Z. Geomorph. N.F.	52	Suppl. 3	179 – 194	Berlin · Stuttgart	November 2008

Sand trapping by brushwood fences on a beach-foredune contact: the primacy of the local sediment budget

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with 8 figures

Summary. Experiments were conducted at two field sites in the Dover Strait and the southern North Sea in order to evaluate the efficiency of brushwood fences in trapping sand and promoting foredune building. The results show contrasting patterns between the Dover Strait site where brushwood fences were rapidly washed away by storms, and the North Sea site where the fences were associated with significant accretion. Analysis of accretion trends and ensuing morphological patterns show that sand trapping formed a ramp at the beach-dune contact that further promoted foredune growth. These patterns show, however, that accretion at this site was primarily dependent on a favourable sand supply context in conjunction with the right storm and wind combinations. The study shows that the location of brushwood fences is an important factor in the duration of this inexpensive dune fence design but that trapping efficiency is subordinate to the availability of sand and sand-transporting winds. Under conditions of a strong deficit in sand supply from the beach, as in the Dover Strait site, fences are of no use as far as fostering dune accretion is concerned.

1 *Introduction*

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 dune rehabilitation has, therefore, become a central theme in the management of many developed coasts, because of the vital role dunes play as a buffer against storms and in balancing beach sediment budgets, and because of their significance as sites of ecological and recreational interest. In order to enhance dune building and to prevent dune erosion by waves and/or by anthropogenic pressure, construction of semi-permeable fences along the seaward faces of coastal dunes is commonly used to encourage the deposition of wind-blown sand (Savage & Woodhouse 1969, Willet & Phillips 1978, Goldsmith 1985, Carter 1988, Hotta et al. 1991, Feilberg & Jensen 1992, Nordstrom & Arens 1998, Nordstrom et al. 2007) and the practice dates back several centuries (Pye & Tsoar 1990). Sand fencing has been widely used along barrier islands to enhance foredune formation after major storm events (Mendelssohn et al. 1991, Miller et al. 2001). Dune fencing is also a technique used to prevent landward sand deflation (Sherman & Nordstrom 1994). This is an inexpensive technique of re-distributing the sand in motion in the beach/dune system. A variety of fencing materials can be used successfully to enhance natural recovery. Cheap brushwood fences have been a traditional means of rehabilitating dunes on coasts where sand availability may favour dune accumulation, but where the wind flow needs to be impeded by the construction of such semi-permeable structures in order to initiate the accumulation. Construction of semi-permeable fences along the seaward face of dunes will encourage the

DOI: 10.1127/0372-8854/2008/0052S3-0179 0372-8854/08/5203-0179 $ 4.00

deposition of wind blown sand, reduce trampling, and protect existing or transplanted vegetation. The amount of sand trapped depends on the fence height, the size of spaces between fence slats, and the wind speed (Carter 1988).

While the empirical basis of sand fence efficiency is well established, the scientific literature aimed at experimental assessment of fence efficiency, as regards the development or the protection of incipient and established foredunes, is relatively rare. Vigiak et al. (2003) proposed a model aimed at spatially simulating wind speed around windbreaks. Spatial and temporal patterns of sand accumulation and aeolian dynamics around fences have been described by Anthony et al. (2006, 2007a) using a combination of digital terrain modelling and wind data. These efforts highlight the variable efficiency of sand fences by bringing out, in particular, micro-scale variations in patterns of accretion and deflation generated by feedback processes between the fences and aeolian accumulation. The aim of the present paper is to assess the performance of sand fences erected in experimental plots at the contact between the upper beach and the foredune on a macrotidal coast subject to large fluctuations in water level.

2 *Setting*

The experimental sites in northern France (Fig. 1) are macrotidal shores characterised by a wide beach and surfzone consisting of parallel intertidal bars and troughs (Reichmüth & Anthony 2007). These bar-trough ('ridge and runnel') beaches are associated with extensive coastal dune fields (Anthony 2000, Battiau-Queney et al. 2000, Anthony et al. 2007b). Along eroding sectors of this coast, wooden fences and brushwood are commonly used to encourage aeolian accumulation and coastal dune development. Brushwood fences are made with local shrubs and are usually erected perpendicular to the beach in order to face the dominant longshore winds prevailing on this coast (Fig. 1). Two sites where dune fences have been used with the aim of delaying coastal retreat and enhancing the accumulation of wind-blown sand have been studied. One site is located in Wissant Bay, a 5.5-km-long sandy beach that forms a well defined single littoral cell between Capes Gris Nez and Blanc Nez (Fig. 1). The other site is located at Leffrinckoucke beach, situated on the North Sea coast, east of the highly urbanised area and port of Dunkerque (Fig. 1). Both Wissant and Leffrinckoucke beaches, like much of this coast, exhibit several sets of intertidal bars and troughs. A gently sloping terrace 20 to 75 m-wide, flooded only during high spring tides and by storm setup, links the intertidal bar-trough system to the foredune front. Both beaches are characterised by fine to medium (D_{50} = 0.17–0.32 mm), well-to very well-sorted quartz sand (Anthony & Héquette 2007). The mean spring tidal range at Wissant is 7 m and the mean neap tidal range is 4.2 m while Leffrinckoucke beach has a mean spring tidal range of 5.6 m, and a neap range of 3.6 m. At low tide, the beaches are 400 to 500 m wide and have a very gentle gradient (0.01). The coast is dominantly exposed to shore-parallel winds from a south to southwesterly window (Fig. 1). Onshore winds from the north, the most efficient in terms of potential dune accretion, are less frequent, but they occur in winter and can induce storm surges responsible for erosion of the upper beach and the foredune (Vasseur & Héquette 2000, Ruz & Meur-Férec 2004). Coastal dunes along these two beaches belong to the *Conservatoire du Littoral* and their management is assured by local authorities, the Conseil Général du Nord for Leffrinckoucke beach and Eden 62 for the Wissant Bay site.

