

MANAGEMENT OF DUNE DEVELOPMENT ON A SEAPORT DIKE, DUNKIRK SEAPORT, FRANCE

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The city of Dunkirk is located on the northern coast of France, a few kilometres from the Belgian border (fig.1). Dunkirk Seaport development since the end of the 1950s has resulted in major shoreline changes. Harbor infrastructures were expanded on reclaimed land, resulting in the development of a 15km long artificial shoreline, oriented WSW-ENE, limited by two jetties (fig. 1A). The eastern part of this coast is backed by a 6km long sand dike coated with asphalt called “digue du Braek”, peaking at 12m above mean sea level, and overtopped in places by low elevated aeolian dunes. On this coast where net sediment transport is directed towards Belgium (Cartier and Héquette, 2011), the mean spring tidal range is 5.60m. The beach, 500m wide at low tide, is characterized by fine to medium, well to very well sorted quartz sand. Winds are dominantly blowing longshore to obliquely offshore, essentially from south to west-southwest, followed by an obliquely onshore component from the northeast (fig.1A). Aeolian sand transport on the upper beach has resulted in dune development on the dike as well as sand deposition on roads and in a maritime basin behind, requiring costly removal and dredging operations (fig.1B & C). Previous studies have revealed that aeolian sand transport over the dike under oblique onshore winds is facilitated by a wind speed-up, and *in situ* measurements have shown that transport rates could reach until $95\text{kg}\cdot\text{m}^{-1}\cdot\text{h}^{-1}$ on the windward slope during strongest winds (Tresca et al., 2012). Our knowledge on aeolian sand transport on dikes and their influence on port infrastructure is still limited. In this context, the aim of this study was to analyse coastal dune development and dune types on the “digue du Braek”, and to test the efficiency of windbreaks usually installed on the upper beach on asphalt in order to control wind blown sand on the dike. Although effects on fencing on dune formation are well documented (Grafals-Soto and Nordstrom, 2009), no studies have been carried out on their efficiency on seaport dikes.



Figure 1. (A) Study site and location map of Dunkirk seaport, wind conditions (1991-2007) and ground photographs of (B) dike toe dunes and (C) aeolian sand accumulation landward the dike.

Study of dune development on the dike is based on a diachronic analysis of aerial photographs from 1988 to 2009. Aerial photographs have been ortho-rectified, and dunes have been delimited using vegetation limits and digitized as polygons using ArcGIS software. For each year, the cumulated area covered by dunes was calculated, and a margin of error of 28% was applied.

Windblown sand accumulation on the dike was tested using wooden slats and synthetic fabrics with a height of 1.2m and a porosity of 50%. Chestnut posts inserted into concrete blocks were used to fix them on the ground. In February 2011, ten experimental structures were erected on the dike at different locations: dike toe, dike landward and seaward slopes. Sand volume was monitored every month until December 2011, within as well as around each structure, using a Differential Global Positioning System. Digital Elevation Models (DEMs) were generated using standard terrain modelling software based on point interpolation techniques. A 10cm empirically derived margin of error, covering both operator and interpolation errors was applied to the raw data. The overall wind conditions that prevailed over the survey periods were determined from MétéoFrance wind records from Dunkirk station, located 1km east of the survey area.

Results show that dune development can be very rapid on a dike. The “digue du Braek” was built in 1963, and in 1988 dunes were covering an area of 7900m². By 2009, the cumulative surface area of dunes was reaching 74000m² (fig. 2A, B & C). Dune formation is initiated by *Ammophila arenaria* colonisation of numerous perpendicular cracks in the dike. Vegetation favoured sand accumulation and formation of nebkhas. Their coalescence resulted in the development of continuous dunes. Five different “dike-dunes” types have been identified. Dike toe dunes (1) have developed at the beach/dike contact in the most eastern part of the site, where a 750m long jetty is interrupting net sediment transport. These partly vegetated dunes are 3 to 4m high, reaching in place up to 10.5m above mean sea level, and cover an area of approximately 13000m² (fig. 2D). Under oblique onshore winds from the northeast, sand passes over the dike and accumulation prevails in the lee side of the dike where wind velocity decreases, enhancing the formation of landward slope dunes (2) and basin dunes (3) on the embankment of the maritime basin. At some places, landward slope dunes developed and reached the top of the dike forming dike crest dunes (4). It is also possible to observe low elevated shadow dunes (5) scattered on the seaward slope of the dike behind obstacles (boulders, rubbish...).

