DECADAL SCALE PREDICTION OF COASTAL DUNE EVOLUTION AT LONG BEACH, WA, USA

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INTRODUCTION

Coastal communities commonly rely upon foredunes as the first line of defense against coastal hazards such as flooding from storm events and sea level rise. Unlike hard infrastructure, like dikes and seawalls, dunes are dynamic features that naturally evolve on varying timescales in response to changes in environmental forcings (oceanographic, meteorological, hydrological, sedimentological). Due to the complex interplay of environmental and morphologic controls on dune erosion during storms and wind-driven dune growth, there can be substantial alongshore variability in the magnitude and style of dune evolution (e.g., Houser et al., 2008). However, historical rates of dune volume change may evolve into the future given non-stationary environmental conditions. The ability to understand, predict and forecast dune evolution is therefore vital to the development of effective coastal resilience strategies, especially in the context of a changing climate.

A range of tools, including statistical, geometric, and process-based models, have been developed to simulate coastal sediment transport and morphological change. These tools are commonly used to hindcast historical events, with calibrated and/or validated models, to either fill in gaps of process-understanding and/or to explore alternative climate scenarios. There is also an increasing need to forecast coastal evolution to optimize coastal management strategies. However, the details of future climate conditions are known only in a probabilistic sense – providing challenges to effectively quantifying future coastal hazards. For example, singular deterministic time series provide only one representation of potential weather patterns, sea states, and local scale forcing conditions. However, new climate emulation techniques, such as the Time-varying Emulator for Short- and Long-term Analysis of coastal flooding and erosion (TESLA; Anderson et al., 2019), provide an efficient means to synthetically represent multiple versions of future oceanographic and meteorological time series that can be used to drive coastal hazard models.

This study aims to quantify future probabilistic estimates of dune evolution along a historically prograding section of coast in the US Pacific Northwest. A reduced complexity dune erosion and growth model is first used in hindcast mode to simulate alongshore variability in dune evolution at Long Beach Peninsula (LBP), WA. Extensive topographic field data, collected quarterly between 1997 and present, is used to calibrate transport coefficients in the model and to validate the model on a multi-decadal scale. The model is then run in forecast mode out to 2100 using emulated climate conditions. Probabilistic outputs from these simulations are used to explore whether future dune growth rates are expected to statistically differ from historical rates. The outputs are analyzed to investigate the role of 1) sea level changes, 2) shifts in shoreline change rates, and 3) increases in the frequency of El Niño occurrences on future dune growth.

STUDY AREA

LBP is a 45 km stretch of sandy, prograding coastline in southwest Washington, USA (Fig. 1a). This mesotidal, dissipative setting is exposed to a relatively intense wave climate and is still adjusting to jetty construction at the mouth of the Columbia River over a century ago (Kaminsky et al., 2010). Shoreline change rates (Fig. 1b) vary from a few meters of progradation per year in the south to over 20 m of growth per year in the north (Ruggiero et al., 2013). Varying shoreline change rates paired with long term monitoring of the beaches and dunes (Ruggiero et al., 2005) makes LBP an ideal study area to explore relationships between alongshore variability in sediment supply, dune morphodynamics and climate projections.

METHODS

The Dune Response Tool (DRT) (Cohn, 2021) is a simple geometric model designed to simulate volumetric sediment losses and gains in coastal foredunes from both marine and aeolian processes. The model requires input beach and dune geometry and time series of wind, waves, and water levels. Total water levels are derived by adding dynamic still water levels from the Toke Point and Astoria NOAA tide gauges (Station IDs: 9440910 and 9349040) to calculated wave runup elevations (Stockdon et al., 2006). Wave data for the runup computations are derived from the Center of Australian Weather and Climate Research (CAWCR) and integrated into SWAN (Simulating Waves Nearshore) (Booij et al., 1999) surrogate models to generate nearshore wave predictions. Wind data are retrieved from the closest geographic ERA5 dataset with a resolution of 0.25 degrees. Profile morphometrics are derived from airborne LiDAR to generate synthetic profiles.

We first apply the DRT in hindcast mode to the LBP topographic beach profiles with a combined observational and hindcast data set of water levels, waves, and winds every 250m alongshore from 1997-2022. As part of this hindcasting effort, transport coefficients in the aeolian transport module of DRT are tuned to match net dune growth rates for Oysterville, WA on LBP, where extensive topographic and volume change data exists. The calibrated model is run at the additional alongshore transect locations along LBP and validated against quarterly scale topographic measurements to demonstrate the regional scale of the modeling tool.

