Co-evolution of landscape and vegetation in sea-level affected coastal wetlands with man-made flow interventions

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1. INTRODUCTION

On a global scale, the sustainability and resilience of coastal wetlands to sea-level rise depends on the slope of the landscape and a balance between the rates of soil accretion (due to eco-geomorphic feedbacks) and the sea-level rise (Kirwan *et al.*, 2010). However, local man-made flow interventions can have comparable effects. Coastal infrastructure controlling flow in wetlands can pose an additional constraint on the adaptive capacity of these ecosystems, but can also present opportunities for targeted flow management to increase their resilience. We explore in this contribution the effect of different flow control interventions that either enhance or attenuate tidal inputs, on the long term eco-geomorphic response of coastal wetlands under sea-level rise. We use the case of wetlands in SE Australia, many of which are managed for habitat conservation, agriculture, mosquito control, etc. and typically present infrastructure including flow control devices like floodgates, culverts and drainage ditches.

We use a spatially-distributed dynamic wetland eco-geomorphic model that not only incorporates the effects of flow modifications due to culverts, gates, drainage ditches, but also considers that vegetation changes as a consequence of changing inundation patterns. We also consider the ability of vegetation to capture sediment and produce accretion, so we can produce a constantly evolving landscape. All these feedbacks are regularly incorporated in the model in order to modify the inundation patterns. We test a number of different flow control interventions on a tidal flat with conditions typical of SE Australian coastal wetlands.

2. METHODS

In this study different configurations of a hypothetical floodplain were created to simulate the effect of drainage ditches, culverts and embankments in the evolution of vegetation and soil elevation during sea-level rise. The applied modelling framework follows Sandi et al. (2018) and Rodriguez et al. (2017), which included survival rules for mangrove and saltmarsh vegetation in a typical southeastern Australian estuarine wetland. The elevation change (accretion) model within is based on Morris et al. (2002) and Kirwan et al. (2010) and its parameters were adjusted to the same Australian ecosystem. Therefore, two important characteristics of the systems analysed in this application are: it represents a low suspend solid concentration (SSC) environment and; deposition and erosion fluxes over non-vegetated areas are similar (no elevation change). This framework was used to predict the effect of sea level rise (SLR) in the evolution of vegetation and landscape under five different scenarios.

2.1 Hydrodynamic simulation

A quasi 2D-hydrodynamic model, VHHMM 1.0 (Riccardi, 2000), was used to represent the detailed flow field on a 320-m wide by 640-m long tidal flat with a constant longitudinal slope of 0.001 m/m at a 10 x 10 m spatial resolution (See Figure 1). At the lower end of the tidal flat a sinusoidal tidal wave with 1 m of amplitude and period of 12 hours was imposed as a boundary condition.