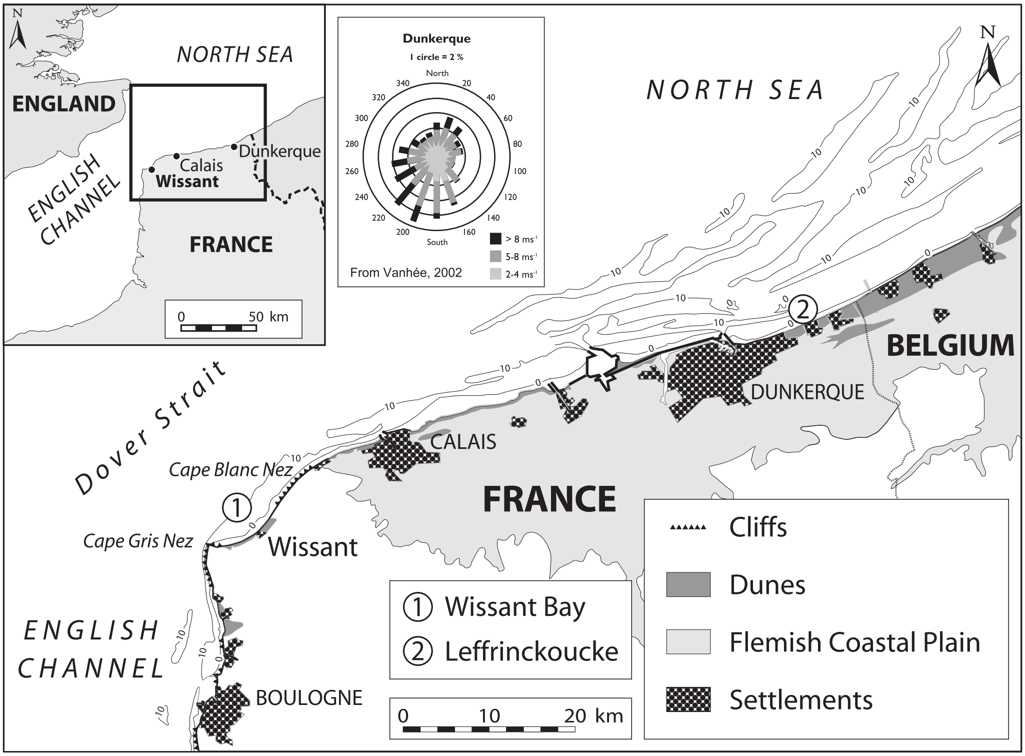

Fig. 1. Location map showing the two study sites and the regional wind conditions at the coast.

2.1 *Wissant Bay*

The beach in Wissant Bay is backed by coastal dunes 100 m to 350 m wide and 2 m to 18 m high. The dunes in the central part of the bay have experienced severe erosion over the last 50 years (Battiau-Queney et al. 2000, Ruz & Meur-Férec 2004). The dune front retreated by up to 250 m between 1949 and 2000 (Aernouts & Héquette 2006). Coastal retreat resulted in the complete loss of the foredunes. Inland dunes, now exposed at the shoreline, exhibit an erosional scarp 2–3 m high (Fig. 2a). In order to encourage sand accumulation during the 'low-energy' summer season and prevent dune scarp erosion, sand fences are usually installed in late spring (by the end of May) and retrieved at the beginning of autumn by the local managers in charge of these protected nature sites. In the central part of the bay, along a 200 m-long area affected by erosion, brushwood fences perpendicular to the beach were erected at the dune toe in May 1998 (Fig. 2b). Sand fences were 1.2 m high, 3–4 m long and spaced approximately every 4–5 m. They were installed at the upper tidal limit, between 4.5 m and 4 m above mean sea level.

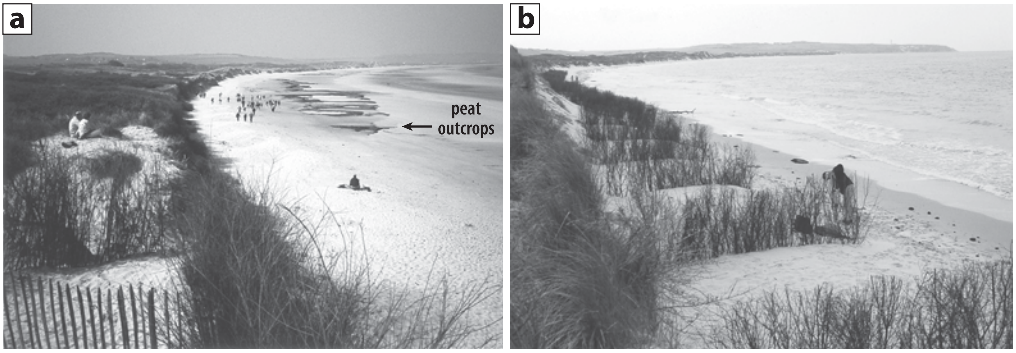

Fig. 2. Ground photographs of the Wissant Bay experimental site. (a) Eroded central part of the bay. Dark shore-parallel features in the central section of the beach are peat outcrops exposed following foredune erosion. (b) Brushwood installed on the upper beach in May 1998.

