Rejuvenating Poldered Landscapes: A Numerical Model of Tidal River Management in Coastal Bangladesh

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INTRODUCTION

The low-lying, coastal region of Bangladesh has relied on poldering (the creation of embanked islands) since the 1960s to mitigate the effects of tidal inundation, storm surge, and, more recently, sea level rise. Poldering has increased the total arable land and the ability to sustain food production for one of the most densely populated countries in the world. However, it has had the unintended consequence of starving embanked landscapes of sediment. Previous studies show empirical and modeled evidence that these landscapes can recover in ~10 years if a direct connection with the tidal channel is restored. Tidal River Management (TRM) provides an alternative and sustainable solution. To combat declining polder elevations and aggrading channels, some polder inhabitants have attempted TRM to allow water and sediment exchange with the tidal network. Anecdotal reports claim great success for these small-scale engineering projects in some locations, but not in others.

Here, we tested the applicability of TRM on the poldered landscapes of southwest Bangladesh using a numerical model of tidal inundation and subsequent sediment accretion. We employed a mass balance Monte Carlo simulation with parameters of tidal inundation height, suspended sediment concentration (SSC), dry bulk density (ρ), and settling velocity (w_s). Tidal height was varied as a function of projected sea level rise. We constrained timing of inundation to simulate a controlled TRM project. Preliminary results suggest, under some circumstances, TRM is a viable solution to help combat elevation offset due to sea level rise and poldering. However, under the most extreme sea level rise scenarios, TRM may not be a feasible solution.

