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Foredune morphological changes and beach recovery from the extreme 2013/2014 winter at a high-energy sandy coast

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ABSTRACT

The beach-dune response at Truc Vert, SW France, is analysed using DGPS topographic surveys sampled every 2–4 weeks covering an alongshore distance of 1.5 km, combined with wave, tide and extreme water level hindcast and beach/dune photographs. During the 2013/2014 winter, which was the most energetic since at least 1948, the beach-dune system at Truc Vert eroded by approximately 180 m^3 per beach width divided equally between beach and dune erosion. Beach and dune erosion was strongly variable alongshore, with cuspate-type rhythmic dune erosion scarps stripped of vegetation with a cross-shore amplitude of 25 m. The alongshore-variable scarps were coupled with an alongshore variability in elevation of the beach, with lower beach levels co-located with the megacusp bays. The following 10 months showed modest morphological beach and dune changes with, for instance, destabilisation of the scarped dune by trough blowouts, scarp slumping and filling and seasonal beach berm dynamics. The most profound morphological and vegetation changes occurred during the subsequent 10 months. Only 1.5 years after that winter, the beach-dune system at Truc Vert almost recovered to its pre-winter volume, but not to its pre-winter foredune profile. Most of the sand volume recovery occurred during spring-summer-autumn 2015 when approximately 120 m^3/m of sand naturally came back in the system. The beach volume recovery rate was relatively steady and uncorrelated with wave conditions, with rates twice as large across the megacusp bay profile as across the that of the megacusp horns. During that period, the widened and risen dry beach provided large fetch length enhancing onshore windblown transport and a rapid rising of the backshore. The slumped and filled dune scarp, which was providing a high barrier to aeolian transport from the beach to the dune since the 2013/2014 winter, reformed as a dune ramp providing efficient conduit for beach-dune delivery/exchange of sediment by the end of the study. This process favoured both natural revegetation into the scarp and incipient foredune formation. Despite the reinstatement of natural processes between the beach and the dune, the dune foot was still located landward by more than 10 m on average with respect to its pre-2013/2014 winter position. This study shows that even after the most severe winter over the last 68 years in terms of average wave energy arriving at the coast, beach recovery can be a relatively fast process along high-energy sandy beaches backed by large dunes. In contrast foredune recovery, which timing and magnitude can provide a proxy measure for the resilience of the system to climatic variability and change, is a much slower process that can take years to decades.

1. Introduction

Sandy beaches and coastal dunes act as both an efficient and natural flooding protection to the hinterland and a buffer against eroding storm waves. Coastal dunes have developed worldwide along coastlines with ample supply of sand, prevailing onshore winds, and presence of vegetation or other obstructions trapping the windblown sand (e.g. Swift, 1976; Nordstrom, 2015). Coastal dunes are dynamic environment whose morphological evolution is inextricably linked to the neighbouring beach and vice versa (Hesp, 1988; Psuty, 1988; Short and Hesp, 1982; Hesp and Walker, 2013). This makes the beach-dune system a complex system where abiotic (marine and aeolian) and biotic processes interact on a wide

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range of temporal and spatial scales (Hesp, 2002). In the context of climate change, increasing anthropogenic pressure on the coasts and increased erosion, beaches and coastal dunes are therefore a critical component to the future of our coasts (Psuty and Silveira, 2010). Because long-term shoreline change is dictated by the erosion-recovery (im)balance that is controlled by the respective contributions of storms and recovery conditions, quantifying beach recovery through field data measurement is of high value to increase our ability to understand and further predict coastal evolution.

Quantitative understanding of beach and dune evolution has mostly been limited to erosion driven by a single storm, or driven by the cumulative impact of a cluster of storms that typically occurs over hours and days (e.g. Birkemeier et al., 1999; Coco et al., 2014; Castelle et al., 2007b; Karunarathna et al., 2014; Masselink et al., 2016b). As a result, the key hydrodynamic processes controlling offshore-directed sediment transport and resulting beach and dune erosion are reasonably well-understood (e.g. Raubenheimer et al., 1996; Sallenger Jr., 2000; van Gent et al., 2008). These scientific advances have been used to feed process-based models of beach and dune erosion (e.g. Roelvink et al., 2009), which were shown to hindcast storm-driven erosion with fair accuracy at different sites (e.g. Roelvink et al., 2009; McCall et al., 2015; Smallegan et al., 2016). In contrast, beach and dune recovery is a much slower process that can take years to decades (e.g. Morton et al., 1994; Lee et al., 1998; Houser and Hamilton, 2009; Houser et al., 2015) that has been given little attention (Kobayashi and Jung, 2012; Scott et al., 2016). Beach and dune recovery involves a myriad of biotic and abiotic processes interacting with one another. Onshore wave-driven sediment transport (Hoefel and Elgar, 2003; Ruessink et al., 2007; Dubarbier et al., 2015; Fernandez-Mora et al., 2015) return the eroded sand from the nearshore to the backshore during low- to moderate-energy wave conditions. Aeolian processes (Bauer and Davidson-Arnott, 2003; de Vries et al., 2014; Houser and Ellis, 2013) move the sand from the dry beach into the dune system. This occurs for onshore and oblique wind conditions, but also for offshore winds through flow deflection by the dune causing locally onshore flow at the beach (e.g. Jackson et al., 2011; Delgado-Fernandez et al., 2013; Walker and Hesp, 2013; Hesp and Walker, 2013). The delivery of sediment back to the beach and ultimately to the dunes also depends on surfzone-beach type (Psuty, 1992; Hesp, 2002; Houser and Ellis, 2013), with dry beach width being critical in providing sediment to the dune (Houser, 2009). In the meantime, the dune vegetation helps to prevent erosion by wind and traps the sediment, and the roots and rhizomes of vegetation below the sand surface help resist wave erosion of the sediment contained in the dune.