2.2 *Leffrinckoucke beach*

From Dunkerque to the Belgian border, inland parabolic dunes fronted by a foredune ridge form a well-developed coastal dune system, 5 to 20 m high and 800 to 1200 m wide (Clabaut et al. 2000). Coastal dunes in this sector bound the reclaimed Flemish Coastal Plain (Fig. 1), and have been massively transformed or obliterated by urban development and by military installations, especially during World War 2 (Fig. 3a). Shoreline evolution in this area during much of the 20th century was dominated by retreat (Clabaut et al. 2000), related to both human pressures and

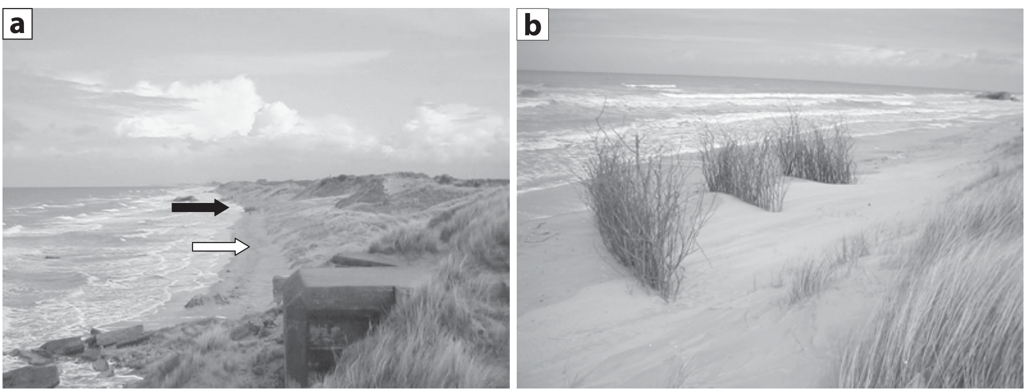

Fig. 3. Ground photographs of the Leffrinckoucke beach experimental site. (a) General view of the site in March 2004. Note the World War 2 block house in the foreground. White arrow points to the experimental site surveyed by Anthony et al. (2007a) between 1999 and 2001. The sand fences erected in 1999 are no longer visible, buried by accretion. Black arrow points to the upper-beach experimental site described in this article. (b) Close-up view of the brushwood experimental site in March 2004.

natural erosional processes. In the 1980s, the semi-vegetated foredune was affected by blowouts and by erosional scarps cut by storms. Measures to combat degradation of the dunes and reduce the threat of marine erosion were implemented in the early 1990s by the Conseil Général du Nord in charge of the management of these dunes. Wooden and brushwood sand fences were erected in order to encourage sand accumulation in the most sensitive areas (Ruz et al. 2005). Fences were erected across major blowouts, and, on bare sand patches, plants (Marram grass) were artificially introduced. From 1998 to 2000 sand fencing complemented by Marram grass plantations was carried out in order to close a former beach access that had evolved into a large wind gap. Pathways to the beach were also closed off by wooden and brushwood fences in order to improve the effectiveness of the frontal dunes as sea defences. To encourage the formation of a foredune ridge, 12 lines of brushwood were installed in late 1998 on the seaward slope of a developing incipient foredune at an elevation between 5.5 m and 7.5 m above mean sea level (1.5 m above spring tides). Detailed monitoring of the performance of five fences between September 1999 and May 2001 showed an accumulation of about 1.75 m on the developing incipient foredune foreslope, demonstrating the efficiency of these management structures (Anthony et al. 2007a). A net sand gain of 195 m^3, of which 42 % was captured by the dune, 46 % by the dune front, and 12 % by the beach, was observed. No monitoring was carried out after the October 2001 survey, but field observations carried out in June 2002 showed complete accretion throughout the monitored dune front on which the fences were implanted, and colonisation by Marram grass. Brushwood became progressively incorporated into the developing foredune and completely buried. Today, it is impossible to detect these structures in the well-developed and vegetated foredune (Fig. 3a). Such measures were, thus, very successful and have contributed to coastal dune rehabilitation and foredune development (Ruz et al. 2005, Anthony et al. 2006, 2007a).

3 *Methodology*

One hundred metres eastward of this afore-mentioned rehabilitated site (Fig. 3a), at the toe of a developing incipient foredune fronting a 12 m high vegetated dune ridge, experimental brushwood fences were erected in February 2004 on the bare upper beach. Along this experimental sector, three lines of brushwood, 3 m long, 1 m high, spaced 2.5 m, were installed perpendicular to the dominant southwesterly winds (Fig. 3b), at an elevation between 4.15 m to 5.25 m above mean sea level, corresponding to the upper limit range of the highest tides.

Detailed topographic surveys over the areas comprising the brushwood fences were carried out on both experimental sites. This technique enabled detailed quantification, through differential contour maps, of aeolian sand volumes trapped by the fences. The topography of the upper beach-dune front was surveyed using a very high-resolution laser electronic station with errors within ±3 mm for distance and height and ±0.0015° for direction. Digital elevation models (DEMs) were generated from these surveys using standard terrain modelling software based on point interpolation techniques. Each DEM grid database was generated from a dense cover of points spaced 2–4 m apart. An empirically-derived error margin of 5 cm, covering both operator and interpolation errors, was applied to the raw data. Volume changes were calculated using terrain-modelling software. The overall wind conditions that prevailed over the survey periods were determined from Météo France hourly wind records. Observed water level fluctuations at Dunkerque and Calais harbour were also analysed.

At Wissant, three digital elevation models were constructed for the following dates: 27th May 1998, 25th August 1998, and 5th January 1999 along a representative sector 19 m long and 17 m wide. Coastal dune retreat was also measured from 19 stakes driven into the sand spaced every 7 m and initially located approximately 5 m landward of the dune front along a 140 m-long representative sector. Measurements from stakes to the upper limit of the dune scarp were carried out in May, July, August, November 1998, and in January 1999.