THE GANGES-BRAHMAPUTRA DELTA

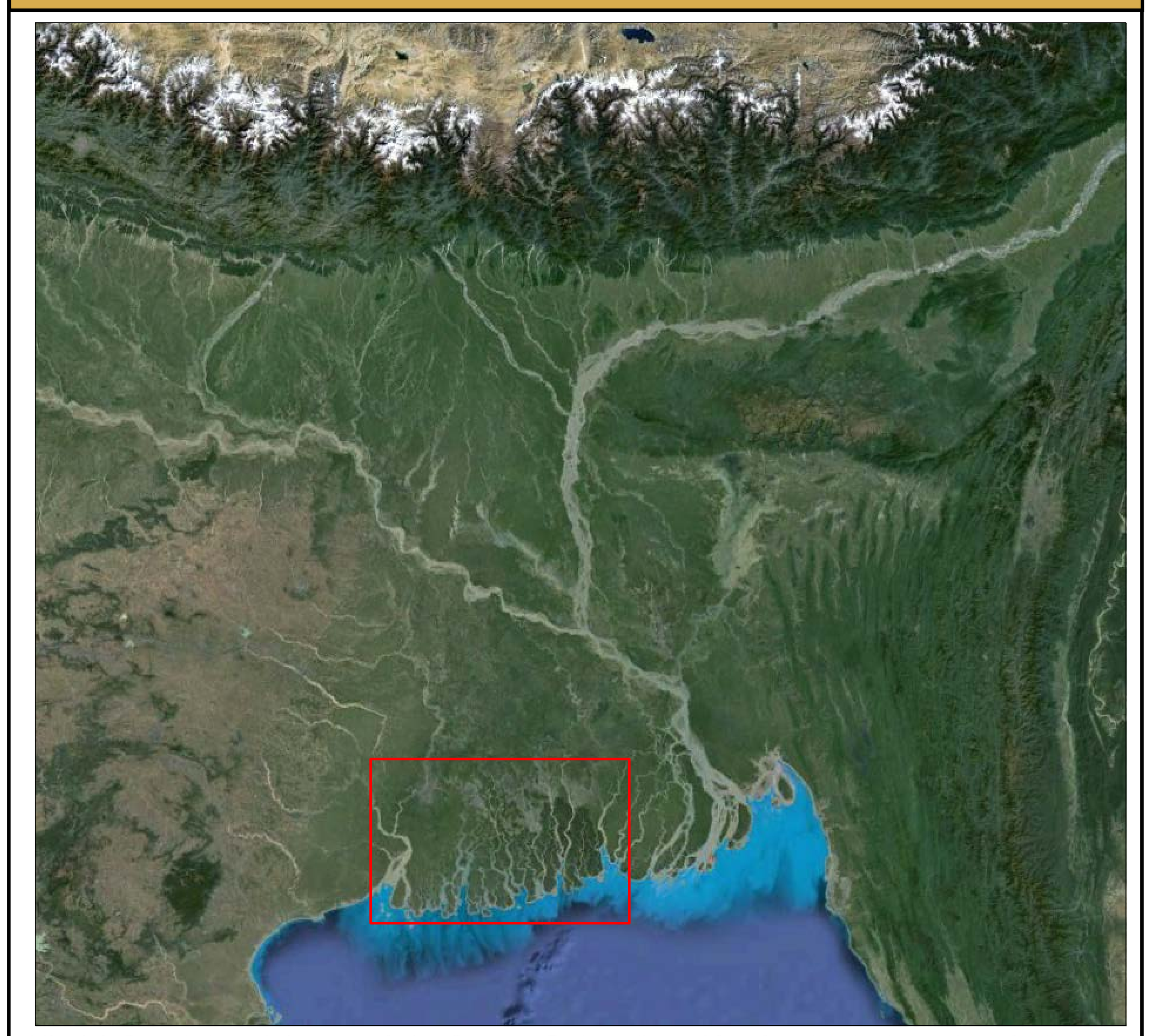

Fig 1 | Google Earth image of the Ganges-Delta. The poldered region is shown in red. The combined Ganges-Brahmaputra system conveys ~1.1 billion tons of sediment per year. The poldered region is disconnected from the fluvial network. However, nearly 200 million tons of sediment per year are reworked in the tidal network.

SEA LEVEL RISE OVER THE NEXT CENTURY

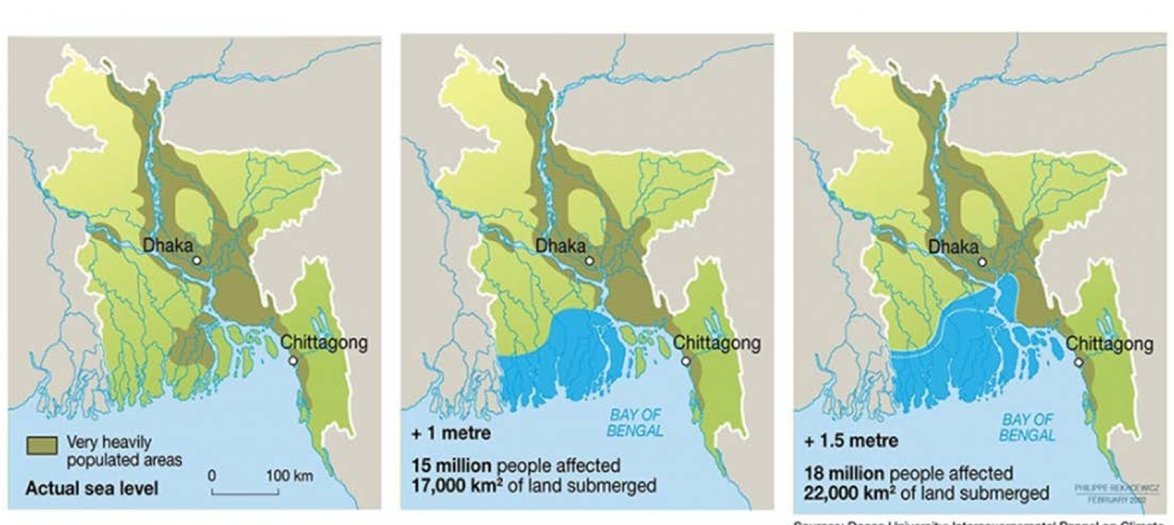

Fig 2 | Sea level rise scenarios (Present; +1 meter; +1.5 meters). Approximately 160 million people living on the delta plain could be adversely affected.

WHAT ABOUT THE SEDIMENT?

Fig 3, 4 | Images of tidal flats around Polder 32. The flat is composed of meters of unconsolidated sediment.

