Restoration of over-stablised coastal foredunes using excavated foredune notches

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Introduction

In recent decades, coastal foredunes on developed coasts have been managed to maximise vegetation cover and stability, and to increase dune height and uniformity, with the goal of reducing coastal flooding. Consequently, many foredunes are now relatively densely vegetated, high and narrow ridges of sand compared with their dynamic pre-managed form; particularly where native species have been replaced by marram grass. Such foredunes may protect the hinterland from marine flooding, but they also block sand exchange between the beach and the backdune. Therefore such foredunes may be less able to migrate landward in response to increased scarping related to ongoing eustatic sea-level rise. Paradoxically, the current 'stable' foredunes, which were developed to manage coastal hazards, might be both more vulnerable to erosion and susceptible to sea-level rise.

Excavation of 'notches' in foredunes – which are essentially artificial blowouts – aims to facilitate sand transport through the foredune to achieve a range of management objectives. Notches have been mainly used in Europe to enhance the biodiversity of the backdune environment where stability has resulted in a loss of habitat for indigenous species. The excavation of foredune notches to facilitate foredune landward migration, and increase foredune resilience to erosion, has been generally proposed. However, to date there has been no consideration of optimal notch morphologies to maximise sedimentation in a range of prevailing wind conditions.

The current study examines flow-form-sediment transport interactions in excavated foredune notches at St Kilda, Dunedin, New Zealand. St Kilda beach is a good example of a dune system that has undergone stabilisation to protect infrastructure and is now experiencing persistent erosion. The morphodynamics of excavated foredune notches are controlled by complex interactions between wind flow, notch morphology, and sand transport (Figure 1). The 'successful' excavated notch morphology (Figure 1a) might facilitate flow steering and acceleration from the beach to the notch in a range of incident wind conditions. In ideal conditions, high speed onshore winds should transport sand well inland of the foredune crest. In contrast, 'unsuccessful' notch morphologies (Figure 1b) result in flow deceleration and sand deposition inside the notch. In the long term, notch in-filling might occur, requiring the notches to be re-excavated.

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Methodology

The recent study used a range of methods for data collection. Wind flow through the notch was measured in the field using ultrasonic anemometers. Sand transport was measured during the wind events using sand traps and laser particle counters (LPC) (Figure 2). Event-scale notch morphodynamics were measured using erosion pins and RTK-GPS. Moderate-scale (months) landscape morphodynamics were described using Unmanned Aerial Vehicles (UAV, or drone). Ten field-based experiments were conducted at different locations in the St Kilda dune system (for example, notch throat, notch