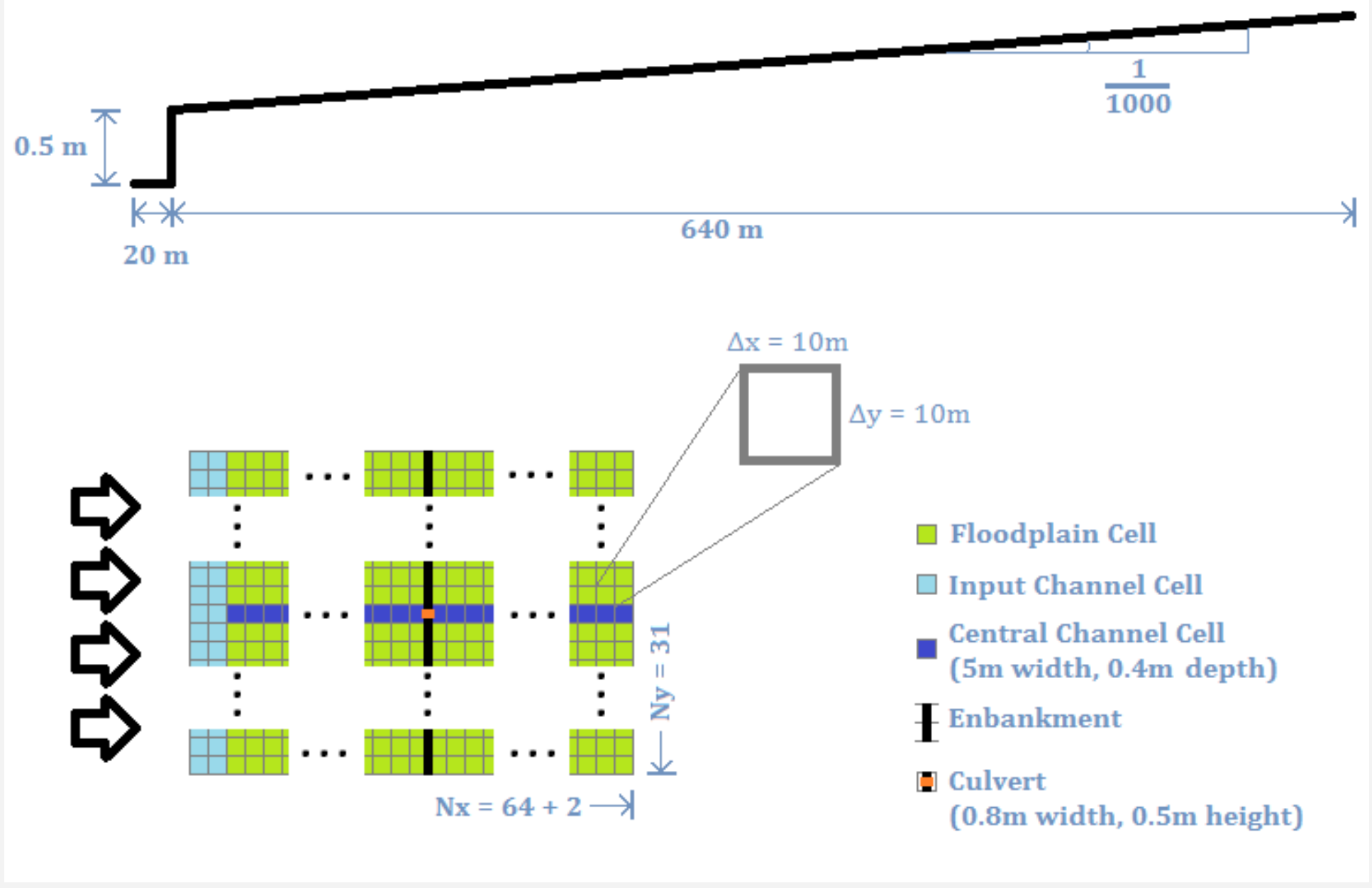


Figure 1. Schematic view of simulated flood plains. Presence of the central channel and/or embankment with culvert changes with the scenario.

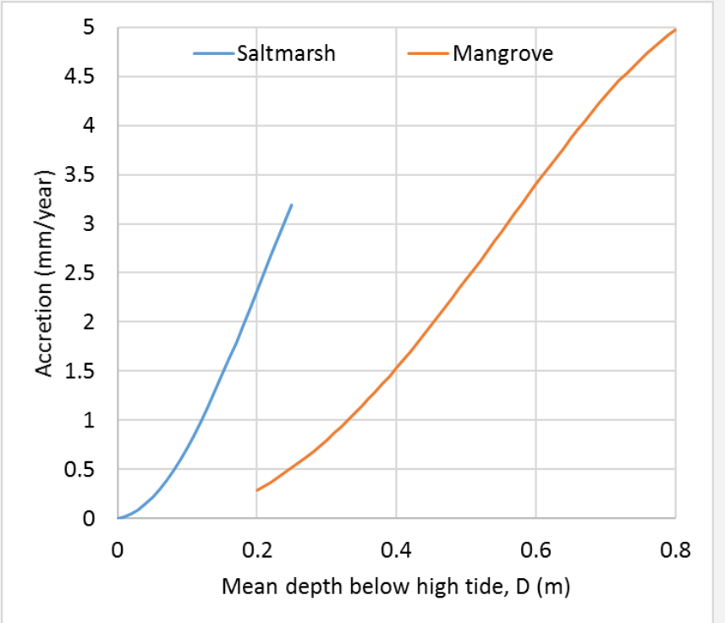
Five scenarios where simulated to address the effects of changes in flow patterns on vegetation evolution. The first scenario considers no hydrodynamic effects on the tidal flat, essentially translating the tidal levels at the boundary to the whole wetland, an approach that is known as bathtub simplification. The rest of the scenarios use water levels computed with the hydrodynamic model. The second scenario also considers the tidal flat but includes the attenuation effects of vegetation (through vegetation specific Manning's n values). The third scenario includes a drainage channel in the middle of the tidal flat 5-m wide and 0.4-m deep. The fourth scenario includes an embankment halfway between the lower and upper ends of the tidal flat with a central culvert 0.8-m wide and 0.5-m tall. The culvert conveys all flow as there is no overtopping flow considered. The fifth scenario includes both the central drainage channel and the embankment with a culvert. All local hydraulic features are included using standard procedures for flood modelling.