At Leffrinckoucke, a 36 m-wide and 35 m-long experimental zone forming a 1260 m^2 plot astride the upper beach and the dune, and comprising the brushwood fences, was monitored for 14 months, from February 2004 to April 2005. Digital elevation models (DEMs) were generated in March 2004, July 2004 and in April 2005 in order to gain insight on volume changes. In addition, 3 topographic profiles, perpendicular to the upper beach and dune front, were monitored in February and July 2004 and in February and April 2005. One profile was located west of the brushwood, upwind of the dominant alongshore winds. Another profile was installed between the first and the second brushwood fences and the third located eastward (downwind) of the fence. Profiles were also monitored in April 2007 after a major storm event. Along these profiles, variations in elevation (in m) were calculated for every metre, and expressed in m/m of length.

4 *Results*

4.1 *Wissant Bay*

Between late May and August 1998, net sand accumulation of up to 0.35 m occurred around the sand fences, mainly close to the dune toe (Fig. 4a, b). DEM comparisons revealed an accumulation of more than 20 m^3 in the surveyed area, which represents a mean accretion of about 1 m^3 per metre of beach width (Ruz & Meur-Férec 2004). During this monitoring period, fair weather conditions were prevalent. The mean wind speed was 5.3 m s^{-1} and dominant winds were parallel to the beach, originating from the south-southwest with a frequency of 53 %. The absence of very high tides reaching the dune toe, as well as moderate wind conditions, prevented wave erosion along the upper beach, and allowed aeolian sand accumulation upwind of the sand fences.

From August 1998 to January 1999 dramatic changes occurred along this coastal sector. Along the 130 m-long survey site, retreat of up to 6 m was observed, with the dune scarp cut into a vertical bluff (Fig. 4c). The upper beach was flattened and its level was lowered by about 0.75 m (Fig. 4d). The brushwood disappeared, washed out by storm waves. DEM comparisons show a deficit of 392 m^3 within the survey area. This represents an erosion of nearly 20 m^3 per metre of beach width. Benchmark measurements revealed a mean scarp retreat of 4 m, with a maximum retreat of 6.1 m 100 m west of the DEM. Within the DEM limits, dune scarp retreat was 3.9 m. Maximum retreat occurred between November 1998 and January 1999, with a mean retreat of 2.17 m. This period was characterised by very large spring tides and stormy conditions. The most significant storm event occurred on October 8, 1998 (Ruz & Meur-Férec 2004). During this

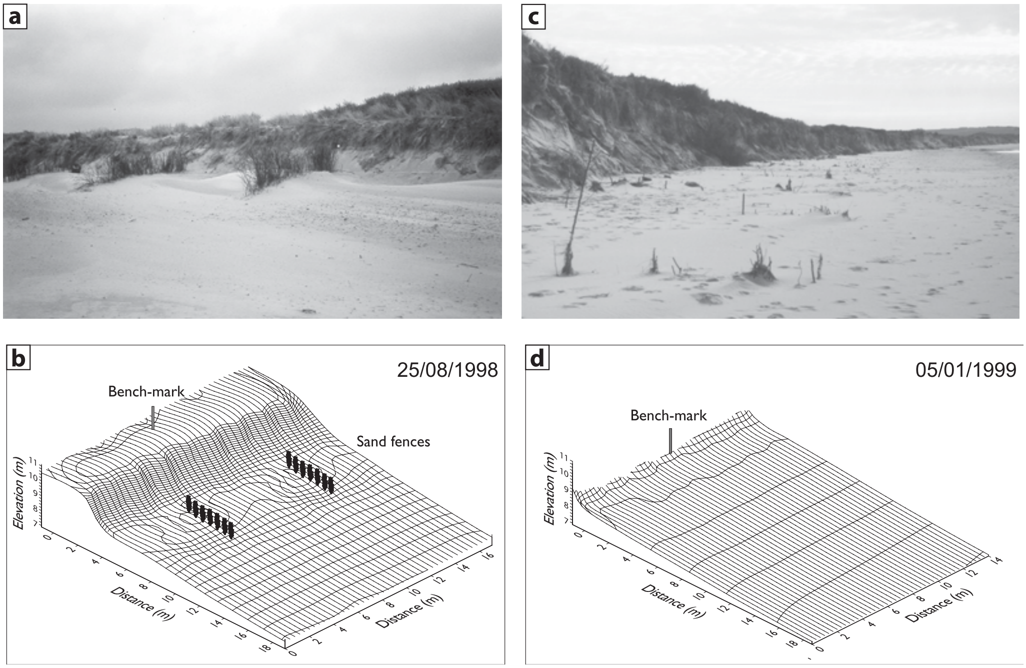

Fig. 4. Evolution of the Wissant Bay site between August 1998 and January 1999. (a) Photograph of the site in late August 1998. (b) DEM showing the upper beach morphology in August 1998. (c) site after a major storm in October 1998. (d) DEM showing the eroded upper beach in January 1999.

event, direct onshore winds (350°) with a mean wind speed of 14 m s^{-1} blew for 8 hours and induced a water level setup of 0.45 m. This surge, combined with the high tide (predicted water level of 4.62 m), resulted in the submergence of the base of the dune toe. Furthermore, strong onshore winds generated storm waves responsible for dune front erosion. This event likely initiated the erosion of the sand that accumulated during the summer, and induced lowering of the upper beach and erosion of the dune scarp. Subsequent high water levels could, therefore, easily reach the dune toe, thus, further promoting beach lowering and dune scarp retreat. Between January and May 1999, erosion was still taking place within the DEM limit. The dune front retreated by 0.9 m and maintained a steep erosional scarp. Since these surveys, dune retreat still prevails in the central part of Wissant Beach (Aernouts & Héquette 2006, Sedrati & Anthony this volume).