The bath tub model (Fig. 2) describing sea level rise is insufficient. **A better understanding of the relationship of sea level and sediment accumulation is needed.**

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ACKNOWLEDGEMENTS

- This work was supported by the United States Office of Naval Research and Vanderbilt University Department of Earth & Environmental Science.
- Faculty and students of Khulna University for their research assistance.
- Faculty and students of Dhaka University for their research assistance.

POLDERED LANDSCAPES

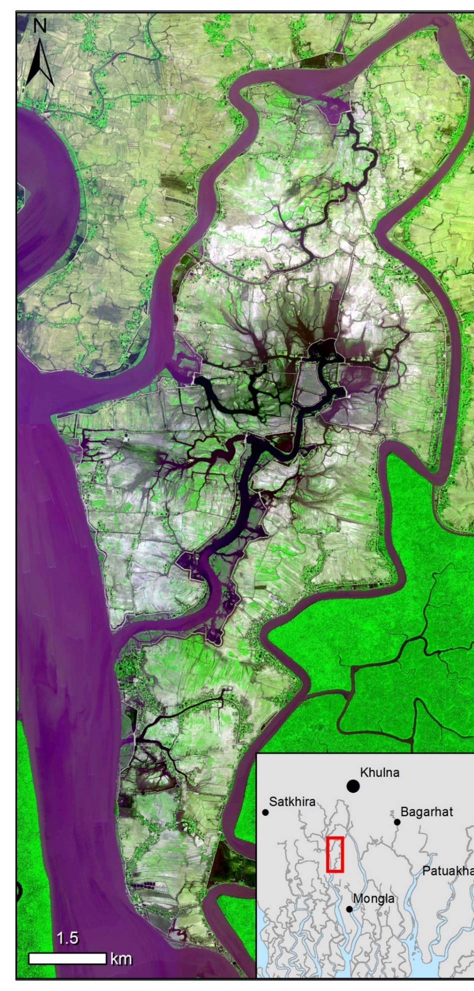
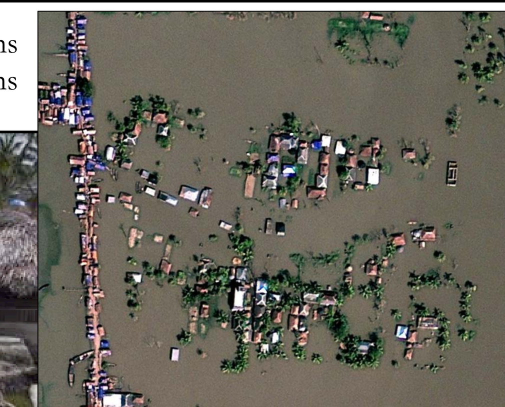


Fig 5 | Geoeye image of Polder 32. Bright green is the Sundarbans National Forest. Elevation offsets between the polder and the Sundarbans are ~1 m.

Fig 6 | Picture from an embankment on the southeast side of Polder 32. The picture was taken during a spring high tide. The offset between the interior of the polder and the high tide is ~1.5 m.



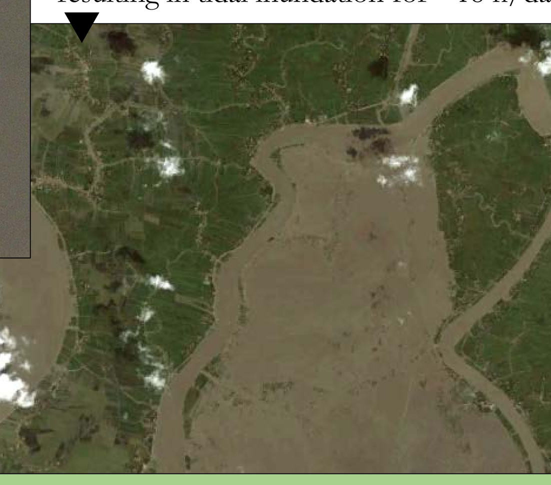


Fig 7, 8 | Flooding from Cyclone Aila (2009). The embankment surrounding Polder 32 failed in multiple locations resulting in tidal inundation for ~18 h/day.

