

## Coastal dune evolution on a shoreline subject to strong human pressure: the Dunkirk area, northern France

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### Abstract

The extreme northern coast of France from Dunkirk to the Belgian border is bounded by coastal dunes that have been massively transformed by urban and port development. The only stretch of preserved dune barrier, less than 8km long, is located east of the port of Dunkirk. The foredune ridge was seriously damaged at the beginning of the 20<sup>th</sup> century by urban development and almost completely destroyed during World War II. In the 1980s, the foredune, 10 to 20m high, was affected by breaches and blowouts, and by erosional scarps cut during storm events. The dunes are presently in a state of meso-scale (decadal) stability. This stability is attributed in part to human intervention. In the early 1990s, active restoration was carried out by the Departmental Authority of the North (Conseil Général du Nord) in charge of the management of these coastal dunes. These measures have resulted in incipient foredune development along accreting sectors. Collaborative work involving beach and foredune surveys carried by the *Coastal Geomorphology and Shoreline Management Unit* of the Université du Littoral Côte d'Opale and the Conseil Général du Nord over the past years has enabled better insight into beach and foredune sediment dynamics. Aeolian sand transport measurements enable quantification of sand exchanges within the dune front. The influence of sand fences and brushwood barriers on incipient foredune growth is presently studied along an experimental sector. These surveys highlight the current stability of this coast. Much of the foredune foreslope is now stabilized by vegetation and only episodic dune scarping occurs during winter, with recovery in summer. There is, however, a need to address more precisely the exact role of human interventions in the present status of shoreline stability. The restoration practices mentioned above have significantly encouraged foredune stability and incipient foredune development. However, no major storms have occurred since 1990 and a context of net sediment supply from foreshore to dune has certainly been a factor in enhancing shoreline stability and dune development.

Keywords: Coastal dunes; Shoreline evolution; Detailed monitoring; Management practices.

## Introduction

The importance of coastal dunes as natural sea defences, sites of ecological interest and recreational areas is now well recognized. Beaches and coastal foredune systems in many parts of the world have experienced erosion in recent decades (Bird, 1985), and coastal dune retreat is a major concern along developed coastlines. Coastal dunes act as sand reservoirs, which may supply sediment to adjacent beaches (Psuty, 1988; Pye, 1991; Sherman and Bauer, 1993), and therefore can delay coastal retreat and protect low-lying backshore areas against marine invasion. This is particularly the case along the southwestern coast of the North Sea where a large proportion of the coastal plain consists of densely populated reclaimed land. The extreme northern coastline of France, bordered by the southern North Sea has been massively transformed by urban and port development and the only stretch of preserved dune barrier, less than 8km long, is located east of the port of Dunkirk (Fig. 1). Along this coastline, coastal dunes are not only a protective natural barrier against marine invasion, but also are a much appreciated recreational area and a 'natural' landscape of biological and geomorphological interests. This paper presents coastal dune evolution along this coastline, with particular attention to natural processes and management practices that resulted in the recent (last decade) stabilisation of this shoreline characterized by erosion since at least the beginning of the 20<sup>th</sup> century. Such an understanding of the factors which influence the present dune morphology is essential in order to make accurate assessments of the effects of natural processes and human activities within the dune system.

## Study area

Macrotidal beaches of the northern coast of France are characterised by a wide beach/surfzone consisting of parallel bars and troughs (Sipka and Anthony, 1999; Masselink and Anthony, 2001). These ridge and runnel beaches are associated with extensive coastal dune fields (Battiau-Queney *et al.*, 2000). The development of these dunes has been related to massive sediment supplies from a sand-rich nearshore zone consisting of tidal banks, the Flemish Banks (Anthony, 2000). From Dunkirk to the Belgian border, inland parabolic dunes fronted by a foredune ridge form a well-developed coastal dune system, 5 to 30m high and 700 to 1100m wide (Clabaut *et al.*, 2000). This coastal dune field, known as Dewulf, Marchand and Perroquet dunes (Fig. 1), is interrupted by the coastal resorts of Zuydcoote and Bray-Dunes (Fig. 1).

Along this coastline the beach is subject to a macrotidal range that increases from 3.5m during mean neap conditions to 5.6m during mean spring conditions. At low tide, the beach is 400 to 500m wide and has a very gentle gradient (0.01). The beach consists of fine homogeneous well-sorted sands and is characterised by irregular ridge and runnel morphology (Sipka and Anthony, 1999; Reichmüth and Anthony, 2002). A gently sloping terrace, flooded only during high spring tides and by storm setup, links the intertidal ridge and runnel system to the incipient foredune front. The beach is backed by an established foredune ridge 15 to 150m wide and 10 to 20m high. This coastline is dominantly exposed to offshore to shore parallel winds from a south to southwesterly window. Northerly onshore winds, the most important in terms of potential dune

accretion, are less frequent, but they occur in winter and can induce storm surges responsible for upper beach/dune erosion (Vasseur and Héquette, 2000).