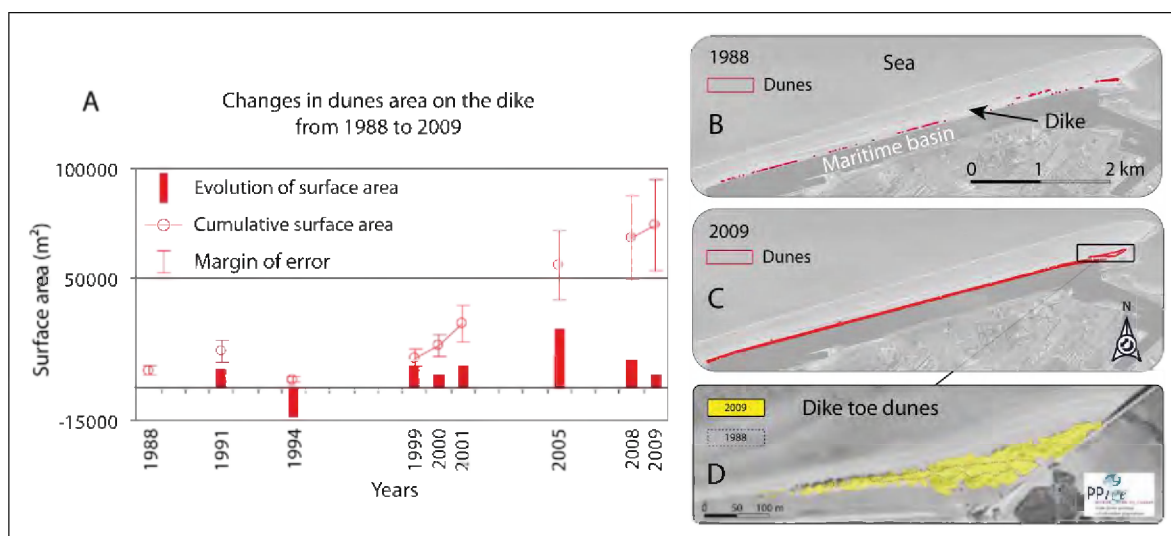


Figure 2. Changes in dunes area on the dike and at the dike toe from 1988 to 2009

Windbreaks were tested at different locations on the dike in order to solve uncontrolled aeolian sand transport problems. DEMs and net volume changes on three of the ten experimental structures are shown in figure 3. All of them were located out of reach of

maximum water levels. It is obvious that each of them played a significant role in sand accumulation within the three areas, showing that sand fences usually installed on the upper beach are also able to trap sand on asphalt. Over a 310 days survey (from February to December 2011), the most efficient structure was D1 (fig. 3), a square of 10m x 3m made with wooden slats. A net volume of almost 100m³ was recorded within and around this structure. On the upper beach, embryo dunes parallel to the windbreak developed and were rapidly colonised by vegetation. This partly explains the greater amount of sand trapped in this area relatively to those located on the dike, which were not in contact with upper beach or dunes. Sand fences installed on the upper seaward slope of the dike captured a lower volume of sand due to run off towards the dike toe during wet weather. Indeed, structure D2, consisting of a cross-shaped structure made with synthetic fabrics, trapped only 17m³ of sand. The linear fence D3 (synthetic fabrics) was located at the toe of the landward slope, and this structure trapped 29m³ (fig. 3). Nevertheless, this number is not representative of the total amount trapped, because this structure was along a road where trucks regularly removed sand deposits.

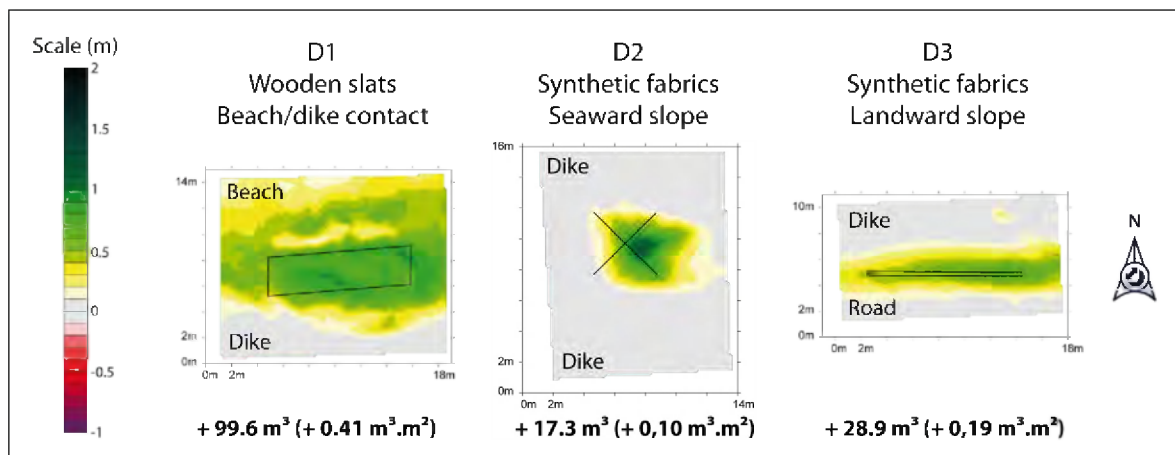


Figure 3. DEMs and net volume change between Feb. 14th and Dec. 21st 2011 on three experimental structures

This paper is an example of how harbor infrastructures can give rise to new kinds of aeolian landforms. In Dunkirk, dune development spontaneously happened on a seaport dike, resulting in a specific dike-dunes typology. It seems important to control aeolian sand transport in order to prevent sand encroachment on infrastructures. It is therefore why experimental windbreaks have been tested on asphalt. Differential volume maps have shown that they were efficient to trap sand on that kind of substrate, but their efficiency seems to have been influenced by their location on the dike, more than by the type of fencing materials. Windbreaks erected at the beach/dike contact were more efficient to trap sand than those installed in the middle of the dike seaward slope, affected by run off during rain periods. The location of the structures well above high water levels makes them dependent of the wind regime exclusively, unlike sand fences usually erected at the dune toe, where erosion can happen due to wave action (Ruz and Anthony, 2008). The results of this study may not only help to fix some aeolian sand transport problems, but it could also help to improve the diversity of landscapes on harbour infrastructures. Indeed, in Dunkirk seaport, dune development has favoured natural development of a new kind of habitat where protected species like *Eryngium campestre* develop. This study will enable Port of Dunkirk to build a management plan of its shoreline, in order to preserve the diversity of landscapes, habitats and species.

References

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