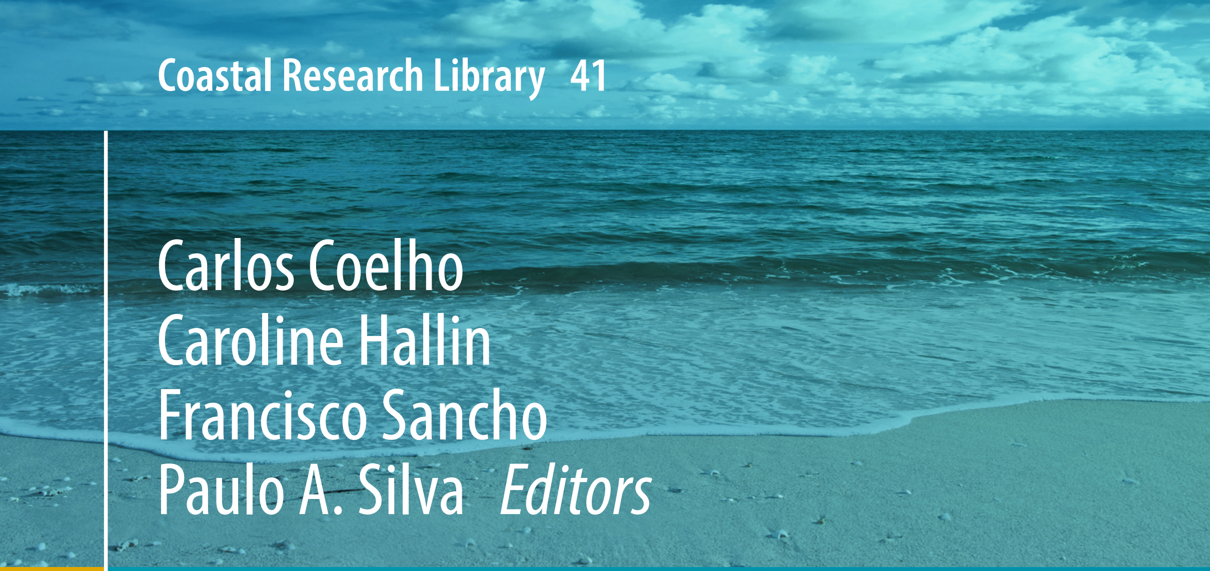
Coastal Research Library 41



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Caroline Hallin
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Coastal Dynamics 2025

Volume 1

OPEN ACCESS

Springer

Coastal Research Library 41

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ISSN 2211-0577 ISSN 2211-0585 (electronic)
Coastal Research Library
ISBN 978-3-032-15472-9 ISBN 978-3-032-15473-6 (eBook)
https://doi.org/10.1007/978-3-032-15473-6

This work was supported by the Coastal Dynamics 2025 conference.

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Parameterised Barrier Morphological Evolution for Future Storm Impact Assessment

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Abstract. Coastal storm impacts are mainly determined by the interaction of extreme water levels with barrier morphology, particularly the height of the foredune. While future projections of storm hydrodynamic forcing, integrating sea level rise, tides, waves and storm surges, are readily available, predicting future barrier morphology at a decadal scale remains a challenge due to uncertainties in modeling morphodynamic processes. This study proposes a simplified model to predict future foredune morphology at decadal scale and determine storm impacts on coastal barriers, focusing on the critical role of foredune morphology. The model identifies three morphological behavior modes based on the nature of the sediment budget and associated shoreline dynamics, distinguishing between: "keep-up mode" for accreting barriers, "catch-up mode" for stable to mildly accreting barriers, and "give-up mode" for eroding barriers. Application to the Portuguese coast, specifically the eroding barrier of Torrão do Lameiro, demonstrates that even with rising sea level and higher total water levels, storm impacts remain within the same regime by 2050. This simplified model offers a practical approach for considering an evolving foredune morphology, which can support first-order assessments of future storm impacts in changing climate.