We then apply TESLA to create a suite of hypothetical environmental time series. TESLA is a weather-type based stochastic emulator in which annual weather types (e.g., El Niño-Southern Oscillation), intra-seasonal weather types (e.g., Madden-Julian oscillation variability), and daily weather types (e.g., synoptic weather conditions) are defined based on observed atmospheric and oceanographic variables. The TESLA generated time series are used to force hundreds of iterations of the DRT to assess how stochasticity in environmental forcings may influence future predictions of dune dynamics at multi-decadal time scales. These simulations are used to assess how alongshore variability in present-day physical factors such as beach slopes and shoreline change rates, may have an influence on long-term alongshore dune growth rates. Additional exploratory simulations alter shoreline change rates, add expected time-varying sea level rise trends for the Pacific Northwest, and alter El Niño frequency by modifying inputs to TESLA and DRT to further assess future potential climate change impacts to the dunes at LBP.

PRELIMINARY RESULTS

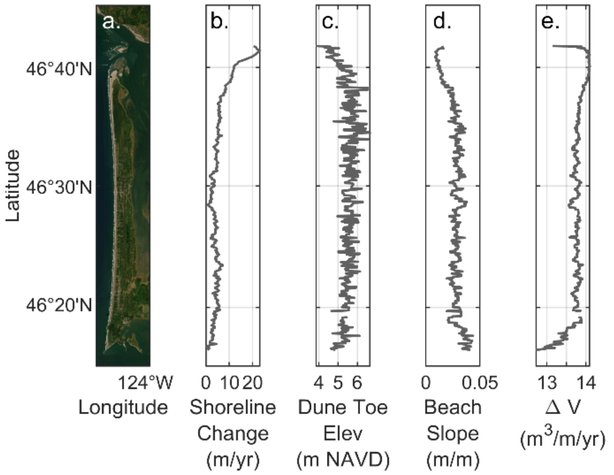

Figure 1 – Map of Long Beach Peninsula, WA (A) with associated shoreline change rates (B), dune toe elevation (C), beach slope (D), and hindcast dune volume change (E).

We use a novel approach to efficiently predict coastal dune evolution over time periods of hours to a century, while accounting for uncertainty in relevant forcing conditions. We compare dune evolution at sites of varying shoreline growth in both the past and the future (e.g., Fig. 1). Consistent with field observations, hindcast simulations show that the dune field in LBP is rapidly growing and the results indicate seasonal and inter-annual variability in net wind-driven dune growth. While the model captures alongshore rates of net dune growth between 12.7 m^3/m/yr to 14.1 m^3/m/yr (Fig.1e), it underestimates alongshore variability relative to field observations. Underestimates are likely related to the assumption of temporally constant beach slopes and dune toe elevations in the simulations. Preliminary model results indicate local rates of shoreline change (proxy for sediment supply) are among the strongest drivers of alongshore variability in dune growth rates at interannual time scales. Shoreline change impacts beach properties (e.g., slope, width) which may influence the likelihood of dune collision by waves and fetch lengths of aeolian transport. At the storm timescale, alongshore variability in net dune change is largely dictated by the dune toe elevation, with the lowest dune toe being the most susceptible to dune volume losses during storms.

Preliminary probabilistic simulations utilizing the combined TESLA and DRT framework similarly show that local morphologic factors are likely to contribute to alongshore variable dune growth rates into the future. The alongshore variability increases when incorporating sea level rise curves in the model, leading to increased frequency of dune collision relative to the baseline case. The net dune growth rates for rapidly prograding (>5 m/yr) sections of coast are not nearly as affected as those sections of coast with stable or only slightly prograding shorelines. The probabilistic outputs show a wide range of potential future outcomes at a particular transect location due to stochasticity in simulated environmental forcings and the sequencing of winds, waves, and tides in individual simulations. This highlights the value of moving away from deterministic simulations alone to guide future vulnerability assessments for beach-dune systems. Collectively, our results can be used to indicate areas of high vulnerability against future threats from climate change.

REFERENCES

Anderson et al. (2019): Time-varying emulator for short and long-term analysis of coastal flood hazard potential, Journal of Geophysical Research, Oceans, vol. 124, pp. 9209-9234.
Booij et al. (1999): A third-generation wave model for coastal regions, Journal of Geophysical Research: Oceans, vol. 104, pp. 7649-7666.
Cohn (2021): Dune Response Tool. Code Repository. https://github.com/erdc/dune-response-tool
Houser et al. (2008): Controls on coastal dune morphology, shoreline erosion and barrier island response to extreme storms, Geomorphology, vol. 100, pp. 223-240.
Kaminsky et al. (2010): Historical evolution of the Columbia River littoral cell, Marine Geology, vol. 273, pp. 96-126.
Ruggiero et al. (2005): Seasonal to interannual morphodynamics along a high-energy dissipative littoral cell, Journal of Coastal Research, vol. 21, pp 553-578.
Ruggiero et al. (2013): National assessment of shoreline change: Historical shoreline change along the Pacific Northwest Coast, U.S. Geological Survey Open-File Report 2012-1007, pp. 62.
Stockdon et al. (2006): Empirical parameterization of setup, swash and runup, Coastal Engineering, vol. 53, pp. 573-588.