- **Poldering has had the unintended consequence of starving the interior land of fresh sediment.**
- **The interiors have compacted and are now below high tide. (Fig. 6)**
- **Storm surge can overtop the embankments and lead to sustained tidal inundation. (Fig. 7,8)**
- **How can we remediate this offset?**

FIELD OBSERVATIONS

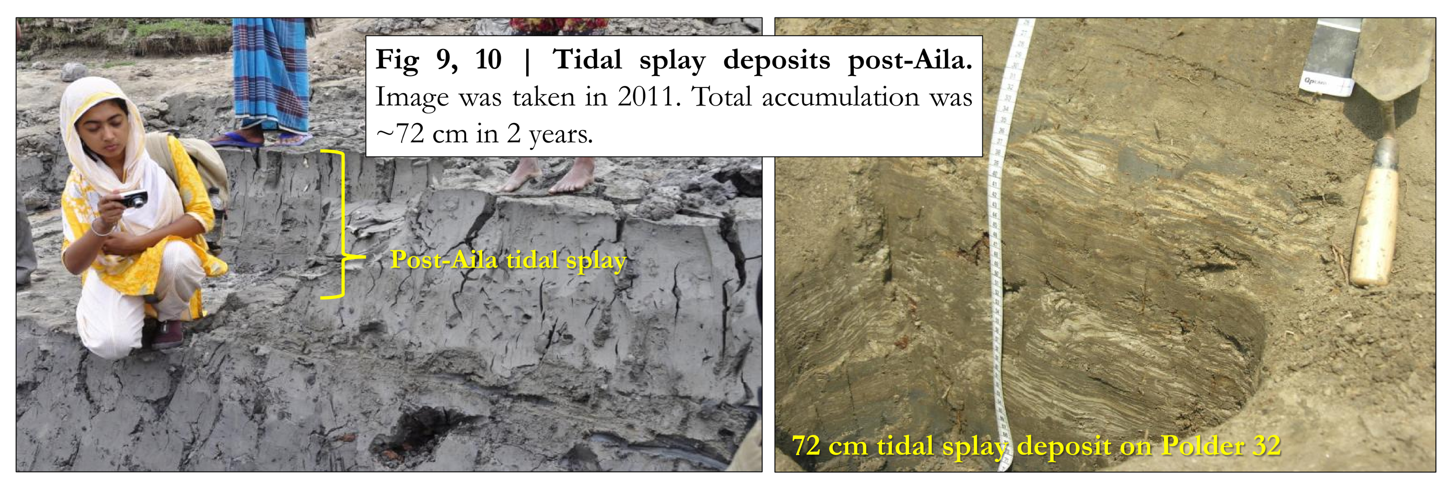


Fig 9, 10 | Tidal splay deposits post-Aila. Image was taken in 2011. Total accumulation was ~72 cm in 2 years.

Fig 11 | Tidal height data from Polder 32. The tidal heights were inferred from CTD pressure sensor data. The natural elevation (green) is in equilibrium with mean high water (MHW). Polder elevations (pink) are ~1.2 m below MHW.

