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Coastal dune dynamics in response to excavated foredune notches

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ABSTRACT

Dune management along developed coasts has traditionally focussed on the suppression of the geomorphic dynamics of the foredune to improve its role in sea defence. Because a stabilized foredune acts as an almost total barrier to aeolian transport from the beach, the habitat diversity in the more landward dunes has degraded. With the overarching objective to mitigate this undesirable loss in biodiversity, dune management projects nowadays increasingly intend to restore aeolian dynamics by reconnecting the beach-dune system with notches excavated through the foredune. Here, we use repeat topographic survey data to examine the geomorphic response of a coastal dune system in the Dutch National Park Zuid-Kennemerland to five notches excavated in 2012–2013 within an 850-m stretch of the 20-m high established foredune. The notches were dug in a V-shape (viewed onshore), with a width between approximately 50 and 100 m at the top, a (cross-dune) length between 100 and 200 m, and excavation depths between 9 and 12.5 m. The 1 × 1 m digital terrain models, acquired with airborne Lidar and UAV photogrammetry, illustrate that during the 3-year survey period the notches developed into a U-shape because of wall deflation, and that up to 8-m thick and 150-m long depositional lobes formed landward of the notches. Sand budget computations showed that the sand volume of the entire study area increased by about 22,750 m^3/year, which, given the 850-m width of the study area, corresponds to an aeolian input from the beach of approximately 26.5 m^3/m/year. Between 2006 and 2012 all wind-blown beach sand deposited on the seaward side of the foredune; since 2013, the notches have caused 75% of the sand to be deposited landward of the foredune. This highlights that the notches are highly effective conduits for aeolian transport into the back dunes. Future monitoring is required to determine for how long the notches will stimulate aeolian dynamics and if (and when) vegetation eventually starts to regrow and enforces the degeneration of the notches.

1. Introduction

Coastal dunes are natural, intrinsically important landform units in the coastal system and provide a wide range of benefits to humankind (e.g., Everard et al., 2010). For example, they act as a vital natural safety barrier against marine flooding, are valuable natural environments, serve for the production of drinking water, and offer recreational opportunities. The safety function has dominated dune management along low-lying developed shores for decades (Arens and Wiersma, 1994; Jackson and Nordstrom, 2011). Planting vegetation is a common practice to increase height and volume of the foredune (e.g., Van der Putten and Peters, 1995; Nordstrom and Arens, 1998). The resulting dune stabilization is considered crucial to safeguard coastal dune systems and low-elevation coastal areas against expected increases in erosion because of global-change induced rising sea levels and potential changes in storm characteristics (e.g., Sigrin et al., 2014; Feagin et al., 2015). While foredune stabilization substantially reduces the risk of marine flooding of the hinterland, it also degrades aesthetic and natural values and markedly reduces species diversity in the back dunes (Martínez et al., 2013). The dense vegetation cover on a managed foredune acts as a barrier to the aeolian throughput of sand from the beach into the back dunes (e.g., Petersen et al., 2011), where spatio-temporal dynamics have thus become limited and ecological succession is no longer locally reset by sand burial. Consequently, many back dune systems suffer from the encroachment of tall grasses and shrubs (e.g., Veer and Kooijman, 1997; Van Til et al., 2002; Hilton, 2006; Lammerts et al., 2009; Pye et al.,

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2014) and reduced biodiversity. This is further exacerbated by increased atmospheric nitrogen deposition, changed land use within the dune system, reduced disturbance by rabbit populations, and stabilization of local bare-sand areas (e.g., Nordstrom and Lotstein, 1989; Provoost et al., 2011). The encroachment by tall grasses and shrubs further reduces the amount of sunlight reaching the surface and potentially causes (internal) soil acidification, which is strongly disadvantageous to the endemic dune flora (Kooijman, 2004). The blocked aeolian input of sand also prevents the back dunes to grow vertically with sea-level rise, which may endanger future coastal safety (Arens et al., 2013).

Since the late 1980s a wide variety of measures to maintain or, preferably, improve coastal-dune biodiversity have been attempted (see Lithgow et al., 2013, for a review). In the Netherlands, which holds major responsibility for the preservation of coastal-dune biodiversity within Europe because of its spatially extensive dune fields, initial measures aimed at resetting ecological succession through the removal of vegetation and topsoil in dune slacks (e.g., Jungerius et al., 1995). While some measures were, at least in part, successful (Grootjans et al., 2002), awareness grew that restored ecosystems could be self-maintaining (i.e., demanding no or minimal further management) when aeolian dynamics are re-established (e.g., Arens and Geelen, 2001). This started with the restoration of individual blowouts, but its impact on landscape-scale aeolian dynamics and hence ecology proved to be minimal (Van Boxel et al., 1997). Landscape-scale measures, such as the reactivation of parabolic dunes by vegetation removal, increased aeolian dynamics dramatically during the first few years (Arens et al., 2004), resulting in the desired burial of tall grasses and shrubs downwind and thus in the development of more diverse habitat types. However, these interventions have not been self-maintaining (Arens and Geelen, 2006; Arens et al., 2013). Most sites began to stabilize because of vegetation regrowth from remaining rhizomes and the seed bank, and the reduction in aeolian erosion through the formation of a lag of dead root material. In line with an international management shift toward more foredune dynamics (e.g., Jackson et al., 2013; Walker et al., 2013; Pye et al., 2014; Konlechner et al., 2015; Darke et al., 2016), the present Dutch dune management strategy seeks to connect landscape-scale restoration efforts of back dunes with the beach-foredune system through the excavation of foredune notches (e.g., Arens et al., 2012, 2013; Kuipers, 2014). In this way, one of the major causes of ecosystem degradation in the back dunes is removed, potentially providing a self-maintaining ecosystem with minimal need for further management (Elliott et al., 2007). It is expected that notches will act as a conduit for the transport of wind-blown beach sand to the back dunes. Potentially, the notches could develop into more natural, self-maintaining foredune gaps, ensuring a sustained influx of calcareous beach sand. Furthermore, the notches may produce harsher living conditions in the back dunes (e.g., higher wind speeds and salt spray), increasing aeolian dynamics and impeding vegetation regrowth on reactivated areas.

