PREDICTING SEA TURTLE NEST FLOODING ON SANDY BEACHES

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INTRODUCTION

Sea turtles depend on sandy beaches around the World for their nesting habitat. They face a major challenge due to flooding and erosion of their nesting beaches. Turtle nests incubate under the sand surface for six to eight weeks until hatching. During this time, high tides, storm surges, wave runup, and elevated groundwater levels can inundate incubating nests, significantly increasing egg mortality (Patricio et al., 2021). Even the capillary fringe can potentially deprive incubating eggs from oxygen. Furthermore, sand moisture content influences the sand temperature in the nests, which determines the sex of the hatchling turtles.

Nature-based solutions—for example, through turtle-friendly design of sand nourishments—may offer promising opportunities to preserve and even expand nesting habitats. To help design such nature-based solutions, this study aims to create a predictive modelling tool to assess the risk of nest inundation on sandy beaches for different profile shapes and hydrodynamic conditions.

CASE STUDY

Galveston Island's beaches in Texas serve as important nesting habitat for the critically endangered Kemp's ridley sea turtle (*Lepidochelys kempii*). Though the area is currently not part of the species' primary nesting sites, which lie further south (Culver et al. 2020), its geographic location may enable it to become an important future climate refuge. However, its beaches are characterized by continuous erosion and frequent (tidal) inundation (Davlasheridze et al., 2019). Therefore, the Gulf Center for Sea Turtle Research currently excavates and moves all encountered nests to the Padre Island National Seashore incubation facility.

The coastal region around Galveston Bay, including the Houston metropolitan area, has suffered severe flooding and erosion from past hurricanes. In response, large-scale coastal protection interventions, including sand nourishments and engineered dune systems along Galveston Island, are planned (USACE and GLO, 2021). These plans offer a unique opportunity to implement new multi-functional nature-based solutions in a large-scale coastal protection plan. Functional requirements of these future climate proof designs are improving flood safety and enhancing the ecosystem–for example through nourishments that provide optimal turtle nesting habitat.

FIELD EXPERIMENT

To calibrate and validate the predictive modelling tool, we set up a field experiment on Galveston Island in the fall of 2023. We monitored beach profiles, nearshore hydrodynamics, ground water dynamics, and sand temperature and moisture content along two different