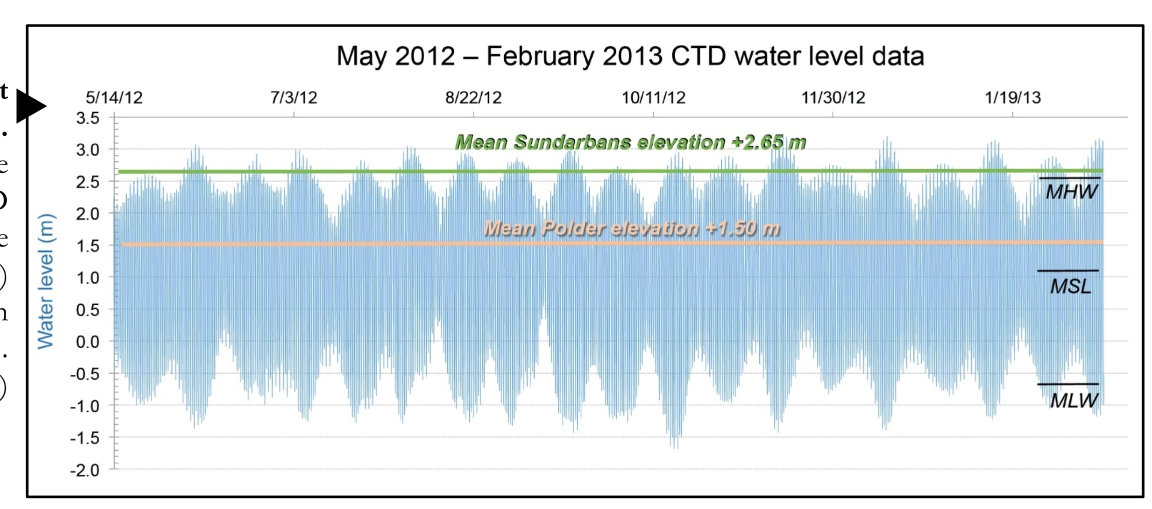
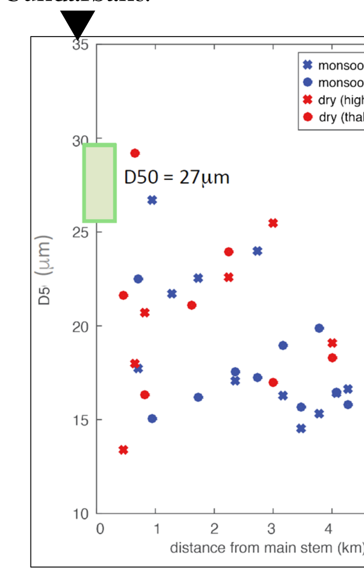


Fig 12 | D50 grain sizes around Polder 32. Measurements were taken during both the monsoon and dry season. Particle diameter increases towards the main stem of the tidal network. D50 for main stem is in green and in purple for the interior of the Sundarbans.



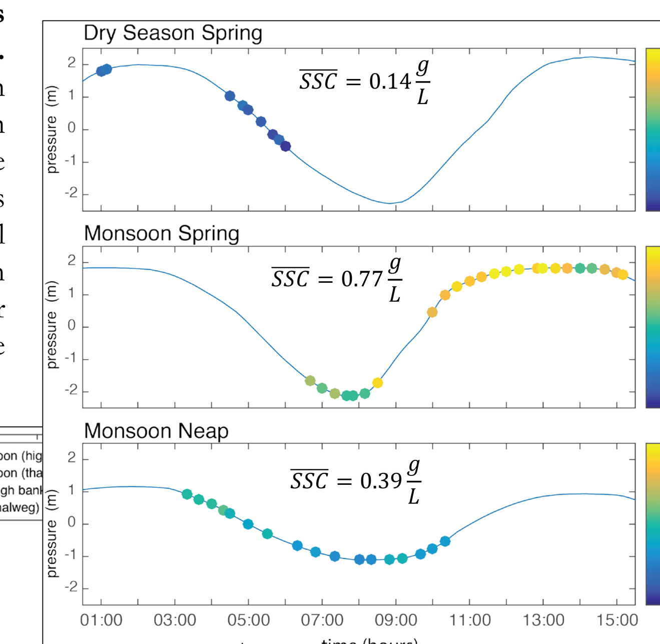
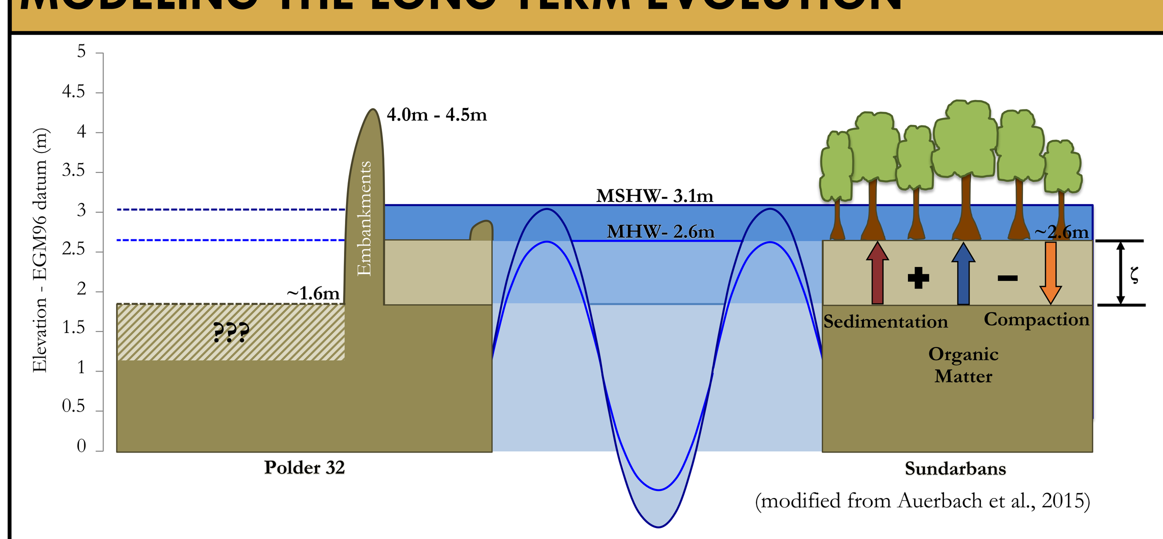