4.2 *Leffrinckoucke beach*

DEM comparisons between March and July 2004 revealed an accumulation of 63 m^3 in the surveyed area. Preferential accumulation occurred between fences 2 and 3 (Fig. 5a), while immediately in the lee side of fence 3, slight erosion was recorded. Net erosion (-0.45 m) also occurred at the dune toe, downwind of profile P3 (Fig. 5a). The uppermost part of the beach and the dune

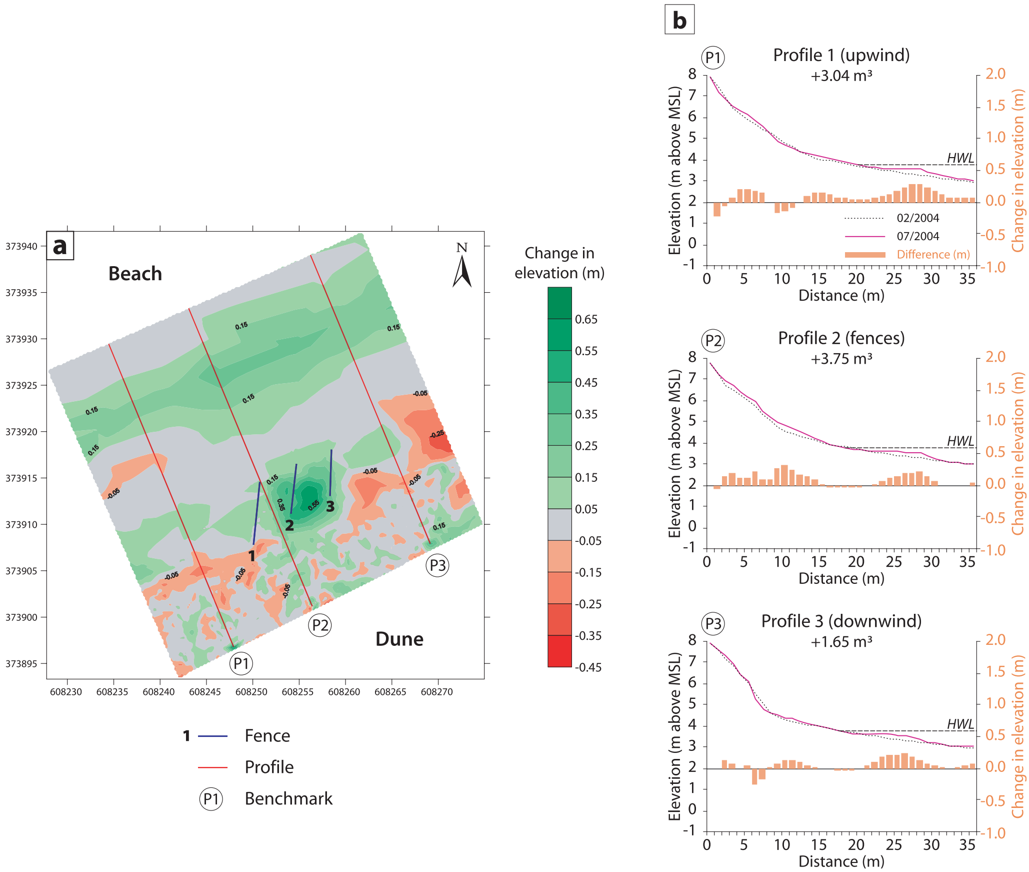

Fig. 5. Evolution of the Leffrinckoucke site between February and July 2004. (a) DEM showing net change in elevation. (b) Profile evolution (HWL corresponds to the highest water level observed at Dunkerque harbour during the survey period).

front remained stable. The topographic profiles revealed little change from February to July 2004 (Fig. 5b). The profile between fences 1 and 2 showed an accumulation of 0.3 m around the fences and slight (0.1 to 0.2 m) accumulation on the foredune front (P2, Fig. 5b). Upwind of the fences, slight erosion prevailed at the foredune toe, while on the upper beach minor accumulation was recorded. Downwind of the brushwood, slight erosion occurred at the dune toe. It is obvious that along all the profiles an accumulation of about 0.25 m prevailed on the beach, at the upper tidal limit (Fig. 5b). During this period, mean wind speed was 5.25 m s^{-1} and dominant winds blew from west-southwest and west-northwest. Winds above 5 m s^{-1}, the most efficient in potential aeolian sand transport, blew 55.3% of the time, with the west-northwest direction representing 34.3% of the hourly wind data. Spring tides reached an elevation of 3.7 m in early May, but no evidence of wave erosion appeared on beach profiles surveyed in July.

From July 2004 to April 2005, more than 148 m^3 of sand accumulated in the surveyed area. A preferential accumulation of up to 0.6 m was recorded around and downwind of fence 3, eastwards of the accumulation observed between March and July 2004 (Fig. 6a). Furthermore, the maximum accumulation was located at the dune toe. Large spring tides in mid March 2004 favoured erosion at the base of the fences. During this period, the dune front also gained a significant amount of sand. Beach profile comparisons show that from July 2004 to February 2005 accumulation prevailed (Fig. 6b). Between fences 1 and 2 an accumulation of more than 0.45 m was recorded (P2, Fig. 6b). The foredune stoss slope also gained a significant amount of sand. Upwind of the fences, an accumulation of about 0.2 m characterised the whole profile, from the upper tidal limit to the dune crest. Downwind of the brushwood, accumulation of up to 0.6 m was recorded at the dune toe (P3, Fig. 6b). During this period, several storms occurred, especially in February 2005. The morphological variations recorded on the profiles were probably due to episodes of strong (> 10 m s^{-1}) north-northeasterly and northwesterly winds in February (10^{th}, 12^{th}–15^{th}, 19^{th}–20^{th}), a few days before the topographic measurements were carried out.