Keywords: Barrier Morphology · Foredune · Sediment Budget · Storm Impacts · Coastal Behaviour Modelling

1 Introduction

The impacts of storms on coastal barriers are largely determined by the interaction of extreme water levels with the morphological characteristics of the beach-dune system [1]. The storm-induced extreme water levels determine the severity of the forcing, while the morphology of the beach and, more importantly the dune, regulates the ability of barriers to withstand erosion and prevent flooding. This interdependency of hydrodynamic forcing and morphological setting is thus fundamental for categorising and predicting storm impacts [2].

C. Coelho et al. (Eds.): CD 2025, CRL 41, pp. 469–474, 2026.
https://doi.org/10.1007/978-3-032-15473-6_71

When considering future storm impacts in a changing climate, predictions of hydrodynamic forcing integrating sea level rise (SLR), tides, storm surge and waves are nowadays readily available from individual or ensemble climate projections e.g. [3]. These are increasingly used to determine changes in extreme water levels and estimate flooding extents at local to global scales [4, 5]. However, predictions of future barrier morphology remain elusive, as morphodynamic linkages in beach-dune systems across scales are still poorly resolved, particularly when scaling from process observations to decadal morphological changes [6]. For storm impact assessments, this results in an incomplete, but often applied approach, where future extreme sea levels are only compared to present day barrier morphology [4, 7].

Predicting future dune morphology, particularly the height of foredunes, is fundamental for assessing future storm vulnerability in coastal barriers [8]. However, despite recent advances in coastal dune morphological models, both process-based or data-driven, there are still many uncertainties in the numerical modelling of long-term (decadal) coupled beach and dune morphodynamic processes [9]. Therefore, simplified models that describe key evolutionary modes, integrating empirical observations or parameterising observed barrier change behaviours, remain a useful solution for predicting coastal morphological change. The reduced complexity in terms of processes and data used, alongside the low computational requirements make such models particularly useful for long-term and large-scale application, and potentially useful for integration in climate change impact assessments. Aiming to evaluate future storm impacts in coastal barriers, this work proposes a parameterised morphological behaviour model of barrier evolution, exploring its application to the Portuguese coast.

2 Model Framework

For first-order assessment of storm impacts on coastal barriers, such as the well-established Storm Impact Scale outlined by Sallenger [1], the elevation of the foredune toe (D_{low}) and crest (D_{high}) are critical morphological parameters. While these two variables simplify barrier morphology, they represent the key vertical dimensions and are commonly incorporated in simplified or idealized coastal behaviour models. Considering this, to parameterise barrier evolution the proposed modelling framework considers exclusively changes to the height of the toe and the crest of the foredune.

Foredune evolution depends primarily on wind, vegetation and sediment supply [10]. At decadal timescales, and assuming quasi-stationary wave and wind regimes, while excluding human impacts and changes in vegetation cover, the elevation of foredunes is mainly controlled by sediment budget, shoreline change and beach morphodynamic type [11]. Although morphodynamic beach type is variable around a modal state, it can be assumed stable at decadal scales if there are no changes to sediment type. This leaves sediment budget and associated shoreline change as key controls of decadal foredune morphological evolution. Different foredune evolutionary behaviour modes can then be considered for accreting, stable and eroding barriers [11]. Taking a sediment budget conceptual approach to foredune evolution [10] and focussing exclusively on the decadal change of the foredune toe and crest elevation in a context of rising sea levels, three morphological behaviour modes are proposed (Fig. 1). In moderately to highly accreting barriers, indicative of a strongly positive sediment budget, foredunes can keep pace with rising sea levels, increasing their toe and crest elevations at the rate of SLR as the shoreline progrades (*keep-up mode*). In stable to mildly accreting barriers, where a slightly positive sediment budget is necessary to maintain the shoreline position with rising sea level, the foredune toe elevation increases at the rate of SLR, but the foredune crest remains at the same elevation (*catch-up mode*). In this mode, most of the sediment is used to aggrade the beach and also prograde the stoss slope of the foredune, limiting the sediment availability for vertical foredune growth. Finally, in eroding barriers the sediment budget is negative, and the foredune retreats landward, with the crest elevation determined by the topography of the landward dune ridges (*give-up mode*). In this mode, the toe elevation continues to increase at the rate of SLR, as sediment is supplied to the beach from the eroding dunes.