Fig 13 | Suspended sediment concentrations around Polder 32. SSC is highest during spring tides. Mean SSC is significantly lower in the dry season as compared to the monsoon season.

MODELING THE LONG TERM EVOLUTION



NUMERICAL MODEL

$$\frac{d\zeta}{dt} = \frac{dS}{dt} + \frac{dO}{dt} - \frac{dP}{dt} \quad (1)$$

$$\frac{dS}{dt} = \int \frac{w_s C(t)}{\rho} dt \quad (2)$$

$$\frac{d[h(t) - \zeta]C(t)}{dt} = -w_s C(t) + C(0)\frac{dh}{dt} \quad (3)$$

PARAMETERS

Settling Velocity (w_s)

Dry Bulk Density (ρ)

Suspended Sediment Concentration (SSC)

Tidal Height (h)

Fig 14 | Conceptual model of Polder 32 and the adjacent Sundarbans. The Sundarbans are assumed to be at equilibrium with the tides. Sediment accumulation is defined by Eq. 1 where $\frac{dS}{dt}$ is sedimentation rate, $\frac{dO}{dt}$ is deposition of organic matter, and $\frac{dP}{dt}$ is compaction rate. Sedimentation rates are much greater than organic deposition and compaction rates. Therefore, we can simplify to Eq. 2 and solve the integral using a finite-difference approximation (Eq. 3).

