates of wetland loss over the past century³. Without coastal restoration, this region is projected to suffer almost 6000 km² of additional wetland loss in the next 50 years, according to a Medium Scenario of RSLR and other environmental changes⁴. The implication is that a large proportion of the maximum global salt marsh loss (~6000 km²) projected by Schuerch et al. by 2100 CE would be accounted for by this region alone. While we appreciate the fact that a global-scale analysis inevitably features some anomalous results, outcomes like these should give reason for pause. Here we show that the modeling by Schuerch et al. violates widely accepted stratigraphic theory, which not only affects the magnitude but also the sign of their projections.

Schuerch et al. rely heavily on the concept of accommodation. In their opening paragraph they state: “the resilience of global wetlands is primarily driven by the availability of accommodation space”, which they define as “the vertical and lateral space available for fine sediments to accumulate and be colonized by wetland vegetation.” Later they write: “Our sensitivity analysis shows that even in heavily sediment-starved regions, an increase in accommodation space could result in a net wetland gain”, further echoed by “these gains ... are driven by inland wetland migration rather than vertical sediment accretion, and therefore independent of sediment availability.” However, landward wetland migration in response to RSLR and with no wetland area loss, at either the seaward edge or wetland interior, cannot occur without vertical sediment accretion. Thus, wetland gain through increased accommodation is highly dependent on sediment supply.

There is a rich literature in sedimentary geology on the concept of accommodation, tracing back to Jervey (1988)⁵. The core principle of this and following studies is that accommodation is fundamentally generated by RSLR. Subsequent work has established the relationship between accommodation and sediment supply (commonly referred to as the A/S ratio) as a primary control on whether a shoreline (along with its genetically associated wetlands) migrates landward, seaward, or remains stationary^{6,7}. The hallmark of this stratigraphic theory is that if the rate of creation of accommodation

increases, the shoreline must migrate landward, unless there is an increase in sediment supply. Such an increase must typically be very substantial for geometric reasons: an increased lateral extent of a coastal plain requires more sediment to keep up with the rate of accommodation creation (Fig. 1). It is important to stress that the A/S theory is scale-independent (i.e., it can be used to examine thick stratigraphic successions representing millions of years as well as present-day coastal environments) and it applies to river deltas as well as to intervening coastal depositional settings⁷. The robustness of this theory is shown by the fact that it has stood up to scrutiny by means of both experimental data⁸ and the stratigraphic record⁹.

