MODELLING MANGROVE ECOSYSTEM ENGINEERING EFFECTS FOR PERSISTENT FLOOD RISK REDUCTION

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INTRODUCTION

Mangroves are recognized as a nature-based solution for coastal flood risk reduction. The salt-tolerant trees occur along sheltered coastlines in the tropics, subtropics and warm temperate regions globally. With their above-ground biomass mangroves reduce energy of long and short-period waves, while they increase soil binding and stability of intertidal flats with their below-ground biomass. This way, mangroves do not only provide functionality for flood risk reduction by attenuating waves, they also provide persistence by stabilizing shorelines and creating sheltered conditions for forest development (Gijsman et al., 2021). These ecosystem engineering effects contribute to the long-term persistence of mangroves for sustained flood risk reduction because they allow mangroves to adapt to, and recover from, impacts of a changing climate.

This study aims to quantify mangrove ecosystem engineering effects with a new biophysical, process-based model. The model is setup, developed, calibrated and validated with a unique dataset of hydrodynamic, morphodynamic and vegetation parameters collected for over a decade in the Firth of Thames estuary in Aotearoa New Zealand. The mangrove forest in the Firth is characterized by distinct cross-shore zones with different elevation and vegetation characteristics, ranging from the most seaward intertidal flat, the seedling establishment zone, the dynamic forest fringe, the scrub forest and, most landward, the relict forest fringe (Figure 1; Swales et al., 2019). Manipulated simulations with and without mangroves' effects on hydrodynamics and morphodynamics are used to quantify their influence on the profile morphology (i.e., surface accretion) and on forest recovery (i.e., seedling survival probability) in these different cross-shore zones.

MODEL DEVELOPMENT

Our new model includes hydrodynamics (water levels and waves), morphodynamics (sediment transport and surface elevation change) and ecological processes (propagule fruiting, seedling establishment and growth). Hydrodynamics and morphodynamics are solved with Delft3D Flexible Mesh. Propagule fruiting and seedling establishment and growth are computed with a new individual-based seedling model. The influence of mangrove above-ground biomass on tidal flows and waves is computed with the equations of Baptist et al., (2007) and Mendez and Losada (2004), respectively. The influence of mangroves on the erodibility of the substrate is incorporated following Van Maanen et al., (2015). Additionally, the positive influence of aerial exposure duration on reducing substrate erodibility is included following Nguyen et al., (2020). This aerial exposure influence proved essential to simulate the observed accretionary profile dynamics in the Firth. Lastly, seedling dynamics are based on field measurements conducted by Balke et al., (2015).

Figure 1 – The seedling establishment zone (front) and dynamic forest fringe (back) in the Firth of Thames estuary

RESULTS AND DISCUSSION

The model simulations show that mangrove ecosystem engineering effects on the profile morphology and on forest recovery vary across the forest zones. In the dynamic forest fringe, located between mean high water neap (MHWN) and mean high water spring (MHWS) tide levels, surface accretion increases due to the mangrove forest presence. In this zone, the seedling survival probability also increases substantially with the presence of mangrove trees. In the seaward intertidal flat and seedling establishment zones, located below MHWN tide level, surface accretion reduces due to the presence of the mangrove forest, inducing a convex up profile near the dynamic forest fringe. The mangrove forest does not affect the seedling survival probability in these seaward zones. In the higher-elevated scrub forest and relict forest fringe, further landward and with limited tidal inundation, surface accretion reduces due to the mangrove forest and seedling survival probability remains high. On an annual timescale, the cross-shore distance of increased surface accretion instigated by the presence of the mangrove forest reaches up to 190 m seaward from the forest edge, while the increased seedling survival probability is simulated up to approximately 300 m seaward from the forest edge.

The model results show that mangrove forests can enhance the persistence of upper intertidal flats for flood risk reduction. The mangrove forest in the sediment-rich, wave dominated, Firth of Thames estuary stimulates the widening of the vegetated upper intertidal flat by increasing the amount of sediment that accretes as well as by improving the conditions for forest recovery and development in the first O(100 m) of mangrove forest. Relations between prevailing hydrodynamic conditions and seedling survival probability were derived from the model results. By linking seedling establishment and survival to the temporal variability in the tidal hydroperiod and bed shear stresses, the obtained parameterizations extent the Windows of Opportunity approach by Balke et al. (2015) such that it can be implemented in longer-term mangrove development models. Moreover, the model results can be used for the assessment of mangrove forests for flood risk reduction as well as informed mangrove restoration design for specific forest zones.

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