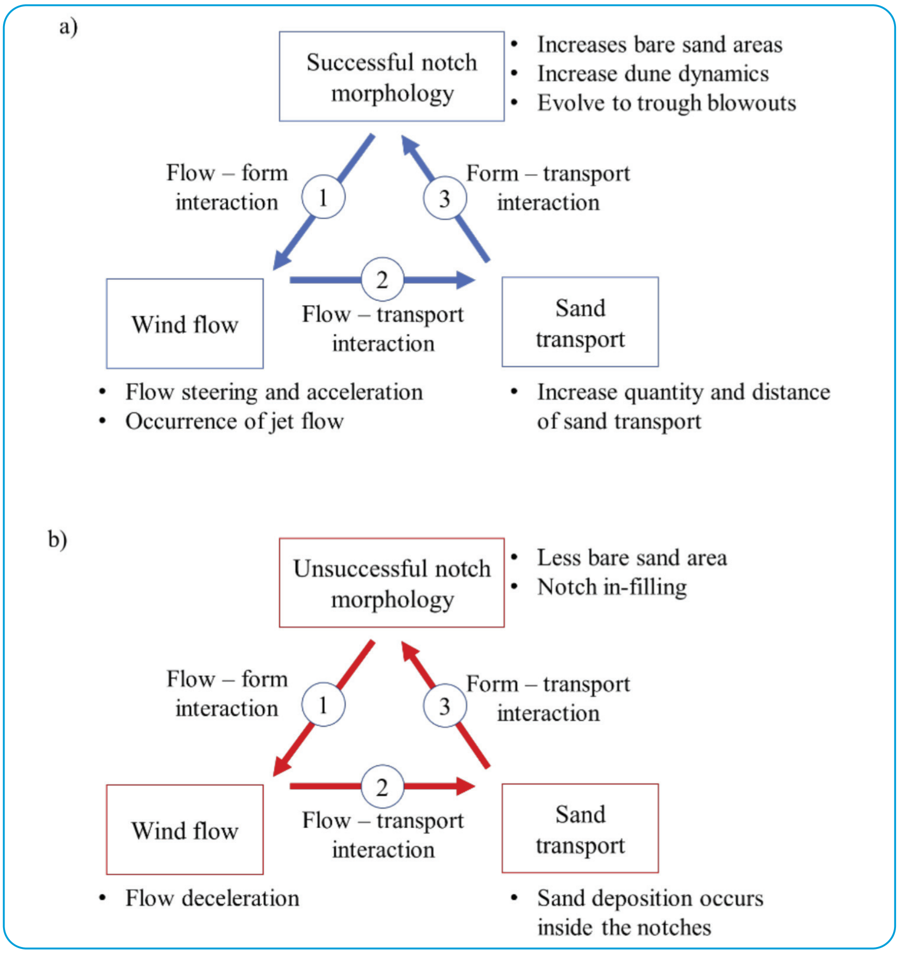

Figure 1: Complex interactions between excavated notch morphology, wind flow and transport (flow-form-transport interactions). The 'successful' notch morphology facilitates flow steering acceleration from the beach to the notches, thus increasing sand transport to the backdune (a). The 'unsuccessful' notch morphology results in flow deceleration and notch in-filling (b) (Nguyen, 2022).

Figure 2: Field-based experiment at Notch C, St Kilda, Dunedin using an array of ultrasonic anemometers (black) and a particle sand counter (LCP) (blue) (Nguyen et al., 2021).

crest) during various incident winds (for example, westerly and south-westerly winds) to capture the effects of various environmental conditions. These landscape morphodynamics were monitored over four years to quantify the long-term evolution of foredune notches and their effectiveness in destabilising sections of the foredune system.

The study combined field-based measurements with Computational Fluid Dynamics (CFD) modelling to examine wind flow dynamics over the complex dune landscape. Field-based wind measurements were used to validate the modelled wind simulated on CFD to select the best model setup (for example, domains, mesh size). The modelled winds were used to provide the results at the landscape scale (for example, at the locations that are not measured using anemometers) over a variety of incident wind conditions (measured on a high mast above the foredune). Overall, combining field-based experiment and CFD is a valuable approach to such problems and questions.

Results and implications

The current study found that excavated foredune notches result in wind flow steering from the beach through the notches to the backdune (Figure 3). Flow acceleration (speed-up) and deceleration (speed-down) from the beach to the notches occurs when the obliquity of incident wind angles to the notch axis decreases and increases, respectively. These results provide insights into the effectiveness of the excavated notches (Figure 4). For example, at St Kilda where the prevailing winds are alongshore and highly oblique onshore, sand transport is generally alongshore. The notches encourage sand transport and sand deposition behind the foredune when the winds are oblique onshore when otherwise sand transport would remain alongshore.

The current study also provides guidance to coastal managers in the design of excavated foredune notches. Flow deceleration occurs from the beach to the notches if the notches are excavated at a high oblique (angle) to the prevailing wind direction. This situation results in lower wind speeds inside the notch and lower rates of sand flux, resulting in sand deposition and notch-infilling. Notches should be excavated so that their long axis is almost parallel to the prevailing wind direction to facilitate flow acceleration and maximise sand transport to the backdune. For example, the angle between the long axis of notch C at St Kilda and incident wind direction should be less than 27° to promote flow acceleration from the beach through the notch.