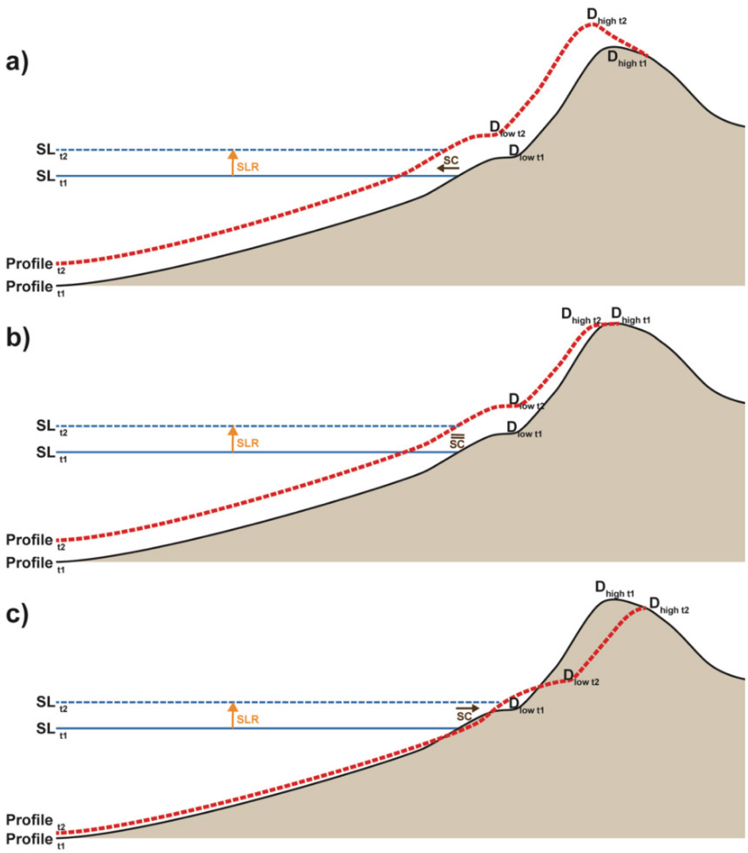

Fig. 1. Schematic overview of change in foredune morphological parameters (D_{low} and D_{high}) in relation to shoreline change (SC) and sea level rise (SLR). a) keep-up mode, b) catch-up mode and c) give-up mode.

Across the three behaviour modes the elevation of the foredune toe increases at the rate of SLR, as the beach profile adjusts vertically to maintain morphodynamic equilibrium with mean sea level [12]. This reflects the fact that, at decadal scales, water levels will be permanently raised by the amount of SLR, but only episodically raised by the storm-induced surge and runup, and foredune toe reflects only the permanent increase in water levels. If the wave regime is not quasi-stationary, changes in the modal wave climate should be incorporated in the trajectory of the foredune toe elevation.

3 Application to the Portuguese Coast

The morphological behaviour model was applied to sandy barriers along the Portuguese coast, using high-resolution LiDAR data of beach and dune systems collected in 2011, combined with multidecadal shoreline change rates from 1958 to 2010 determined by Lira et al. [13]. Storm impact regimes were determined following Sallenger [1] for the present and in 2050 considering the RCP8.5 climate change scenario. Extreme water levels, specifically total water level (R_{high}) and maximum still water levels (R_{low}), were computed for the 100-year return period storm using wave and storm-surge projections from the Copernicus Climate Change Service for the European coastline, alongside the regional IPCC AR6 median sea level projection and considering a mean high tide level.