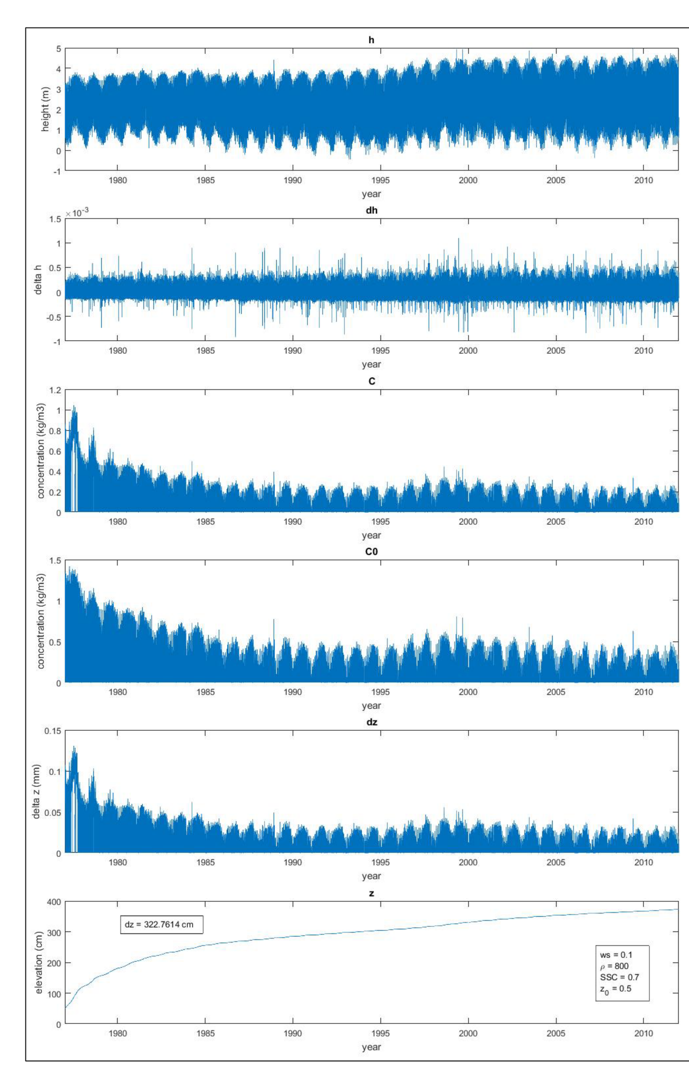


Fig 15 | Model results from historic tide gauge data (1977-2011). The model time step is equal to the tide gauge resolution (1 h). Model results show an asymptotic relationship with MHW.

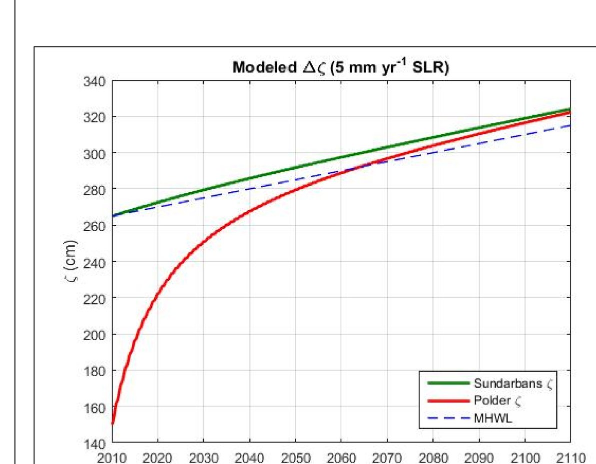


Fig 16 | Model projections using historic data and superimposing 5 mm of sea level rise per year. Using realistic parameters, Polder elevations eventually equilibrate to that of the natural level.

MONTE CARLO SIMULATION

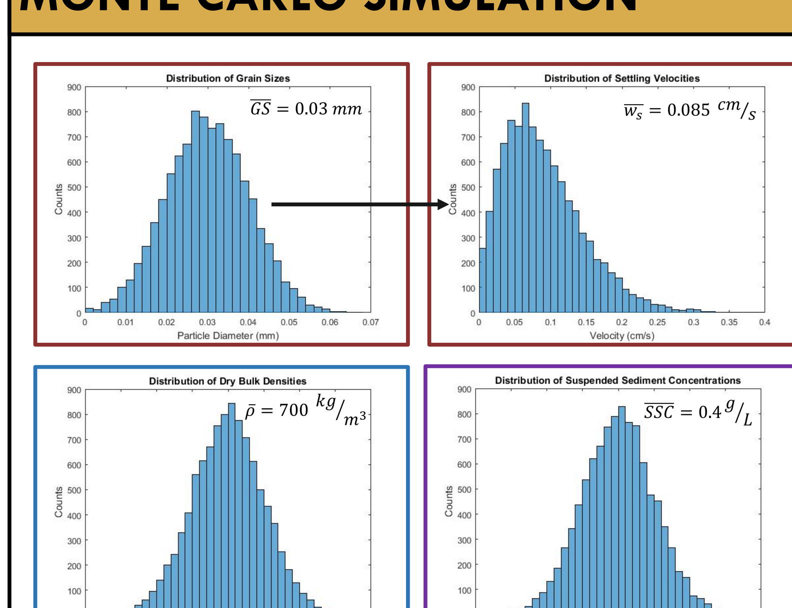


Fig 17 | Parameter distributions for Monte Carlo. Parameters were drawn from normal distributions about a realistic mean and standard deviation. Partial correlation coefficients were calculated (Table 1) for each parameter to determine model sensitivity.