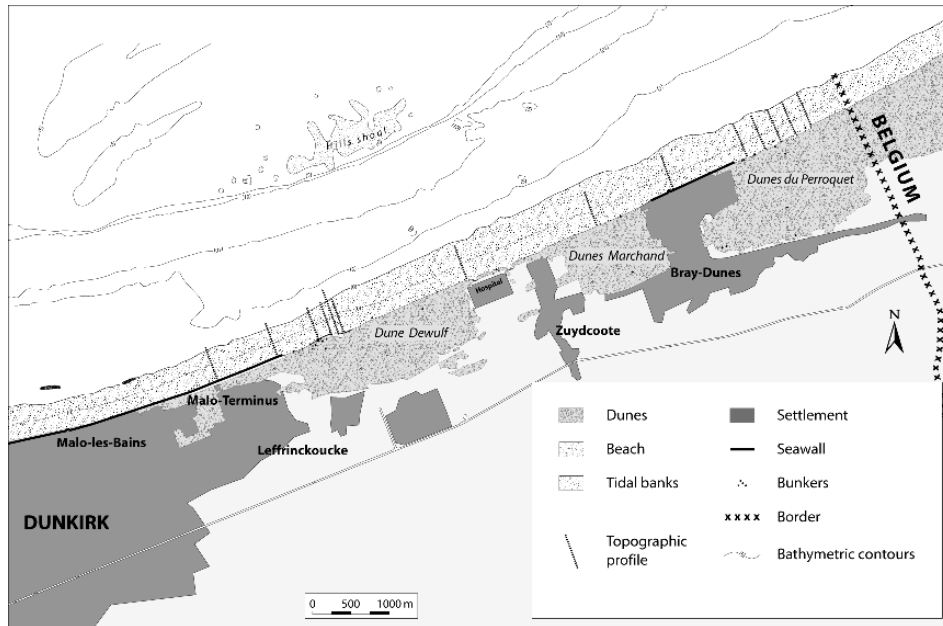


Fig. 1. Location map.

### Medium-term coastal dune evolution (20<sup>th</sup> century)

The very high population density of the « Département du Nord » has resulted in strong human pressure on these coastal environments. East of Dunkirk, the shoreline evolution during the 20<sup>th</sup> century is dominated by coastal retreat. This evolution is related to both human pressure and natural erosional processes under storm conditions. Coastal erosion however varied through time and was not spatially uniform. The foredune was seriously damaged at the beginning of the 20<sup>th</sup> century by urban development. The extension of the seawall, east of Malo-les-Bains (Fig. 1), around 1906, resulted in the destruction of the adjacent foredune and the formation of active parabolic dunes, migrating eastward in response to the dominant south westerly winds (Fauchois, 1998). From 1894 to 1939 the erosion rate was estimated at up to 2.5m.yr<sup>-1</sup> east of Bray-Dunes (Fauchois, 1998). Coastal dunes were also badly damaged during World War II. On the upper beach, as well as on the foredune ridge, several German bunkers (Fig. 2) and an anti-gunfire defence wall illustrate the strong impact of these buildings on the shoreline morphology. From 1947 to 1977 erosion still prevailed along the eastern and western part of the study area while in the central part, foredune development occurred (Clabaut *et al.*, 2000). From 1971 to 1994, erosion rates were of the order of 1.7 to 2.9m.yr<sup>-1</sup> in the western part

of the Dune Marchand (Fig. 1) while in the western part of the dune Dewulf the mean retreat rate was less than  $1\text{m.yr}^{-1}$ . Along the Dune du Perroquet close to the Belgian border, stability prevailed (Clabaut *et al.*, 2000). In these fairly stable sectors, the foredune was progressively rebuilt and stabilized by vegetation. In the 1980s, the foredune was affected by breaches and blowouts, mainly due to human disturbance, and by erosional scarping during storms. Erosion was related to storm intensity and frequency. Analysis of storm at Dunkirk from 1962 to 1995 revealed an increase in intensity and duration from 1971 to 1977 (Clabaut *et al.* 2000; Vasseur and Héquette, 2000). Over the last few decades shoreline retreat was counterbalanced by sand accumulation at the top of the dune crest and on the backslope, resulting in a widening of the foredune. The refilling of dune blowouts and the development of a vegetation cover suggest a relatively balanced sand budget (Clabaut *et al.*, 2000).



