Exploring the role of vegetation and sediment supply to coastal dune states using integrated process-based modelling

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Introduction – objective

- Complex adaptive systems may exhibit a range of assembly “states or stability domains” (sets of unique biotic and abiotic conditions) derived from non-linear interactions among their components (Perry, 1995; Levin, 1999). Transitions occur from one state to another, in what is known as a state shift and occurs when the system is “perturbed”.

- Coastal dune morphology is controlled by complex interactions and feedbacks between sediment transport and vegetation cover, displaying a continuum of topographic states that determine system resilience.

- Coastal dune morphology is key to achieve maximum efficiency of nature-based solutions. Therefore, developing approaches that integrate processes that are key to coastal dune morphology becomes crucial to efficiently design and test solutions that meet the timescale requirements of coastal management.

- The process-based XBeach-Duna model has been developed to integrate nearshore, aeolian and ecological processes across the beach-dune profile, thus allowing long-term simulation of complex coastal features and feedbacks.

- The potential of XBeach-Duna model to simulate the morphological response of coastal dunes to changes in sediment supply and vegetation cover over decadal timescales is examined here.
**Problem setting**

**THE CHALLENGE**

Can we reproduce the response to perturbations of highly intricate systems such as coastal dunes where morphology results from complex interaction between marine, aeolian and ecological processes?

**THE APPROACH**

![Diagram showing the model execution loop with input, initialization, and flow hotstart file](Diagram.png)

*Input:*
- wave and SLs
- winds
- calibration parameters

*Initialisation (from previous time step):*
- flow conditions
- bed level update

*XBeach*

*flow hotstart file*

*bed level*

Roelvink & Costas (2019)
The study area is Praia de Faro (Faro Beach) in the eastern part of Ancão Peninsula (W end of the Ria Formosa barrier system in S. Portugal; Figure).
The area is characterised by a **steep beach-face**, with average slope around 10%, varying from 6% to 15% (Vousdoukas, Almeida, & Ferreira, 2012), coarse to medium sand and multiple foredune ridges with relatively low vegetation density.

**CROSS-SHORE PROFILE**

Evolution of the profile between November 2009-November 2011

1. Former and fixed dune ridge
2. First active foredune
3. Second active foredune
Meteocean forcing

- Meteocean conditions for the period November 2009- November 2011

- Storm threshold = 2 m
- Critical for aeolian transport = 9.25 m/s

Wave Hindcast

Wind Observations
The approach

- Schematisation of meteocean (wave and wind) conditions for the period November 2009 - November 2011.

- Intra- and Interannual variability;
- Moderate waves (green bars) $H_0 < 2m$
- Storms (blue bars) defined by $H_0 > 2m$
- Winds (orange bars) above critical velocity
- Morfac parameter; moderate (25) and storms (5)
- Bermslope parameter (0.12)

Input:

Process-based models:

<table>
<thead>
<tr>
<th>Model</th>
<th>Parameters</th>
<th>Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td>$V_{10m}$ dir</td>
<td>1D Duna</td>
</tr>
<tr>
<td>Storm waves</td>
<td>$H_0 T_p$ dir $z$</td>
<td>1D XBeach (surfbeat mode)</td>
</tr>
<tr>
<td>Moderate waves</td>
<td>$H_0 T_p$ dir $z$</td>
<td>1D XBeach (stationary mode)</td>
</tr>
</tbody>
</table>
The approach

- Simulations run for ...

1) Testing the effect of variable sediment supply and wind strength on beach-dune profile evolution over 20 years
   - Runs with variable longshore gradients and wind magnitude

<table>
<thead>
<tr>
<th>DUNA &amp; XBEACH</th>
<th>longshore gradient (LS in $10^{-4}$ m$^{-1}$) (progradation rate m/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-2</td>
<td>2</td>
</tr>
<tr>
<td>(-5 m/yr)</td>
<td>(5 m/yr)</td>
</tr>
<tr>
<td>5</td>
<td>(11 m/yr)</td>
</tr>
</tbody>
</table>

2) Testing the effect of different functional vegetation types on beach-dune profile over 20 years
   - Runs with variable vegetation growth rates

<table>
<thead>
<tr>
<th>DUNA &amp; XBEACH</th>
<th>vegetation growth rates</th>
</tr>
</thead>
<tbody>
<tr>
<td>very low</td>
<td>standard</td>
</tr>
<tr>
<td>very high</td>
<td></td>
</tr>
</tbody>
</table>
Testing the effect of variable sediment supply on the 1D beach-dune profile by changing longshore gradients (LS) and progradation rates (PR)

- LS = $-2 \times 10^{-4}$ m$^{-1}$
- PR = -5 m/yr

<table>
<thead>
<tr>
<th>LS</th>
<th>PR</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>-2x10$^{-4}$ m$^{-1}$</td>
<td>-5 m/yr</td>
<td>Narrow ridge – close to cross a threshold – with relative increase in elevation</td>
</tr>
<tr>
<td>2x10$^{-4}$ m$^{-1}$</td>
<td>5 m/yr</td>
<td>One large new dune ridge similar to former ridge (1)</td>
</tr>
<tr>
<td>5x10$^{-4}$ m$^{-1}$</td>
<td>11 m/yr</td>
<td>Multiple and low dune ridges resembling ridges (2) and (3)</td>
</tr>
</tbody>
</table>

*The calibration of modelling parameters was done using the evolution of the profile observed between 2009 and 2011. Simulations used the same parameters and the schematized meteoccean conditions between 2009 and 2011 repeated 10 times to simulate 20 years of change*
Results

- Testing the effect of different vegetation functional groups (i.e. dune builders, burial tolerant and burial intolerant) on the 1D beach-dune profile as well as possible environmental changes that may modify vegetation growth (e.g. precipitation)

<table>
<thead>
<tr>
<th>GR</th>
<th>PR</th>
<th>New state (transgressive dunes) after system perturbation</th>
<th>One single ridge state dominated by dune builder plant communities</th>
</tr>
</thead>
<tbody>
<tr>
<td>very low</td>
<td>5 m/yr</td>
<td>Growth rate drops (e.g. very low precipitation)</td>
<td>Shift in plant communities to burial intolerant</td>
</tr>
<tr>
<td>high</td>
<td>5 m/yr</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The approach was tested to reproduce the natural response to changes in sediment supply, shifting the shoreline position and simultaneously modifying the overall shape of the dune, within a range of dimensions that are in agreement with observations.

In general, narrow and low dunes are formed under high supply conditions, wide and high dunes develop if sediment supply is low and the shoreline position stable, while narrower and higher dunes are created after a relative drop in sediment supply that induces a negative budget.

The approach was able to reproduce different states as a consequence of changes in the feedbacks between morphology and plants community. The latter tentatively represented shifts in vegetation functional types provoked by perturbations affecting the system.

Denser and healthier vegetation coverage favours taller dune morphologies while weak vegetation cover may favour the formation of transgressive dunes and inland transference of sand.

The results demonstrate the capacity of the approach to reproduce different dune states, resulting from alternative evolutionary pathways, and its potential to identify coastal dune (in)stability domains and critical morphological shifts, factors that are key to better understand the efficiency of dunes as nature-based solutions for coastal management.

Future steps will include the explicit introduction of different vegetation functional groups and real meteocean conditions.
References


Acknowledgments

The work was implemented in the framework of the ENLACE project (ref. 28949 FEDER), funded by FCT (Fundação para a Ciência e a Tecnologia, Portugal.)