From February to April 2005 accumulation was less obvious around the sand fences and erosion characterised the three profiles (Fig. 6c). The seaward limit of the brushwood was attained by a spring high tide of 3.9 m above mean sea level, on March 12^{th}, 2005. On the profiles, the limit of the upper tide is outlined by erosion of up to 0.3 m. During this period, dominant winds blew from the westerly and south-southwesterly sectors and the mean wind speed was 6.28 m s^{-1}. Winds above 5 m s^{-1} blew 64.8 % of the time.

For the whole survey period, the accumulation within the DEM limits was of the order of 210 m^3. It is noteworthy that sand accumulation was massive and indifferently concerned both the sand fences and spaces between fences (Fig. 7a). No preferential accumulation occurred around each brushwood fence, in contrast to observations from the nearby experimental site monitored by Anthony et al. (2007a). Downwind of fence 3, a "shadow dune-like" accumulation occurred (Fig. 7a). Further eastward, however, minor erosion (0.15 m) still persisted. Net deposition occurred not only around the sand fences but also on the seaward slope of the incipient foredune. Accumulation prevailed both upwind and downwind of the fences. The upper beach also gained a significant amount of sand during the survey period, with a uniform accumulation of 0.2 m on the three profiles (Fig. 7b). The volume gained from the dune crest to the upper tidal limit was almost identical for the two profiles delimiting the fenced area (of the order of 6.6 m^3). The profile across the experimental site equipped with the 3 fences gained 8.8 m^3 of sand. During this 14-month survey period, winds blew dominantly onshore (51.2 %) and efficient winds for aeolian sand transport blew 35.6 % of the time, and were mainly shore-parallel to slightly obliquely onshore. The strongest winds (> 15 m s^{-1}) recorded during the survey blew onshore and occurred only 0.9 % of the time.

From April 2005 to April 2007 this survey site was still characterised by a positive sediment budget, and brushwood still captured a large amount of sand (Fig. 8a, b). The incipient foredune evolved significantly between April 2005 and April 2007, with an accumulation of up to 1.4 m of sand, and became progressively vegetated. On March 21^{st}, 2007, strong direct onshore winds, with a mean hourly wind speed above 12 m s^{-1}, blew for more than 20 hours. This storm event coincided with a spring high tide that reached 4.1 m above mean sea level. The foredune toe retreated by 2 to 3 m and the brushwood fences were uprooted and transported offshore by storm waves. The waves induced scarping of the foredune and the formation of a 1.1 m high erosional bluff (Fig. 8c) that was remarkably uniform all along this coastal section. The developing foredune ridge remained, however, out of reach of these storm waves.