Considering the example of Torrão do Lameiro barrier, located in the exposed NW coast of Portugal and experiencing a shoreline change rate of −0.5 m/yr, applying the give-up mode to project the 2050 dune toe and crest elevations results in a D_{low} of 7.6 m and D_{high} of 12.6 m, respectively (Fig. 2). The exact crest location is adjusted from the stoss slope to the adjacent peak to better align with dune crest morphology. In this case, even with a projected increase in R_{high} of 1 m and R_{low} of 0.6 m, the total water level remains under the dune crest elevation estimated for 2050, as the retreating shoreline will reach a higher dune ridge located landward of the current foredune. As such, a collision storm impact regime is maintained between the present and 2050, despite the rise in sea level and the increased severity of storm forcing.

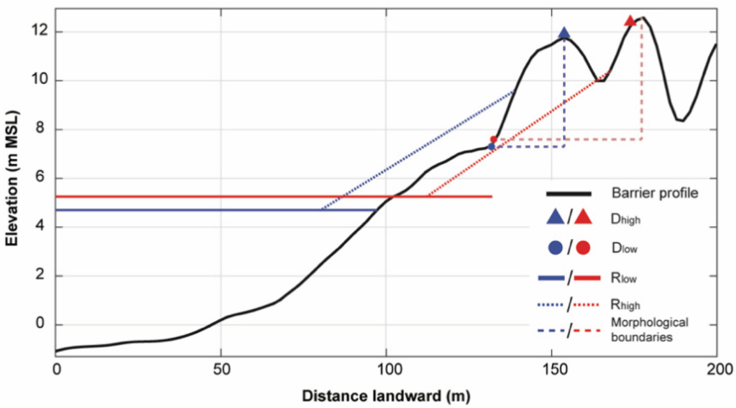

Fig. 2. Overview of present (blue) and RCP8.5 2050 projection (red) of foredune morphological parameters (D_{high} and D_{low}) and and extreme water levels (R_{high} and R_{low}) for Torrão do Lameiro.

4 Discussion

Sandy barriers are highly variable in form and setting, which results in a range of morphological responses to SLR that depend on a variety of processes and variables that cannot be meaningfully captured by a single model [14]. However, at decadal to centennial scales, the nature of the overall sediment budget and associated shoreline change can be used to infer generic barrier and foredune morphological change patterns under positive, neutral and negative sediment budgets [12]. The parameterised morphological behaviour model of barrier evolution proposed in this work incorporates simplified relationships between shoreline and foredune morphological change under rising sea levels, which although not universally valid, attempt to distinguish between common behaviour modes. The reliance on shoreline change and barrier topography metrics makes this approach widely applicable, particularly given the increasing availability of medium resolution global datasets that can be used to obtain, even if with limitations e.g. [15], all the hydrodynamic and morphological parameters considered in the model.

Although the use of on invariant coastal morphology is commonly recognised as a key limitation for assessments of future storm impacts [4, 7], very few studies have incorporated changes to future barrier morphology when modelling the potential impacts of storm events in a changing climate e.g. [16]. As first-order storm impacts in coastal barriers are largely controlled by foredune height [1, 8], predicting the entire barrier profile is not essential. Foredune toe and particularly crest, i.e. D_{high}, are the fundamental variables that must be considered for more confidently determining if future storms are likely to lead to increased collision, overwash and inundation of coastal barriers. Applying the parameterised model to Torrão do Lameiro, a coastal barrier under significant erosion and exposed to more extreme total water levels, indicates that storm impacts will remain within the same regime towards the mid-century. This is due to the presence of a second, inland-located, dune ridge, which highlights the critical importance of landward morphology when evaluating storm impacts in retreating coastal barriers under the give-up mode.

5 Conclusion

This work proposes a new simplified morphological behaviour model to estimate future foredune morphological parameters required for first-order assessments of storm impacts in coastal barriers. This model can be applied with limited information, but addresses a critical limitation in storm impact assessments in a changing climate, which typically evaluate future extreme water levels but do not consider the expected multi-decadal variation in barrier morphology. The application to Torrão do Lameiro in the NW coast of Portugal demonstrates that, despite the increase in total water levels, future storm impacts remain in the collision regime, even for extreme 100-year return period storm conditions.

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