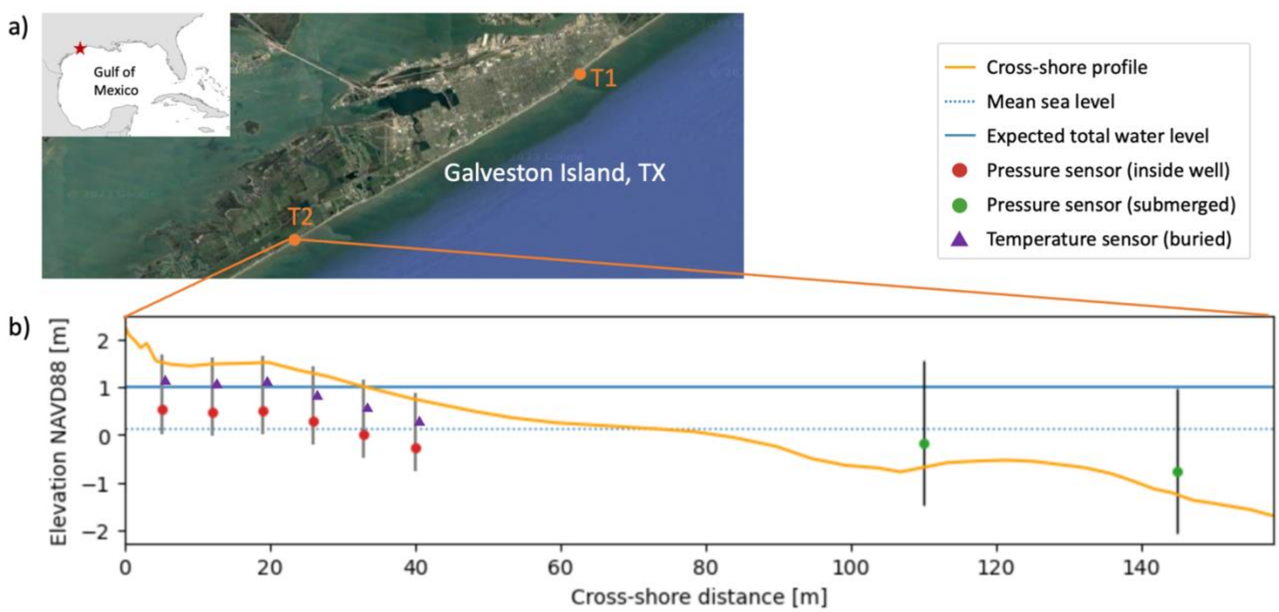

Figure 1 - a) Overview of the two field sites on Galveston Island, and location of Galveston in the Gulf of Mexico; b) Experimental setup of the pressure and temperature sensors for one of the deployments at site T2.

beach transects: a frequently nourished location (T1), and a more natural beach (T2, Figure 1a).

On each transect, we deployed an array of six slotted PVC wells, ranging from the dune toe (where most turtles nest) to the high tide line (Figure 1b). Each well was equipped with a pressure sensor at ≈1m below the surface to monitor groundwater fluctuations. Next to each well, we buried a temperature sensor in the sand, at a typical nest depth (40cm), to correlate temperature drops to inundation events. We also deployed a vertical array of moisture and temperature sensors near the dune toe, to monitor the characteristics of the capillary fringe.

We deployed two submerged pressure sensors in the surf zone to monitor incoming waves and water levels, along with two wave buoys 1.5 km off the beach to measure offshore wave conditions. To link wave action to ground water fluctuations in the swash zone, we made video recordings of wave runup with GoPro cameras. Finally, we took sediment cores and GPS measurements of the beach profile to derive sediment characteristics that could be important to the groundwater dynamics and monitor the evolution of the cross-shore profile.

PREDICTIVE MODEL

The field data is used to calibrate a 1D non-hydrostatic XBEACH model coupled with groundwater modelling, to predict, wave runup, surge, groundwater levels, and sand moisture content along the beach profile (Figure 2). While the XBEACH model can predict the groundwater table, we use empirical formulations along with the field data to estimate the thickness of the capillary fringe. Inundation events are detected whenever the ground water table and/or capillary fringe reach above the nesting depth.

We apply machine learning to derive characteristic sea states during the nesting season, which are used to force the model. The outputs of these model scenarios are used to make a probabilistic risk assessment of nest inundation for the given beach profile. Once the model is validated on the field data, we can change the beach profile to simulate different nourishment strategies and assess the impact on nest flooding likelihood.

OUTLOOK

The resulting predictive model can be used (i) directly by coastal managers to make informed decisions regarding whether to relocate or leave turtle nests in situ; and (ii) in the long-term to help design and implement beach nourishment strategies that provide optimal nesting habitat for sea turtles, like the critically endangered Kemp's ridley.

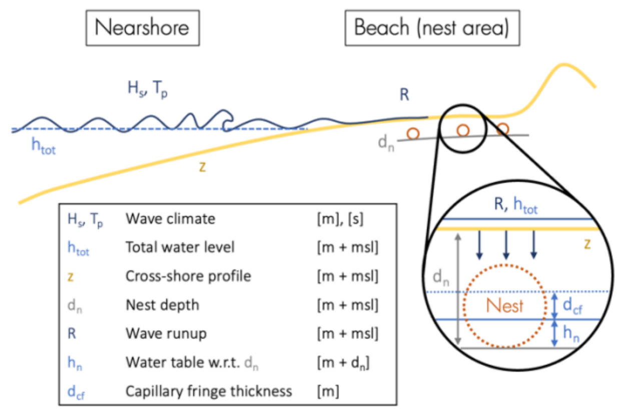

Figure 2 – Overview of relevant processes in the predictive model. The XBEACH model takes the beach profile (z) and offshore conditions as input and predicts the total water level (h_{tot}) and wave runup (R) at the beach. It is coupled with groundwater modelling to derive the groundwater table (h_n) and capillary fringe thickness (d_{cf}).

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