Fig. 2. German bunkers on the upper beach, Leffrinckoucke.

### Recent (10 yr) dune evolution

The foredune is presently in a state of meso-scale (decadal) stability (Vanhée *et al.*, 2002). The seaward slope of the foredune, which was cut into an erosional scarp (Clabaut, *et al.*, 2000; Vasseur and Héquette, 2000) up to 1998, is now stabilised by vegetation. This stability is attributed in part to human intervention. In the early 1990s, measures to combat degradation of the dunes and reduce the threat of marine erosion were implemented by the Departmental Authority of the North (Conseil Général du Nord) in charge of the management of these coastal dunes. Wooden and brushwood fences were erected in order to encourage sand accumulation in the most sensitive areas. Wooden fences were erected across major blowouts and bare sand patches were fenced off and plants artificially introduced (Fig. 3a). Attempts have also been made to improve the effectiveness of the frontal dunes as sea defences by encouraging artificial accumulation of blown sand along parts of the backshore. Access to the public was restricted and panels showing information aimed at increasing people's understanding of

the area were put up at the entrance of the pathways. In order to promote the recovery of natural habitats, these rehabilitation measures have involved, since 1994, manual collection of detritus and debris accumulating at the high tide lines at the Perroquet and Marchand dunes (Lemoine *et al.*, 1999). These measures have resulted in incipient foredune development along accreting sectors (Fig. 3b).

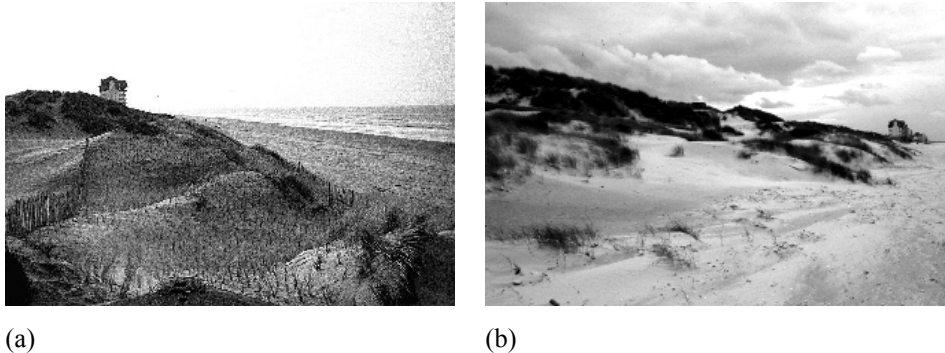


Fig. 3. Coastal dunes evolution east of Bray-Dunes: (a) wooden fences and marram planting along in a deflation hollow; (b) development of incipient foredunes.

Detailed beach and dune topographic surveys and hydrodynamic measurements have been carried out along this coast by the Coastal Geomorphology and Shoreline Management Unit of the Université du Littoral since 1996, in order to gain a better understanding of morphological variations and beach sediment budgets on a short time-scale. Several beach profiles, extending from the foredune crest to the low tide level (Fig. 1) were regularly levelled from 1994 to 2004 (Sipka, 1997; Triquet, 1998; Vanhée, 2002; Reichmüth, 2003; Brulez, 2004). The study of spatial and temporal beach variability along this coastal sector revealed equilibrium sediment budget conditions (Reichmüth, 2003). Short-term (< 2 months) ridge mobility is only triggered when successive storm events occur, especially when they coincide with large spring tides. However, volumetric changes in the profiles over the period 1996-2000 were insignificant (Reichmüth and Anthony, 2002). Under fair weather conditions (usually during summer) the bar formed in the upper beach welds onto the extreme upper beach and forms a low terrace which acts as a sediment source for the incipient and established foredune zone (Vanhée, 2002; Brulez, 2004; Quesnel, 2004). Much of the foredune foreslope is now stabilised by vegetation and only episodic dune scarping occurs during winter, with recovery in summer (Valet, 2002; Visayze, 2004).

East of Leffrinckoucke (Fig. 1) a study of the effects of ridge and runnel morphology on aeolian sand transport was carried out between 1999 and 2002 (Vanhée, 2002). Experiments involved short (30 mn) deployments of anemometers, weather stations and sand traps along systematically surveyed beach profiles along which ground surface moisture was measured. The results show that, along this macrotidal beach, in spite of potentially large wind fetch with onshore winds, the effective fetch is generally limited to the upper beach terrace and to the first ridge on the upper beach. The fetch is

especially segmented by the runnels, which may act as efficient sand traps (Vanhée *et al.*, 2002).