Recovery phase is typically addressed by measuring the return of shoreline position, system volume, foredune height or shape from a post-storm to a pre-storm value (e.g. List et al., 2006; Splinter et al., 2011). The initial phase of recovery from storm-driven erosion can be extremely fast, e.g. even during the subsiding phase of the same storm (e.g. Roberts et al., 2013). In contrast, the full recovery defined as the return of the system to a pre-storm(s) shape, position and volume can be achieved by a few years and even decades (Mathew et al., 2010; Suanez et al., 2012; Bramato et al., 2012; Houser et al., 2015). Houser et al. (2015) studied the long-term beach and dune recovery and showed that time to complete dune recovery increases with increasing pre-storm dune height, usually up to a decade for 2–6-m high dunes (see also Cleary and Hosier, 1979). Mathew et al. (2010) showed that for comparatively larger 8–12-m high overwashed dunes, recovery can even take more than 5 decades to complete. In addition, Houser et al. (2015) showed that the growth of the dune follows a sigmoid curve with foredune formation being initiated only when vegetation is able to colonize the backshore. Hesp (2002) proposed a beach-dune interaction model describing the different stages of foredune development. He showed that after large-scale erosion and scarping, foredunes can follow different courses, from a complete destruction to revegetation and reformation to various degrees via dune crest deposition, scarp slumping, filling through sediment deposition by aeolian delivery (sand ramp development) and revegetation. Foredune recovery is also strongly influenced by the neighbouring beach and backshore as a wider dry beach provides both more sediment for aeolian transport and greater protection to the dune foot during storms (e.g. Anthony et al., 2006). The fetch distance is also critical to foredune recovery, with fetch effect and angle of wind approach leading to tradeoffs that govern the magnitude of aeolian sand transport across the beach (Bauer and Davidson-Arnott, 2003). For instance, as the angle of wind approach becomes more oblique, the fetch distance increases and allows greater opportunity for the saltation system to evolve toward an equilibrium transport state before reaching the foredunes (Bauer et al., 2009). Accordingly, sediment accumulation in the dune depends on the available fetch and wind speeds, and on the availability of dry sediment in the backshore.

The 2013/2014 winter was outstanding in terms of storminess with severe wet and stormy weather over parts of Europe (Davies, 2015). These storm systems generated severe wave events battering the W coast of Europe that drove widespread coastal erosion (Castelle et al., 2015; Suanez et al., 2015; Masselink et al., 2016a,b; Pye and Blott, 2016; Autret et al., 2016). Using a numerical 68-year wave hindcast, Masselink et al. (2016a) demonstrated that this winter was the most energetic along most of the Atlantic coast of Europe, say south of 55°N, over the 1948–2015 period. In SW France, the 250 km long sandy coast was severely eroded (Castelle et al., 2015). Sandy beaches in SW France are backed by high (10–20 m) and

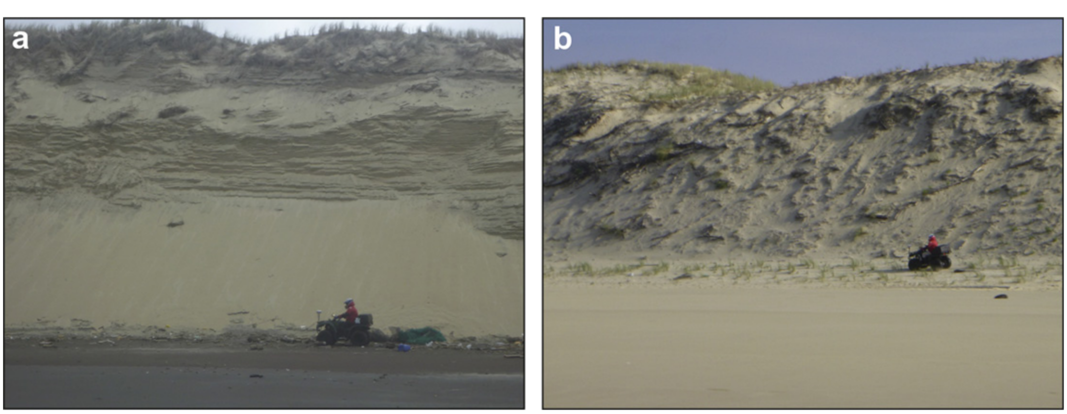

Fig. 1. Photographs of the dune scarp a few kilometres north of Truc Vert (a) just after the 2013/2014 winter (April 4, 2014) and (b) approximately 1.5 years later (November 16, 2015), showing large morphological changes and the formation of an incipient foredune. In both pictures the ATV gives the scale.
Source: Ph. B. Castelle.