ANALYZING UPSCALED NOURISHMENT SCENARIOS FOR SEA LEVEL RISE MITIGATION

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INTRODUCTION

Sand nourishments are increasingly utilised to protect low-lying coastal areas against coastal erosion and sea level rise. To face projected higher rates of sea level rise, there have been proposals for nourishment strategies that involve significantly greater volumes of sand. For instance, Haasnoot et al. (2020) estimated that to address extreme sea level rise rates of 60 mm per year, nourishment volumes up to 20 times larger than those currently employed may be necessary. Achieving this could involve drastically changing either the individual nourishment volume, the frequency of return, or both. However, the extent to which such substantial quantities of nourishment can effectively distribute within the given timeframe remains uncertain.

A widely accepted perception is that coastal profiles respond to nourishment by rapid adjustment to a (new) equilibrium shape incorporating the added sand volume. From this point of view, only the total added amount of sand is relevant, while nourishment design characteristics such as cross shore location, and return frequency and nourishment volumes are of minor importance. The validity of this viewpoint hinges on the timescale of equilibration of a coastal profile in relation to the timescale and extent of the changing boundary conditions. This equilibration of is realized under the force of waves, wind, and tidal currents. These forces do not exert uniform effects across the entire profile; the upper profile experiences higher energy levels compared to the lower part. Consequently, the average rate of sand redistribution varies along the profile, leading to varying timescales for morphological adaptation in response to altered boundary conditions (Stive and de Vriend, 1995). This ranges from hours around the waterline to millennia near the inner shelf.

In nourishment projects involving substantial sand volumes for sea level rise mitigation, the capacity for sand redistribution can become a limiting factor in the choice of nourishment strategies. The nourished sand may then not effectively distribute in the given timeframe, resulting in suboptimal outcomes. For instance, it may take several decades for the added sand to reach areas of the profile where the response is slower, typically at greater depths. This phenomenon, albeit to a moderate degree, has been observed in the Netherlands, where 30 years of nourishment has resulted in notable steepening of the profile (Dutch Ministry of Public Works, 2023). Our research objective is to map the nourishment-induced cross-shore dynamics on yearly to decadal timescales, contingent upon factors such as sea level rise, strategy duration, nourishment volume, nourishment cross-shore location, nourishment frequency, and background erosion. Thereby we aim to address the fundamental question: to what extent are upscaled nourishment scenarios viable under different rates of sea level rise?

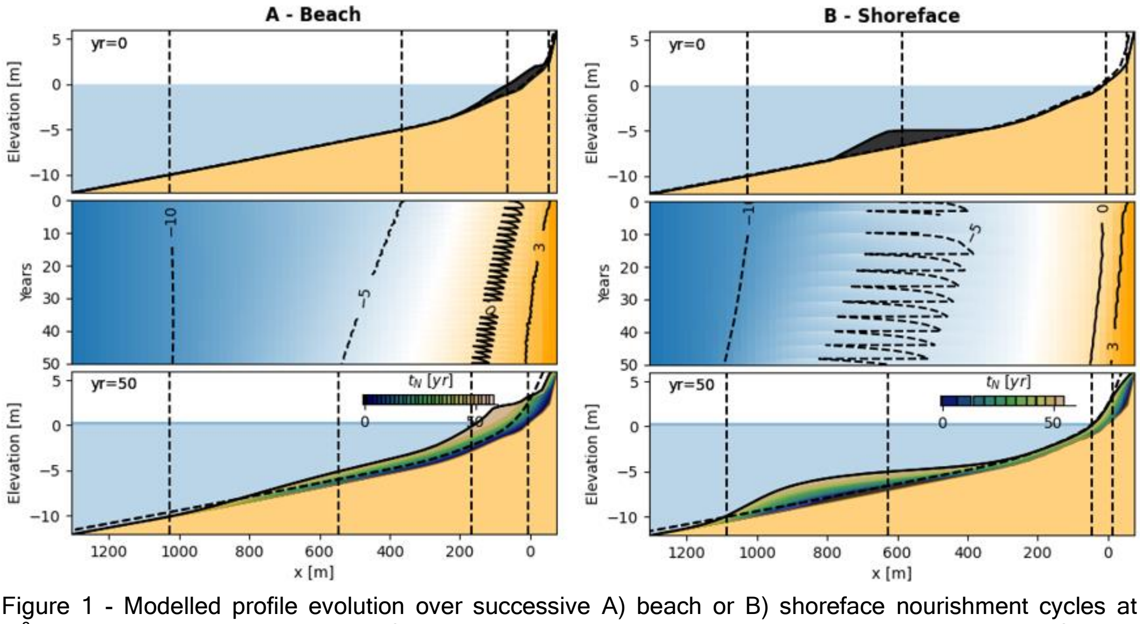

Figure 1 - Modelled profile evolution over successive A) beach or B) shoreface nourishment cycles at a -40 m^3/m/yr background erosion rate at 8 mm/yr sea level rise. The top and bottom panels display profile snapshots at the beginning and the end of the simulation. The center plot shows the profile depth evolution over time. Dashed lines indicate depth contours, t_N refers to the nourishment placement year.