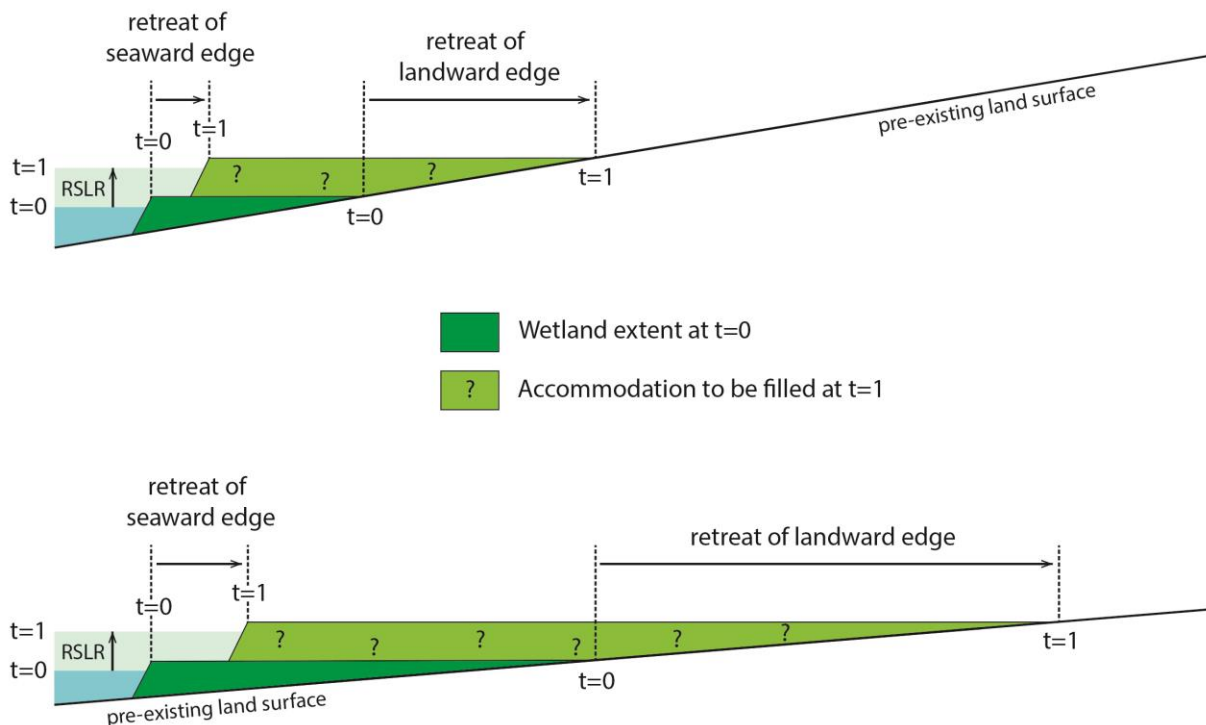


Fig. 1. Schematic dip-oriented cross sections illustrating coastal wetland evolution on a gently sloping substrate. Relative sea-level rise (RSLR) generates accommodation that may or may not be filled, depending on sediment supply (i.e., depending on the accommodation/supply ratio). In both scenarios, sediment supply must increase to enable coastal wetland expansion at $t=1$. The two scenarios differ only in the slope of the pre-existing land surface. The gentler slope (lower panel) creates better opportunities for coastal wetland expansion, but also requires much more sediment to fill the accommodation that is created. It should also be noted that landward retreat will commonly be precluded by human-made infrastructure (urban areas, flood-protection systems, and so on), which is currently increasing rather than decreasing worldwide.

Refinement of the A/S theory has shown that shorelines cannot remain stationary under conditions of constant accommodation creation and constant sediment supply. This is due to autoretreat, a geometrically dictated and inevitable result of the fact that a constant sediment volume must be dispersed across a progressively larger coastal plain^{7,10}. In conclusion, widely accepted stratigraphic principles show that an increase in the rate of RSLR nearly always leads to landward retreat of the shoreline. Therefore, the expansion of coastal wetlands as projected by Schuerch et al. for many of their scenarios can only occur due to retreat of the landward boundary – a retreat that must be much faster than the retreat of the shoreline.

The above considerations are relevant because the basic tenet of the Schuerch et al. model is that the accommodation created by RSLR is generally filled with sediment. They also argue that their model is relatively insensitive to changes in sediment availability (their ED Table 3), a finding that cannot be reconciled with A/S theory (Fig. 1). As stated in their Methods section: “The WAS [wetland adaptability score] thus represents the ability of the coastal wetlands within a coastline segment to adapt to rising sea levels by sediment accretion. A positive WAS value indicates that sediment availability is sufficient to maintain the present wetland area, whereas a negative WAS value suggests that coastal wetlands are inundated and (partially) lost in response to SLR [sea-level rise].” Thus, WAS is defined in terms of sediment surplus or deficit (their Eq. 4) and the parameter of choice is suspended sediment concentration (SSC). Unfortunately, it appears that SSC is conflated with sediment supply (also referred to as sediment load or sediment flux) – two fundamentally different things. The implicit assumption in their model is that given adequate SSC values, vertical accretion can track RSLR regardless of the areal extent of the wetland. Put differently, SSC is essentially considered to be an unlimited resource in coastal waters, with the ability to feed nearby wetlands regardless of their size. These assumptions are in conflict with A/S theory, which explicitly considers sediment supply in terms of volume (or mass) per unit time^{11,12}. SSC values may be useful to predict wetland change at the plot scale, but they cannot simply be upscaled to a larger area without conversion into sediment volumes. This critical distinction was recognized by Weston (2014)¹³ who stated: “While the horizontal extent of a tidal wetland system may

be determined, in part, by the sediment load, the vertical accretion potential of any given patch of wetland will be a function of the SSC in the flood water.” The implication is that calibration of the Schuerch et al. model with datasets of present-day vertical wetland change is inadequate to underpin projections over longer timescales.

While coastal wetlands may partly depend on sediment from nearby marine environments, they are ultimately fed from the continents by rivers. The recent decline of the riverine sediment supply has been demonstrated both at the continental¹³ and the global¹⁴ scale. Worldwide, this decline from comparatively pristine to anthropogenically disturbed sediment fluxes (primarily due to damming) is about 10%¹⁴. With more dams in the planning globally¹⁵ as well as attempts to reduce soil erosion rates¹⁶ that may well expand in the future, it is unlikely that this trend will be reversed¹⁷.