Table 1 | Partial Correlational Coefficients

Parameter	Elevation (ζ)
w_s	0.79
ρ	-0.17
SSC	0.32

* Controlled for tidal height above platform

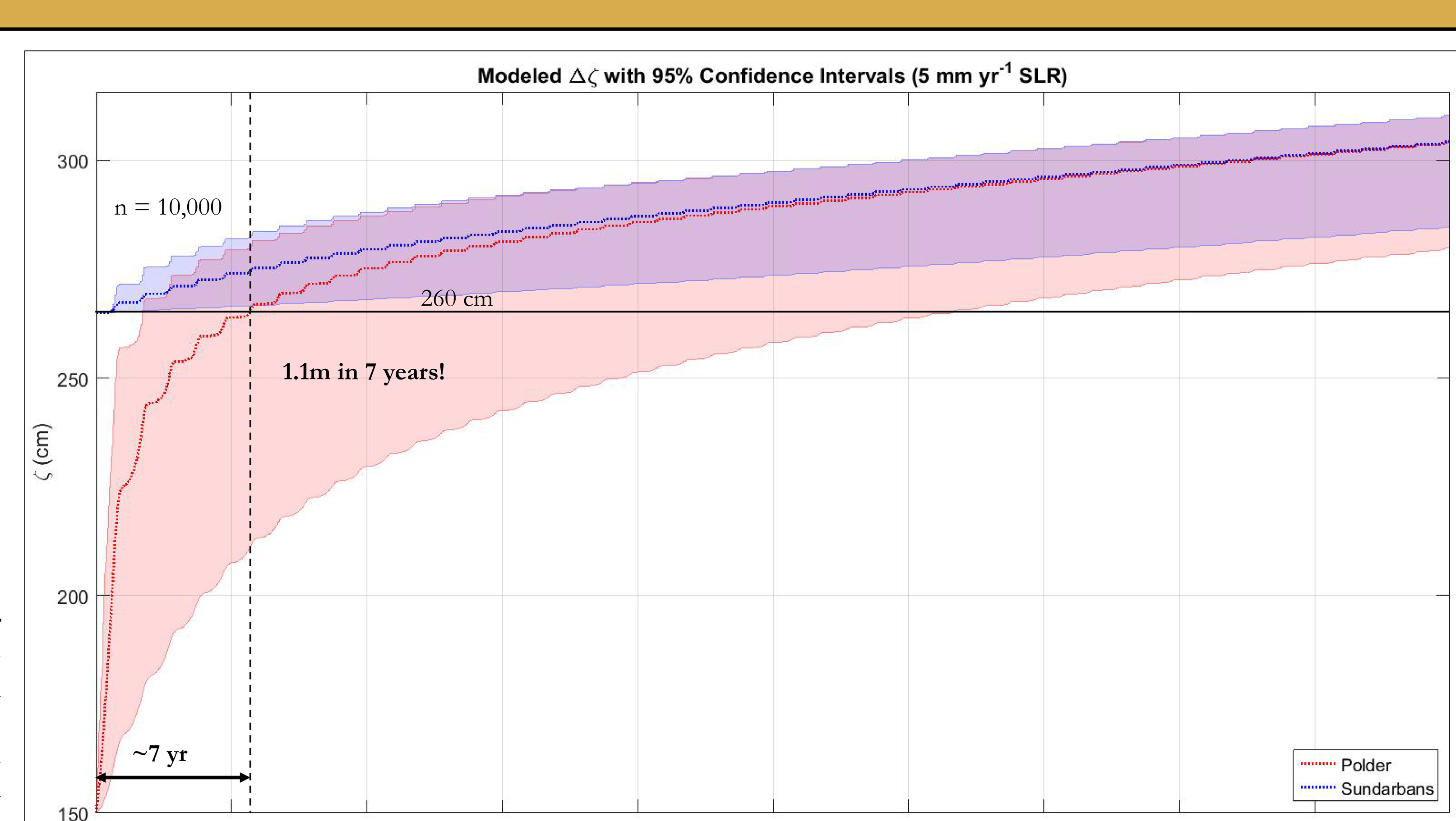


Fig 18 | Model projection for elevation change for poldered (red) and natural environments (blue) (2010-2060). The 50th percentile plotted as a dotted line with the 95th percentile plotted as the shaded area about the median. 50% of model runs result in the poldered environment recovering to the natural level within 7 years.