METHODS

For this purpose, we conduct simulations with the numerical diffusion-based model Crocodile, which has been developed to simulate effects of nourishment strategies on coastal volume, coastline position and beach width over a multiple-decadal timeframe (Kettler et al., *submitted*). This model incorporates elements to compute cross-shore diffusion, sand exchange with the dune and longshore sand losses. Thereby, it allows for the computation of both (repeated) nourishment as well as sea level rise. With Crocodile we conduct 50-year simulations of nourishment scenarios, considering a broad spectrum of stationary sea level rise rates and longshore erosion, with the Netherlands as our case study location. In these scenarios, we implement nourishment strategies to maintain the coastline and the volume of the coastal profile. These strategies involve nourishment placement either directly on the beach, or as a shoreface nourishment. Hereby, a new nourishment is implemented if I) the coastline crosses landwards from its initial position or II) the profile volume falls below the sum of its initial volume plus the additional volume needed to accommodate sea level rise. Subsequently, we analyse how sea level rise impacts nourishment lifetime and the extent of profile deformation.

RESULTS

The modelled scenarios show how nourishment strategies under high sea level rise rates become affected by the sand redistribution capacity along the profile. Over the successive nourishment cycles of beach nourishment, we observe that the beach gradually widens with each nourishment. Simultaneously, the added sand does not reach the lower section of the profile, resulting in a gradual steepening of the profile over time, as illustrated in Figure 1. Moreover, this profile steepening leads to a reduction in the lifespan of nourishment across successive nourishment cycles. In the case of sand applied as shoreface nourishment, there are inherent limitations on its scalability due to the slow lateral dispersion in the cross-shore direction. When high nourishment volumes are applied in a short timeframe, the sand lacks sufficient time for effective redistribution and accumulates in the nourishment region. This sand fails to reach the beach and dunes quickly enough to keep pace with sea level rise, and same applies to the lower shoreface. Because of the increasing deformation induced by the nourishment, nourishment lifetime decreases over the successive nourishment cycles.

The impact of sea level rise on the lifetime of a single beach or shoreface nourishment is contingent upon the rate of longshore erosion, as displayed in figure 2. In the beach nourishment scenarios, the nourishment lifetime is limited by a volumetric shortage in the profile rather than coastline exceedance. When sea level rise exceeds 16 mm per year, we observe that nourishments of present-day size all dissipate within 2 years. For shoreface nourishment, the primary factor limiting its effectiveness over time is associated with the need to maintain the coastline, particularly under combinations of high erosion and sea level rise. In such instances, the rate of sand dispersion to the beach and dune is insufficient to maintain the coastline. As a result, we find that nourishments have lifespans of are less than one year, rendering these strategies practically unfeasible.

UPTAKE OF FINDINGS

The findings from this research hold potential to aid enhancing the design of forthcoming shoreline maintenance schemes. By gaining a deeper understanding of the dynamics involved in nourishment strategies under sea level rise, we can better inform and optimize future strategies for maintaining and protecting our coastlines.

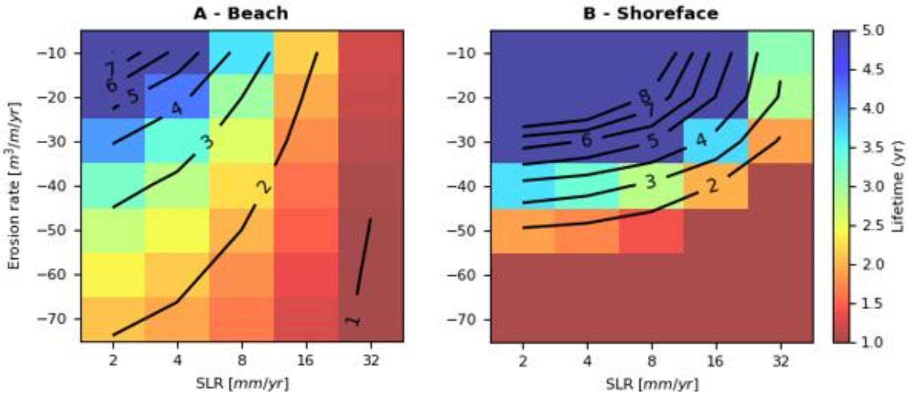

Figure 2 - Nourishment lifetime for A) 200 m^3/m beach nourishments and B) 450 m^3/m shoreface nourishments as a function of sea level rise (SLR) and background erosion rate. The contour lines represent equal lifetime levels.

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