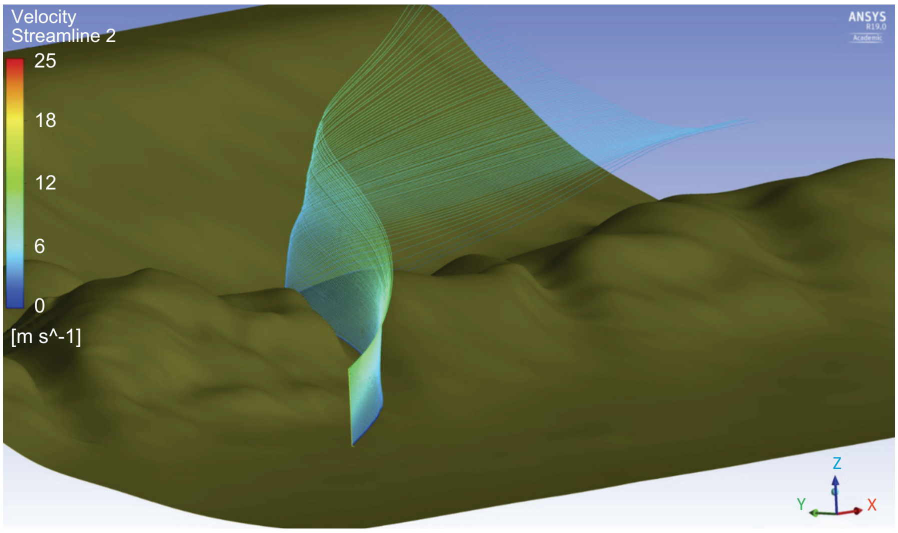

Figure 3: Computational Flow Dynamics (CFD) wind flow modelling during oblique onshore incident wind conditions. The excavated foredune notches result in flow steering from the beach through the notches to the backdune.

On-going and future work

The coastal research group at the University of Otago has been continuing with this work, supported by the Coastal Programme of the Resilience to Nature's Challenges, Kia Manawaroa – Ngā Akina o Te Ao Tūroa and Dunedin City Council. A key focus is how to utilise this method on metropolitan coasts where foredunes are confined by hinterland infrastructure, and where the potential for foredunes to migrate is limited. The St Kilda study indicates that the rate and direction of sand transport through notches, and hence foredune evolution, can be controlled through careful notch design. In such circumstances it may be advantageous to achieve 10% or 20% 'rollback', over periods of years to decades, while longer-term solutions are designed and implemented.

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Recent publications

Nguyen, D, Hilton, M, and Wakes, S (2022a). Wind flow dynamics and sand deposition behind excavated foredune notches on developed coasts. *Earth Surface Processes & Landforms 47*. doi: 10.1002/esp.5341

Nguyen, D, Hilton, M, and Wakes, S (2022b). Aeolian sand transport thresholds in excavated foredune notches. *Earth Surface Processes & Landforms* 47, 553-568. doi: 10.1002/esp.5271

Nguyen, D, Hilton, M, Wakes, S, and Simons-Smith, T (2021). Incident wind angle and topographic steering through excavated foredune notches. *Geomorphology* 392, 107982. doi: 10.1016/j.geomorph.2021.107982

Nguyen, D (2022). *Wind flow dynamics and sand transport through excavated foredune notches* (PhD Thesis). University of Otago. http://hdl.handle.net/10523/12831

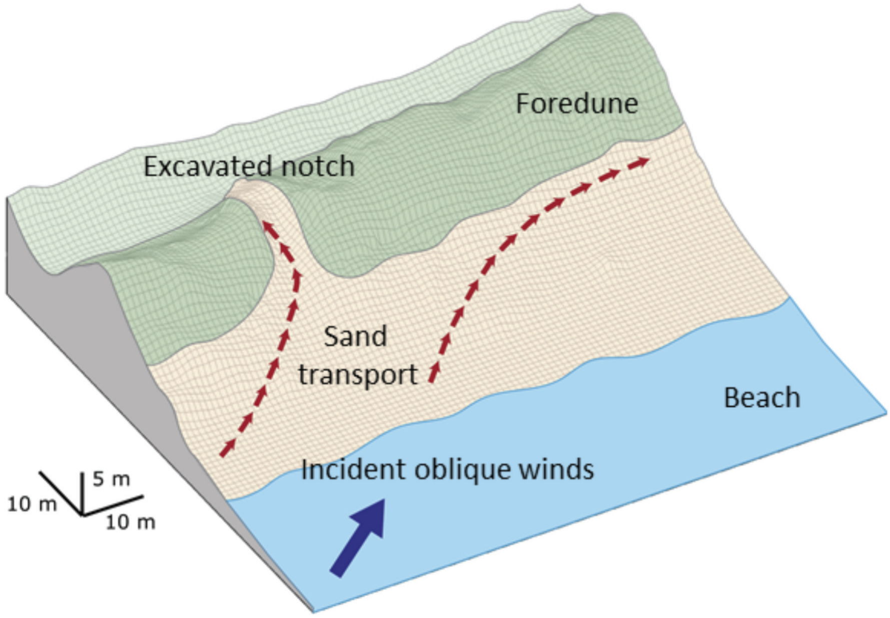

Figure 4: Conceptual model of aeolian sand transport through an excavated notch and along a section of intact foredune during highly oblique onshore winds (Nguyen et al., 2022a,b).

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