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Editorial

Morphodynamic Evolution and Sustainable Development of Coastal Systems

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Coastal systems are highly dynamic morphological environments due to erosion and sedimentation at different spatio-temporal scales as a result of natural forcing [1–3] and human interventions [4,5]. These morphodynamics are expected to increase in the future due to sea level rise and climate change [6], as well as other anthropogenic effects. Understanding the forcing factors, natural morphological evolution, and response to potential future forcing scenarios will help coastal policy makers to develop suitable adaptation strategies and to assure the sustainable use of coastal systems, enhancing the socio-economic and environmental benefits.

In this Special Issue, 10 articles are published that can be categorized into 3 main groups:

- Analyses of field data for morphodynamic evolution [1–3];
- Sustainable development for coastal protection [4,5];
- Numerical modelling of hydro-morphodynamic processes [6–10];

These topics are discussed below in the context of the articles.

- Analyses of Field Data for Morphodynamic Evolution

Averes et al. [1] analysed the contribution of cliff retreat to the littoral sediment budget along the Baltic Sea coastline of Schleswig-Holstein (Germany). This analysis used field data of cliff retreat and the geological and sedimentological characteristics of cohesive cliffs in the study area from scientific publications and unpublished work such as project data and reports and PhD and student theses. The littoral sediment budget (Equations (1)–(4) [1]) was assessed based on volumetric material erosion from cliffs, the degree of decompaction of the highly compacted glacial material was due to mobilization, and the loss of carbonate and fine fractions was due to reworking and transport. In areas without observations, it was assumed that cliffs are entirely composed of glacial till with a homogeneous sediment composition. The analysis found that ongoing cliff erosion contributed a sediment (0.063–64 mm) volume of about 39–161 $\times$ 10^3 m^3 annually to the littoral sediment budget as a result of an annual average cliff retreat rate of 0.24 m (range: 0.10–0.73 m). The authors suggest that including the sediment supply from the hard bottom seafloor erosion (abrasion) is an important sediment source for littoral transport, though it was not considered in this analysis.

The barrier beach roll-back at Medmerry (southern England), after ceasing management, was investigated by Dornbisch [2]. The study used 40 topographical surveys collected over 7 years (2013–2020) along a 1.5 km long micro-tidal shingle barrier stretch. The field data were analysed using several parameters (Section 3), including Barrier Inertia (BI). A high BI indicates stability, while instability by overtopping and overwash are represented by low values. These two morphological states are bounded by wave steepness. The estimated historical (1876–1896) retreat was equivalent to 1.5 m/y, while the predicted retreat for the 50-year design life was 0.4–0.7 m/y. This analysis showed that the barrier roll-back is influenced by the creation of an artificial tidal breach, the elevation of the underlaying marsh and clay sediments, storm occurrence, and the presence of groynes. The estimated roll-back averaged over the analysis period exceeded 16 m/y, which is an order of magnitude higher than the historic shoreline retreat. The BI can be used to describe the observed morphological response of a micro-tidal barrier as long as the foreshore geometry is similar to the state when the BI is developed.

Evans et al. [3] investigated the multi-decadal morphodynamic evolution of the salt marsh in the East Anglia region, UK. The approach is based on a time series of Landsat satellite images from 1984 to present. These images, which have a 25 cm resolution, were analysed using 30 m $\times$ 30 m pixels to estimate the morphodynamics of vegetated surfaces, creeks, pools and pans within the salt marsh area. The areal unvegetated–vegetated marsh ratio was calculated to indicate the marsh's vulnerability. From Google Earth Engine, the normalised difference vegetation index, which indicates chlorophyll and thus vegetation, was estimated to reflect the percentage change of vegetation cover of each pixel. The analysed results were then represented by matrices of topographical and morphological changes separately. Marsh degradation at pixel-scales indicated loss of vegetation. The overall probability of marsh degradation was 0.144 for the entire dataset (~1985–2016). These results suggest that marsh areas that already have some form of fragmentations and are located far from the nearest creek and towards headlands of estuaries and inlets are the most likely to exhibit degradation.

- Sustainable Development for Coastal Protection

The performance of a new soft coastal defence, the Sand Net Device (SND), against erosion along the northern shoreline of the Authie estuary (Normandy, France) was investigated by Do et al. [4]. The SND is implemented using several nets assembled in an inverted V-shape creating a porous structure designed to trap sediment. This hydraulic structure for coastal protection is under consideration for a patent. The objective of the SND is to decrease the flow velocity and therefore enhance sedimentation. The effectiveness of the SND was investigated using 2DH/3D numerical experiments with the TELEMAC-MASCARET modelling suite. The presence of the SND was implemented at the model bed by applying an additional drag force over the enclosed area (Section 3.3 [4]). The model was forced using the predicted astronomical tide only. The simulations spanned a 45-day period starting on 15 February 2019. The measured bathymetries indicated sedimentation near the shoreline after deployment of the SND. The simulated morphodynamics qualitatively showed no sedimentation with zero drag coefficient and an increase in sedimentation towards the shoreline as the drag coefficient increases. Numerical experiments indicated that the influence of the SND extends about 500 m in the upstream and downstream directions.