2.2 Vegetation and soil elevation

Four classes of soil coverage were considered in this study. Non-vegetated areas where used in the central drainage channel (3^{rd} and 5^{th} scenarios) and in areas where local conditions where inappropriate for establishment of any vegetation. Mangroves, saltmarshes and freshwater vegetation comprised the other coverage types. In addition, it was assumed that only mangrove and saltmarsh produced significant accretion due sediment trapping, settling and organic soil production.

All these features of the eco-geomorphologic (EGM) model are computed based on the local values of hydroperiod, *H*, and water depth below mean high tide, *D*. The first quantity reflects the portion of time that significant inundation occurs, while the second is related to an average of maximum water depths. Table 1 summarises the EGM features of each coverage type.

Table 1. Eco-geomorphological features used in the study

Soil Coverage	Manning's n	Establishment rule	Soil Elevation Rate
Non-vegetated	0.12	Imposed to channel cells. Applied to terrain cell where none vegetation survived (represent mud flats)	0.0
Mangrove (*Avicennia marina*)	0.50	10% < H < 50% and D > 0.20 m Prevails over any other coverage in terrain-type cells	
Saltmarsh (*Sarcocornia quinqueflora* and *Sporobolus virginicus*)	0.15	H < 80% and D < 0.25 m Prevails over freshwater vegetation	
Freshwater veg-	0.12	H ~ 0% and D < 5 cm	0.0

2.3 Sea level rise and simulation setup

We used a yearly time-step in the EGM model covering a simulation period of 100 years. From the second year on, cell's elevation data was updated by adding the accretion estimated in the previous year, and the prevailing vegetation changed when establishment rules did not match the requirements anymore. The input tidal flow data was updated by adding the SLR value in the series. This value changes from 2.77 mm in the first year to 11.79 mm in the year 100 following the IPCC AR5 PCP8.5 climate change scenario (Church et al., 2013). The total accumulated rise after 100 years is 0.72 m.