Finally, the argument could be made that – in principle – deficiencies in clastic sediment input could be offset by organic matter produced by wetland vegetation contributing to vertical accretion. While this organic contribution can make a difference when relative elevation is optimal for plant growth, even then there is a limit to primary production and, hence, biogenic accretion¹⁸. Thus, a sediment supply that is unlikely to increase and limits to organic matter contributions, combined with a rapid increase in accommodation due to accelerated RSLR, makes shoreline retreat and net coastal wetland loss almost inevitable.

References

- 1 Schuerch, M. *et al.* Future response of global coastal wetlands to sea-level rise. *Nature* **561**, 231-234 (2018).
- 2 Spencer, T. *et al.* Global coastal wetland change under sea-level rise and related stresses: The DIVA Wetland Change Model. *Global and Planetary Change* **139**, 15-30, (2016).
- 3 Day, J. W., Jr. *et al.* Restoration of the Mississippi Delta: Lessons from Hurricanes Katrina and Rita. *Science* **315**, 1679-1684 (2007).

- 4 Coastal Protection and Restoration Authority of Louisiana, *Louisiana's Comprehensive Master Plan for a Sustainable Coast* (Coastal Protection and Restoration Authority of Louisiana, Baton Rouge, 2017).
- 5 Jervey, M. T. Quantitative geological modeling of siliciclastic rock sequences and their seismic expression. *Society of Economic Paleontologists and Mineralogists Special Publication* **42**, 47-69 (1988).
- 6 Helland-Hansen, W. & Martinsen, O. J. Shoreline trajectories and sequences: description of variable depositional-dip scenarios. *Journal of Sedimentary Research* **66**, 670-688 (1996).
- 7 Muto, T. & Steel, R. J. Principles of regression and transgression: the nature of the interplay between accommodation and sediment supply. *Journal of Sedimentary Research* **67**, 994-1000 (1997).
- 8 Kim, W., Paola, C., Voller, V. R. & Swenson, J. B. Experimental measurement of the relative importance of controls on shoreline migration. *Journal of Sedimentary Research* **76**, 270-283 (2006).
- 9 Amorosi, A. *et al.* Global sea-level control on local parasequence architecture from the Holocene record of the Po Plain, Italy. *Marine and Petroleum Geology* **87**, 99-111, (2017).
- 10 Straub, K. M., Li, Q. & Benson, W. M. Influence of sediment cohesion on deltaic shoreline dynamics and bulk sediment retention: A laboratory study. *Geophysical Research Letters* **42**, 9808-9815 (2015).
- 11 Castellort, S. & Van Den Driessche, J. How plausible are high-frequency sediment supply-driven cycles in the stratigraphic record? *Sedimentary Geology* **157**, 3-13 (2003).
- 12 Allen, P. A. *et al.* The Q_s problem: Sediment volumetric balance of proximal foreland basin systems. *Sedimentology* **60**, 102-130 (2013).
- 13 Weston, N. B. Declining sediments and rising seas: an unfortunate convergence for tidal wetlands. *Estuaries and Coasts* **37**, 1-23 (2014).
- 14 Syvitski, J. P. M., Vörösmarty, C. J., Kettner, A. J. & Green, P. Impact of humans on the flux of terrestrial sediment to the global coastal ocean. *Science* **308**, 376-380 (2005).
- 15 Zarfl, C., Lumsdon, A. E., Berlekamp, J., Tydecks, L. & Tockner, K. A global boom in hydropower dam construction. *Aquatic Sciences* **77**, 161-170 (2015).
- 16 Montgomery, D. R. Soil erosion and agricultural sustainability. *Proceedings of the National Academy of Sciences of the United States of America* **104**, 13268-13272 (2007).
- 17 Dunn, F. E. *et al.* Projections of declining fluvial sediment delivery to major deltas worldwide in response to climate change and anthropogenic stress *Environmental Research Letters* **14**, in press (2019).
- 18 Morris, J. T. *et al.* Contributions of organic and inorganic matter to sediment volume and accretion in tidal wetlands at steady state. *Earth's Future* **4**, 110-121 (2016).

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