An increasing number of coastal restoration projects involve excavating foredune notches, however, experience with their performance is limited. Meerkerk et al. (2007) examined the sand transport dynamics through a single 60-m wide gap in the foredune near Schoorl, the Netherlands, that was excavated to a depth that would allow marine flooding during severe storms. However, wind-blown beach sand quickly filled the gap. Aeolian dynamics was found to be at a maximum 3 years after the excavation, with calcareous beach sand blown up to 350 m inland. However, aeolian processes then diminished as vegetation started to grow in the (almost) closed gap. Schupp et al. (2013) reported on 14 30-m wide notches cut through a low, constructed foredune at Assateague Island, Maryland, USA, to stimulate overwash processes. Although some of the sediment subsequently deposited on the island's interior may have been aeolian in nature, this was not further investigated. Pye and Blott (2016) examined the evolution of 27 notches at 3 sites in Wales, which had typical (alongshore) widths of 20–30 m, lengths between 22 and 185 m, and maximum excavation depths between 0.2 and 8 m. The occasional shallow excavation depths were imposed to prevent marine flooding during severe storms. Following their excavation, all notches were seen to deliver sand inland, deposited as lobes at the landward notch ends. The degree of aeolian dynamics depended on the beach sediment budget. In general, the largest dynamics were observed where notches fronted rather wide, high beaches (i.e., positive beach sediment budget). Notches that forced the wind to accelerate because of, for example, a convex notch floor or notch narrowing in the landward direction, were more effective in stimulating landward aeolian transport (Pye and Blott, 2016). Finally, Riksen et al. (2016) measured an influx of sand through three notches on the barrier island of Ameland, the Netherlands, to some 50 m from the foredune crest. They ascribed this rather limited distance to the small width (about 20 m) of the notches and their large alongshore separation.

The aim of this paper is to quantify and interpret the geomorphic dynamics of a (fore)dune system in response to the excavation of five notches in the approximately 20-m high foredune of National Park Zuid-Kennemerland, the Netherlands. In comparison to the notches mentioned above, the present notches are relatively closely spaced (the study site measures 850 m in the alongshore direction), wide (50–100 m at the top), and deep (maximum excavation depths of 9–12.5 m). After a brief description of the study site and the restoration project (Section 2), the airborne-Lidar and UAV-photogrammetry methodology adopted to collect topographic surveys during the 3-year observational period is outlined, including an assessment of survey accuracy (Section 3). Two-dimensional (2D) profiles and three-dimensional (3D) digital terrain models are used to quantify geomorphic changes and sand budget responses on the seaward slope of the foredune, in the notches, and in the dunes further landward (Section 4). In Section 5 we discuss the notches' potential future evolution. The main conclusions of our work are stated in Section 6.

2. Study area

The study area is an approximately 850-m stretch of frontal coastal dunes located in the National Park Zuid-Kennemerland (NPZK) near Bloemendaal, the Netherlands (between regional beach poles with km-indication 59,25 and 60,25). A continuous, approximately 20-m high established foredune existed along the entire study area prior to notch excavation (Fig. 1a). The foredune was almost fully covered by European marram grass (*Ammophila arenaria*) and resembled a linear sand dyke because of decades of management to minimize sand loss (e.g., Klijn, 1981; De Ruig and Hillen, 1997). Management measures, carried out by the Rijnland District Water Control Board until 1984 (Arens, 1999), consisted of the adjustment of the seaward foredune slope with ground-moving equipment, the planting of marram grass and the placing of sand fences (Bochev-van der Burgh et al., 2011). The cessation of management measures in 1984 has given the foredune a slightly more natural look (e.g., the formation of embryo dunes) compared with the coast a few kilometers to the south, where management persisted until 1990 (Arens, 1999). The sediment budget at the site has been moderately positive for the last decades (Luijendijk et al., 2011). To provide insight into foredune dynamics in the years leading up to notch excavation, we examined annual airbone Lidar surveys (see Section 3.1 below for details) available on a 1 × 1 m grid since 2006. During the period 2006–2012 surface elevation z (with respect to Mean Sea Level, MSL) changed most