3. RESULTS

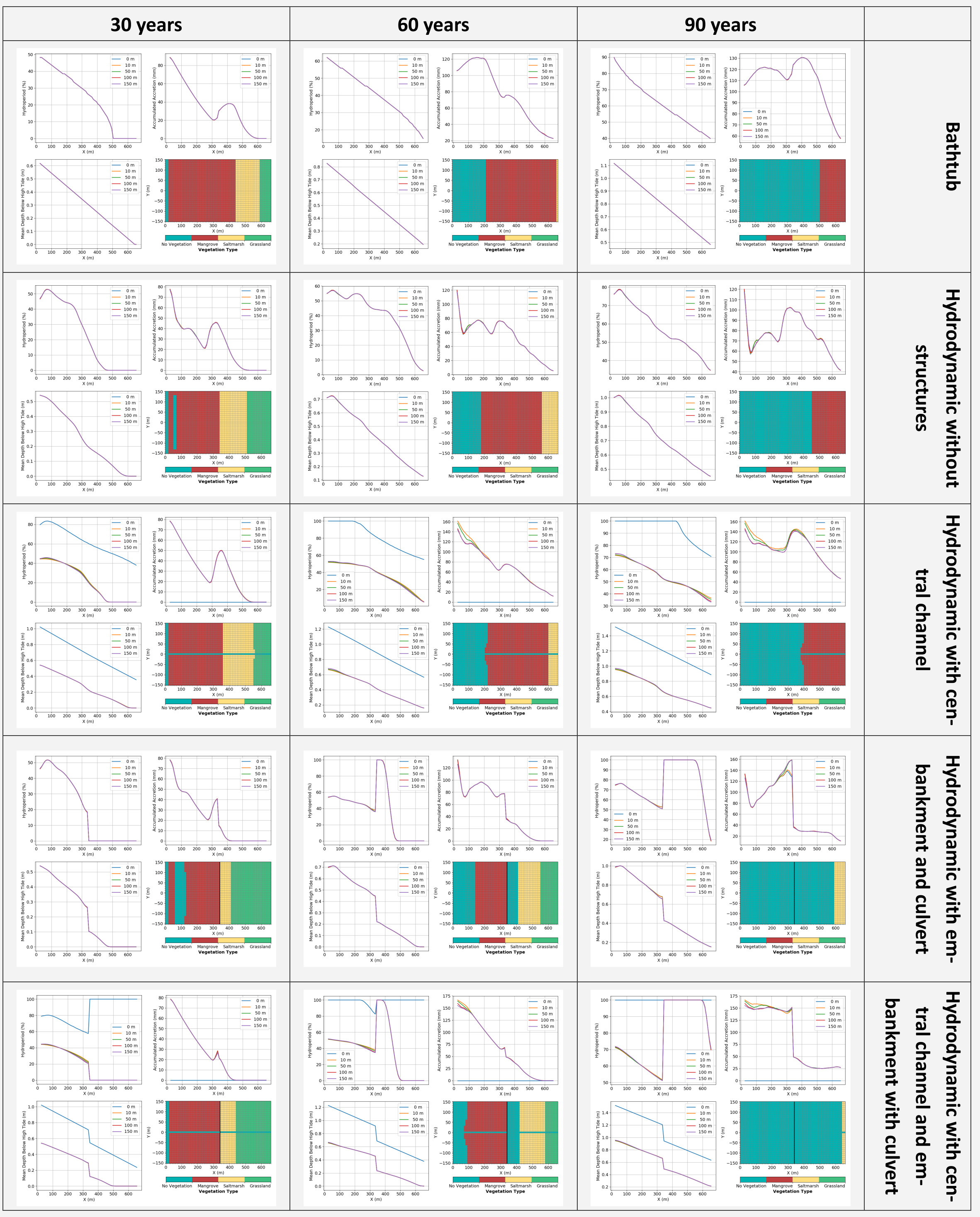


Figure 2. Longitudinal profiles of Hydroperiod (top left), Depth Below Mean High Tide (bottom left) and Accumulated Accretion (Soil Elevation, top right). Vegetation map.

3.1 Landscape evolution

Figure 2 presents the profiles along the tidal flat for H, D and soil accretion. Soil coverage is represented by a classification map. Results are for the years 20, 60 and 90 which gives a general idea of the system evolution.

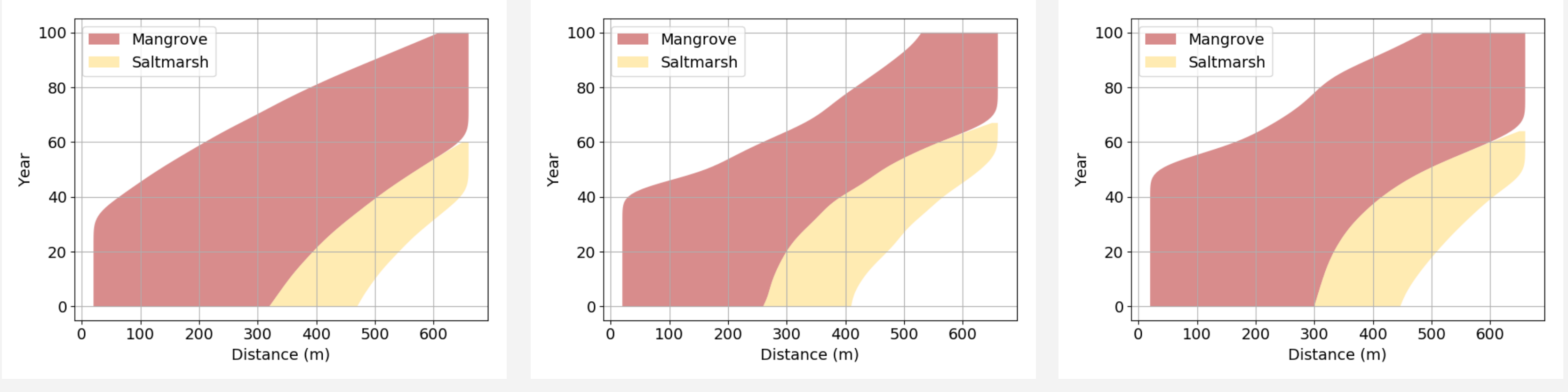
All the scenarios show that in 60 years, major vegetation changes will occur, but losses will not be significant. However, after this, accretion rates will not cope with SLR and 2/3 of the area will submerge.

Other relevant aspects:

- Attenuation due to surface roughness results in slower migration at the upper end and favours saltmarsh presence until later times;
- The presence of a central channel allow water to flow more freely, expanding suitable areas for vegetation;
- The embankment imposes the most drastic change. It keeps mangrove downstream, allow saltmarsh to survive for longer, but results in the highest vegetation loss at the end;
- Accretion profiles change significantly through the different scenarios, showing how dynamic is the feedback among all variables.