Eichmanns and Shüttrumpt [5] investigated the effectiveness of sand trapping fences on coastal dune evolution at two East Frisian islands: Norderney and Langeoog (southern North Sea coast, Germany). This analysis was based on digital elevation models, which were developed using drone images (Norderney: 24 August 2020 to 9 March 2021, Langeoog: 20 May 2020 to 12 March 2021). The dune volume was estimated by analysing images in ArcGIS, and the aeolian transport was calculated using the Bagnold model (Section 4 [5]). The porosities of the sand trapping fences were determined by processing photographs using the MATLAB tool, Colour Thresholder Application. Dune toe growth and its relation to the aeolian transport were derived for boundary conditions and the characteristics of the sand trapping fences. The results showed that the dune toe growth is significant immediately after the construction of a sand trapping fence, and the effectiveness decreases over time. Protruding height and porosity of the branches are less important in sand trapping when fences are in place for a long time. The lower porosity of the sand trapping fences promotes dune toe growth at the fence location, while a higher porosity results in deposition further downwind. The dune toe growth influenced by sand trapping fences is a product of potential transport and sand trapping.

- Numerical Modelling for Hydro-Morphodynamic Processes

Climate change impacts on coastal-scale wave dynamics were investigated by Dissanayake et al. [6] applying the Delft3D modelling suite at Vougot Beach, France. Simulations were carried out using a measured historical wave time series, which was then projected into the future. Three globally averaged sea level rise scenarios for 2100 (SLR_{min} = 0.53 m; SLR_{avg} = 0.74 m and SLR_{max} = 0.98 m) and combined SLR and wave climate scenarios for A1B, A2, and B1 emissions paths of the IPCC were considered. Future waves following the B1 scenario indicated an increase in storm occurrence. Future scenarios showed larger relative changes at the beach than in the nearshore area. Increases in both the wave energy and bed shear stress relative to the historical values are higher in the combined scenarios (wave energy: +95%, bed shear stress: +190%) than the SLR only scenarios (+50% and +35%, respectively). This investigation emphasized that combined SLR and future wave climate scenarios need to be used to evaluate future changes in local hydrodynamics and their impacts.

Gundlach et al. [7] investigated the long-term development of two channels in the Outer Weser estuary (North Sea coast, Germany) using a schematised flat bathymetry in Delft3D. The long-term morphodynamic evolution was simulated considering the influence of the tidal range, Coriolis effect, Kelvin waves, and river discharge. All simulations predicted reaching morphodynamic equilibria over a period of 4000 years with different two-channel shapes. The two-channel system was developed as a result of the tidal forcing interacting with the basin geometry. The dominance of each channel depends on the tidal influence for the west channel and the river discharge influence for the east channel when the Coriolis force is included. The period of the simulated pattern of alternation between the 1- and 2-channel system was about 10 times larger than the observations (between 20 and 120 years). The alternation pattern and the period were dominated by the tide rather than the river discharge. Kelvin waves influenced the generation of a dominant eastern channel, while the Coriolis force resulted in an enhanced western channel because the incoming tides approached the east side of the Outer Weser based on the northwestern origin of the Kelvin wave inertia. These results qualitatively agree with the nautical charts with respect to the extent and migration area of individual channels, though the exact locations and dimensions vary.

Beach morphodynamics in a geologically controlled area from calcarenite limestone reefs were investigated by Bosserelle et al. [8]. Numerical experiments during a winter storm event were carried out using a modified version of the XBeach model at Yanchep beach in Southwest Australia. The modification of the model formulation included considering different values for the bottom dissipation parameter (see f_w in Equation (1) [8]) and the bed friction parameter (see c_f in Equation (2) [8]) for sandy and reef outcrops. Simulated currents showed that the model was twice as sensitive to roughness than wave braking parameters, and three-times more sensitive to the roughness than to the roller dissipation viscosity factor (see Table 4 [8]). The morphodynamic response of the beach varied considerably along the shore due to sharp variations in the reef topography. Strong current jets (>1 m/s) enhanced the beach's erosion at the boundary of the reef and influenced the morphological response of the beach hundreds of meters away from the reef.

Applying a novel root model in XBeach, Schweiger and Schuettrumpt [9] investigated the effect of belowground biomass on dune erosion volumes. The root model allows two modes: a constant mode with a unique rooting depth and a dynamic mode with spatial varying rooting depth. The Manning roughness coefficient in vegetated areas varied following Equation (3) [9] in order to account for spatial and temporal variability of the bed friction. The root model was validated for a large-scale experiment by upscaling a small-scale model setup (flume experiment). Control experiments without vegetation resulted in overestimated erosion around the waterline, even though the parameters of the morphodynamic processes were adjusted. Applying the root model to the upscaled below ground biomass cases reduced the prediction of dune erosion. These results were further improved at the dune front by applying spatially varying rooting depths. However, the overall effect of the root model differed due to different hydrodynamic conditions. Separate investigations are suggested to analyse the effects of above and below ground biomass on the wave-induced dune erosion and the individual contribution of different plant characteristics.

The effect of roller dynamics on storm erosion was investigated by Dissanayake and Brown [10] using XBeach and Delft3D. Simulations were carried out based on the North Sea coast of the Sylt island. Wave predictions in Delft3D agreed better with the measured data than the predictions with XBeach. Both models predicted the highest sensitivity to the roller parameter *beta*. The simulated storm erosion and accretion patterns along the coast were similar in both models, albeit with different magnitudes. Delft3D cannot produce comparable storm erosion to XBeach when the roller dynamics and avalanching are considered. Delft3D was less sensitive to roller dynamics compared to XBeach. In the nearshore area, including roller dynamics increased storm erosion up to 31% in Delft3D and decreased erosion up to 58% in XBeach, while the erosion in the dune area increased up to 13% in Delft3D and up to 97% in XBeach. The choice of model had more impact on the hydrodynamic and morphological predictions than the option to include or omit roller dynamics. These results indicate that both models produce increased storm erosion in the dune area with roller dynamics.

These articles present novel approaches in estimating coastal morphodynamics and related processes, enhancing the general understanding of these complex systems and the applications of soft engineering measures for coastal protection. The different proposed approaches could be applied to similar systems aiming to develop sustainable coastal management strategies.

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