Collaborative work involving beach and foredune surveys carried by the Coastal Geomorphology and Shoreline Management Unit and the Conseil Général du Nord over the past years has enabled better insight into beach and foredune sediment dynamics. Aeolian sand transport measurements enable quantification of sand exchanges within the dune front in a coastal sector where brushwood barriers and sand fences were erected and where marram was planted in order to favour the formation of a protective incipient foredune. This study permitted a detailed quantification, through differential contour maps, of aeolian sand volume trapped by brushwood barriers and sand fences. An accumulation of about 1.75m was recorded between September 1999 and May 2001 on the developing incipient foredune foreslope, demonstrating the efficiency of these management structures (Vanhée *et al.*, 2001). Sand transfer from the upper beach to the backshore through aeolian processes has resulted in sand accumulation that put the dune toe out of reach of the highest tides. Furthermore, the absence of major storm events since the early 1990s reinforced this natural accumulation trend.

A detailed measurement of the elevation of the dune toe, from Leffrinckoucke to Bray-Dunes (Fig. 1) was carried out in spring 2004 (Visayze, 2004) in order to determine the sensitivity of this shoreline to erosion and submersion in case of extreme storm events (storm surges combined with spring tide). The elevation of the highest annual water levels recorded at Dunkirk harbour for the period 1956 to 2003 were coupled with the present-day dune toe elevation. Dune sectors below the uppermost limit of high water levels were identified and mapped. Results show that the central part (Dunes Marchand) of the area is still at risk while the eastern and western parts are presently out of danger. Such a map is a useful tool for managers in charge of the dunes as it indicates the locations of the most sensitive sectors.

The influence of sand fences and brushwood barriers on incipient foredune growth is presently studied along an experimental sector at Leffrinckoucke (Fig. 1). Brushwood barriers and fences perpendicular to the dominant southwesterly winds have been erected on the bare upper beach, above the highest high-tide levels (Quesnel, 2004). The aim of this experiment is to evaluate the efficiency of these two types of dune-rehabilitation structures.

Near the Belgian border, east of Bray-Dunes, accumulation in the backshore zone has prevailed since at least 1995 (Clabaut *et al.*, 2000, Valet, 2002; Brulez, 2004) and is emphasized by incipient foredune development. This coastal sector, less than 150m long, is of particular interest as recent shoreline evolution can be studied along a 'managed' sector and a natural one located a few metres apart. The eastern part of this sector was subject to sand deflation and the dune was an irregular assemblage of poorly vegetated hummocks (Fig. 4a) while the western sector was characterized by a breach opened by waves during a storm in the early 1980s (Fig. 4c). Erection of wooden fences and marram planting were completed in the eastern sector (Fig. 4a) while the western one evolved naturally. From 1998 to 2004 an 'artificial' foredune developed along the eastern sector, well behind the uppermost water levels (Fig. 4b). Along the western sector, the former breach was naturally closed by wind blown sand, and incipient

foredunes, up to 2m, high have recently developed on the upper beach (Fig. 4d). Such an evolution shows that along a coastal sector with a positive sediment budget, deployment of dune rehabilitation structures is not always necessary.



Fig. 4. Recent evolution of a 'managed' and a 'natural' sector at the Belgian border between 1998 and 2003: (a) erection of wooden fences on poorly vegetated chaotic dunes; (b) development of an 'artificial foredune'; (c) morphology of the breach in 1998; (d) natural formation of incipient foredunes.

## Conclusion

These surveys highlight the current stability of this coast. Detailed monitoring shows that coastal erosion has slowed down since dune protection schemes were implemented, but this trend has been favoured by the non-occurrence of major storm events in conjunction with large spring tides since the early 1990s. There is, however, a need to address more precisely the exact role of human interventions in the present status of shoreline stability. The restoration practices mentioned above have significantly encouraged foredune stability and incipient foredune development. Nevertheless, a context of net sediment supply from foreshore to dune has certainly been a factor in enhancing shoreline stability and dune development. This present-day state of stability is spatially limited, however, and likely to be temporary. Along the northern coast of France, several beaches are presently experiencing rapid coastal retreat, a remarkable example being Wissant Bay located south of Calais (Ruz and Meur-Férec, 2004).

Reactivation of coastal retreat can occur at any time, after a stormy winter, for instance. The evolution of the coastline east of Dunkirk therefore still needs to be carefully observed through detailed monitoring and cautious management.

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