OBSERVATIONS AND MODELING OF A HYBRID-DUNE LIVING SHORELINE OVERWASH EVENT AT A LONG-PERIOD SWELL DOMINATED BEACH

Maria A. Winters, University of California, Los Angeles, mariawinters@ucla.edu
Margit Maple, University of California, Los Angeles, margitmaple@gmail.com
Timu W. Gallien, University of California, Los Angeles, tgallien@seas.ucla.edu

INTRODUCTION
Sea level rise will significantly increase the need for building and upgrading coastal protection such as coastal dunes and living shorelines. (Morris et al., 2020). Even if emission goals are reached, most coastlines will experience an increase in mean sea levels and energetic wave events and storms (Morris et al., 2020). Coastal protection measures, such as dune restorations and engineered dunes, are crucial in adaptation efforts worldwide (Temmerman et al., 2013; Morris et al., 2022) and hold many advantages over traditional hard engineering structures such as sea walls. However, at sites with more urgent needs for protection and limited space, hybrid structures offer the benefits of both soft (e.g., dunes) and hard structures, for example hybrid dunes consisting of a sand dune containing a solid structure or rock core (Almarshed et al., 2020).

There is a fundamental knowledge gap regarding the performance and design of hybrid structures (Morris et al., 2022; Almarshed et al., 2020) and a need for observations and case-studies. In this study, data from five years of hybrid dune living shoreline observations are presented, including performance during a historic 20-year wave event on an intermediate, long-period swell beach. Morphological models are tested on a hybrid-dune erosion and overwash event and compared to high resolution morphological field observations.

METHODS
Cardiff State Beach, located in Southern California, United States, is a low-lying sand spit located between the San Elijo Lagoon and the Pacific Ocean. The site is backed by critical transportation corridor Highway 101 and is highly vulnerable to high tides and energetic waves. To serve as a sea-level rise adaptation strategy, protect the highway, and provide native dune habitat, a hybrid-dune living shoreline structure was constructed in 2019. The central protective feature is a novel hybrid sand-cobble-rock dune design that consists of large riprap buried by a sand berm with a native cobble toe, planted with native vegetation (Winters et al., 2020).

In January 2023, Southern California experienced a historic energetic storm (H_s ~4 m, T_p ~20 s), resulting in large-scale flooding and erosion across the coastline. Uncrewed aerial vehicle (UAV) surveys conducted pre- and post- storm reveal Cardiff State Beach experienced up to ~10 meters of sand loss in the horizontal along with about 5-7 meters of loss in the horizontal at the toe. The buried cobble berm experienced significant exposure and erosion (Figure 1a), and the riprap core was exposed at some portions of the dune. Additionally, the dune structure experienced significant overwash onto the highway across the length of the project.

The analytic wave impact model by Larson et al., 2004 (LE04) has been used to model sand dune toe retreat and volume loss (e.g., Splinter and Palmsten, 2012). Models such as XBeach-G (McCall et al., 2014) and CSHORE (Kobayashi and Kim, 2017) have been previously utilized to more specifically model cobble beach and dune-buried sea wall erosion, respectively. Dune volume change and toe retreat during the storm duration (from the pre-storm UAV survey date to post-storm survey date) were estimated first using the LE04 model for initial skill on this mixed sand substrate structure at a single cross-shore location.

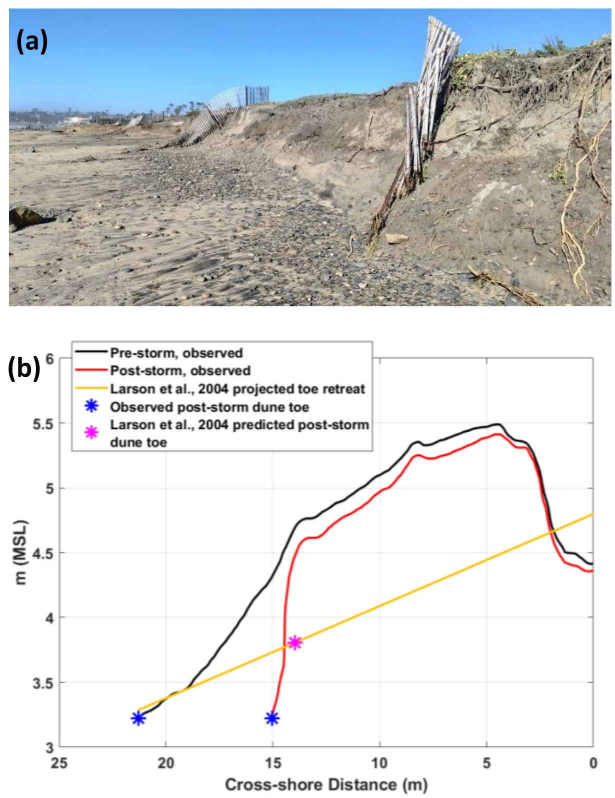

Figure 1 - (a) Photo of hybrid dune structure erosion post-storm (b) Selected cross-shore profile from the study site depicting pre- and post-storm dune and beach topography measured by UAV surveys, as well as predicted dune toe retreat predicted by the Larson et al., 2004 model.

PRELIMINARY RESULTS
The observed dune volume loss was ~5.07 m^3/m, while the LE04 model predicted a volume loss of 3.77 m^3/m. The modeled post-storm dune retreat is shown in Figure 1b. LE04 assumes a constant toe retreat slope and constant

water level, possibly accounting for the underestimation of the dune volume loss.

ONGOING AND FUTURE WORK

Future modeling efforts are planned. XBeach-G and CSHORE will be tested, and because at present these models do not resolve multi-substrate hydromorphodynamics, a hybrid modeling framework will be created for this site. There are limited modeling applications of these hybrid dune structures in the literature, and ultimately, this work will be used to help develop, implement, and test the effectiveness of dune restoration and living shorelines as a sea-level rise adaptation strategy.

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