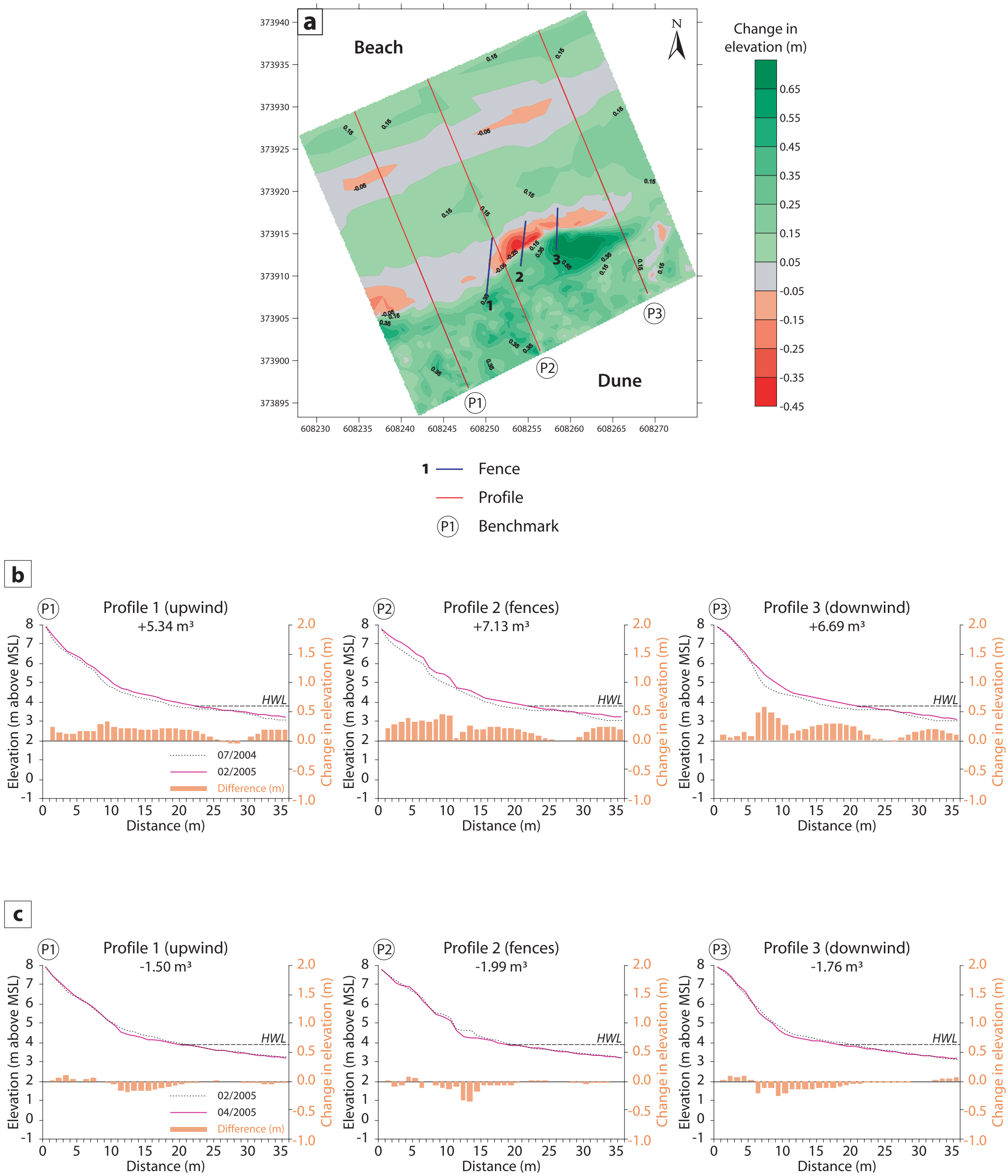

Fig. 6. Evolution of the Leffrinckoucke site between July 2004 and April 2005. (a) DEM showing net change in elevation over this period. (b) Profile evolution from July 2004 to February 2005; (c) Profile evolution from February 2005 to April 2005.

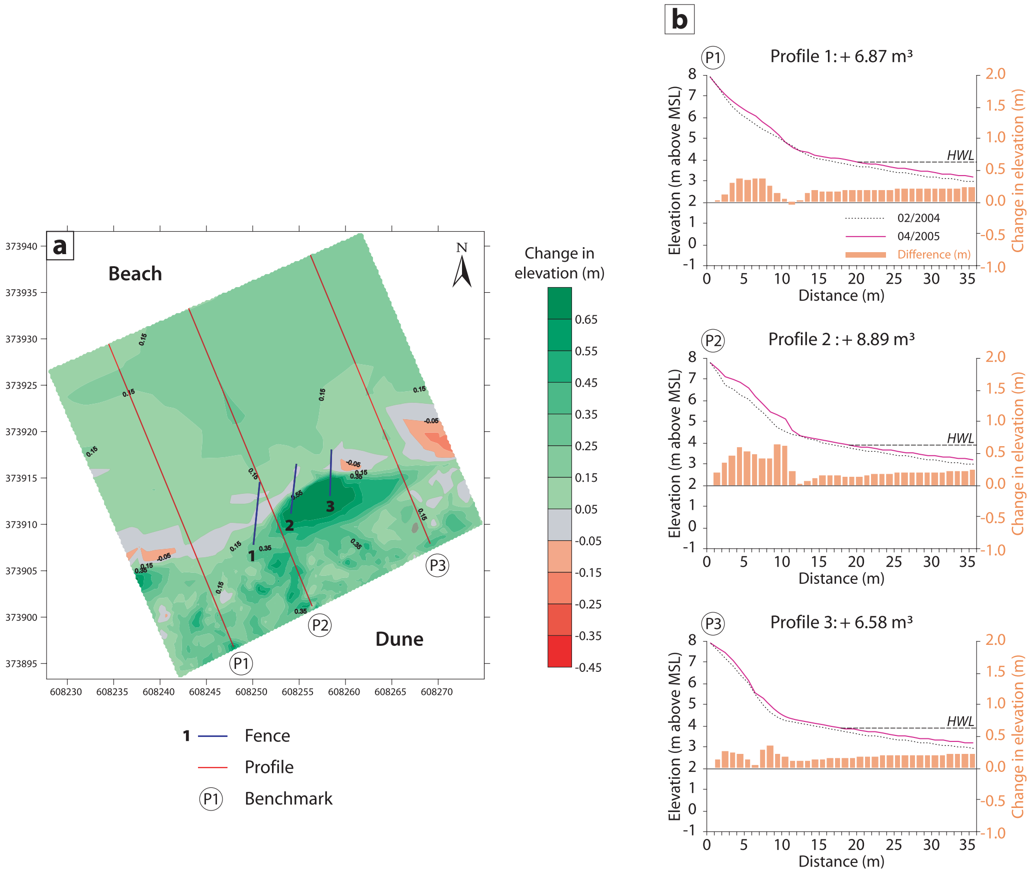

Fig. 7. Overall evolution of the Leffrinckoucke site (February 2004 to April 2005). (a) DEM showing net change in elevation. (b) Profile evolution.

5 *Discussion and conclusions*

In the two cases analysed in this study, brushwood fences were erected at the dune toe in order to create a sand buffer effect aimed at protecting the foredune behind. The evolution evinced at the Wissant site is an example of a very short duration of brushwood fences. Erected at the dune toe, along an erosive coastal compartment characterised by a low beach susceptible to storm incursions, their efficiency lasted a very short time. During the summer, and more specifically during a period of fair weather conditions, the brushwood fences captured a significant amount of sand at the dune toe and this accumulation encouraged the dune managers to believe that dune retreat would be delayed. A major storm event induced, however, severe erosion of the upper beach, and destruction of these fences. Their role as barriers against wave action was therefore nil.