3.2 Vegetation change

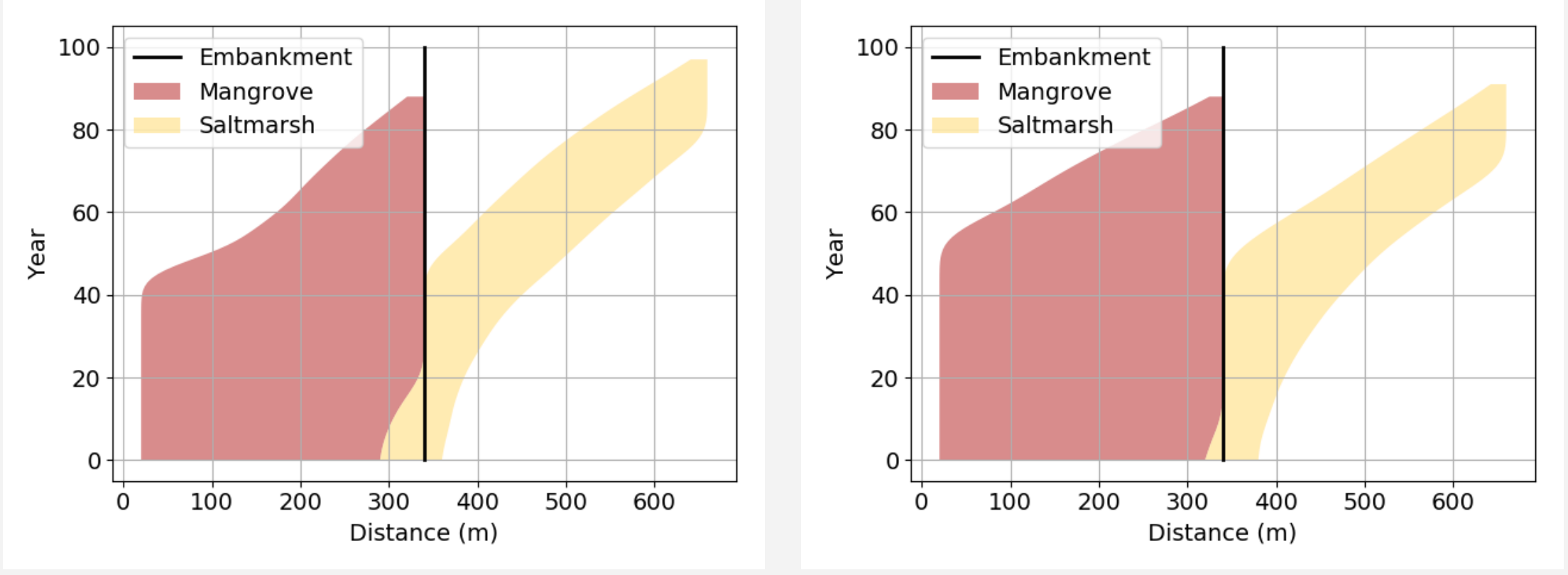
Figure 3 presents the average position of mangrove and saltmarsh areas over the years for the different scenarios. The distance in the chart represents the average longitudinal position of the vegetation obtained by transverse averaging. Since there was no noticeable transverse changes, this procedure gives representative values of the overall position of the vegetation.



(a) Bathtub

(b) Hydrodynamic without structures

(c) Hydrodynamic with central channel



(d) Hydrodynamic with embankment and culvert

(e) Hydrodynamic with central channel and embankment with culvert

Figure 3. Mangrove and Saltmarsh positioning evolution over time

When the attenuation effect is included in the modeling framework, it is quite clear that saltmarsh can remain longer at the expense of mangrove (Figs. 3a and b). However, inserting a small channel in the middle of the tidal flat changed the water fluxes in such a way that both mangrove and saltmarsh where benefited.

The major effect of the embankment was that mangrove could not grow in the upper areas upstream of it. This allowed saltmarsh to remain in the simulation area for much longer than in the scenarios without this constraint. The addition of a central channel had a positive feedback on the mangrove community, allowing it to remain over a larger area for longer. Upstream of the embankment, the channel increased saltmarsh occupation over the first half of the century, however in the second half it helped the same area to submerge faster.

The results produced here corroborate and help generalize the results of Rodriguez et al. (2017) and Sandi et al. (2018) for a real estuarine wetland, with a complex network of channels, levies and culverts. This real wetland, as most of SE Australian wetlands, display mangrove encroachment over saltmarsh as an added detrimental effect associated with sea-level rise (Oliver et al., 2012).

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