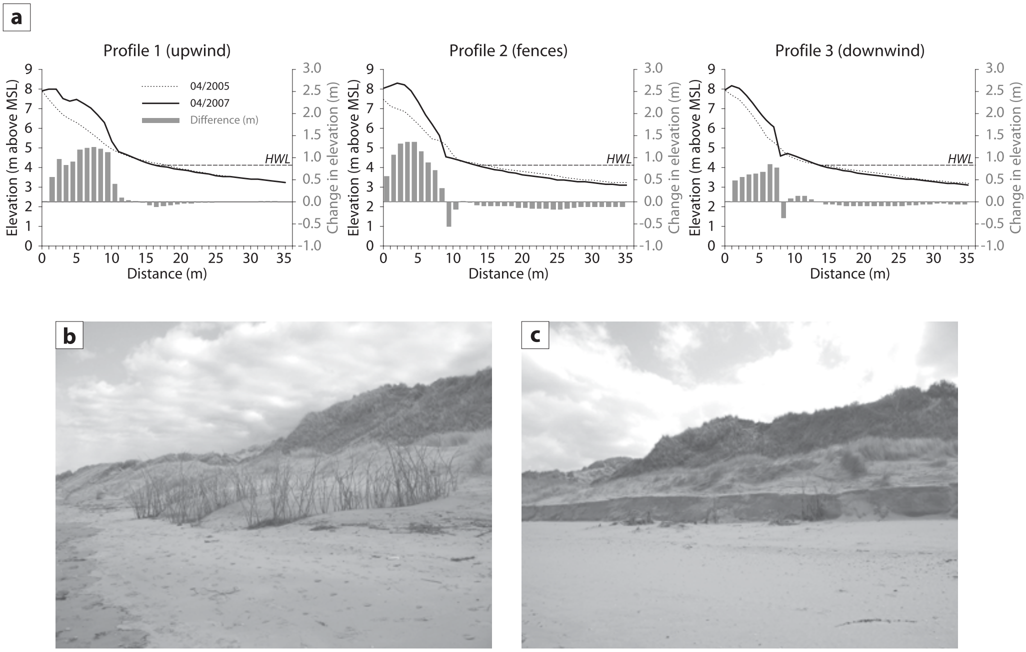

Fig. 8. Evolution of the upper beach-foredune at the Leffrinckoucke site from April 2005 to April 2007. (a) Profile evolution over this period. (b) Photograph of the upper beach in April 2005 showing sand trapping by the brushwood fences. (c) Morphology of the upper beach two days after a major storm in March 2007.

At the Leffrinckoucke site, sand fences installed at the upper tidal limit captured a significant amount of sand at the dune toe that formed a ramp, thus, enhancing the development of a foredune. Under normal conditions, with dominant moderate southwest to west-southwest winds, the nearly shore-normal design of the brushwood fences, similar to that of groynes on a beach (Anthony et al. 2007a), proved to be an efficient design in Leffrinckoucke. At the beginning of the survey, the structures captured a small amount of sand and most of the sand accumulated on the lee side of the second fence. With time, preferential accumulation with a shadow dune-like morphology developed at the upper limit of the third fence. This evolution can be related to the wind regime. Under dominant but moderate alongshore southwesterly winds, the sand body captured by the fences slowly migrated eastward. During strong episodic northerly winds, the sand was redistributed landward, on the foredune stoss slope. After 14 months, elevation changes show important accumulation over the whole survey area, suggesting generalised sand remobilisation from the upper beach to the dune toe and the foredune via the accumulation ramp. The role of such dune ramps in beach/dune interactions has been acknowledged in several studies (Christiansen 2002, Christiansen & Davidson-Arnott 2004). The formation of a dune ramp is dependent on the local beach sediment budget, the frequency and magnitude of storm surge and the patterns of wind speed and direction (Christiansen & Davidson-Arnott

2004). As the ramp extends up to the dune crest, it favours beach/dune sediment transfer. It is likely that the ramp induced wind speed-up, as noted on Skallingen spit by Christiansen and Davidson-Arnott (2004). The ramp was, however, ephemeral as the foredune was later scarped by a large storm surge.

The trend in the southern North Sea site of Leffrinckoucke illustrates the pattern of medium-term foredune development along this coast, which is dominated by moderate longshore winds. At the foredune toe, under prevailing southwesterly winds, accumulation occurs on the lee side of obstacles (litter or pioneer annual plants), leading to the formation of low shadow dunes. These embryo dunes are usually ephemeral accumulations, washed out during storm events. The accumulation at the dune toe can, however, merge with the foredune under strong onshore wind events that transport substantial amounts of sand that first form an accumulation ramp that subsequently further enhances beach-foredune sand transfers. Although these strong wind events are of low frequency, they are fundamental in foredune development, notably in redistributing inland the sand that accumulates at the dune toe.

The structures resisted a spring tide, in March 2005. In March 2007, a storm event induced surge combined with a spring tide, resulting in a major erosive event along this coast which has been previously described as being in a state of meso-scale stability (Ruz et al. 2005). The brushwood fences did not resist this storm. It is worthy of note that despite the significant volume of sand trapped at the dune toe by fences, these structures were no more efficient in mitigating erosion than adjacent sectors without fences, as shoreline retreat induced by this event was uniform throughout this coastal sector. This signifies that under extreme conditions, sand accumulating around fences, and fences installed at the upper tidal limit, are easily washed away and do not protect the foredune against storm wave attack. The brushwood fences enhanced, however, sand accumulation on the incipient foredune, which was not reached by waves. This occurs through the positive morphological ramp feedback effect. Once significant accumulation occurs at the dune toe, forming the ramp connecting the upper beach to the dune crest, sand is then actively transferred landward along this low-sloping surface and trapped by vegetation on the dune crest. From April 2005 to April 2007, more than 1.4 m of sand accumulated on the incipient foredune. Although the seaward face of the foredune showed a 2 to 3 m retreat, brushwood largely contributed to a positive sediment budget on the foredune front. On the other hand, the topographic profiles show that accumulation also prevailed not only on the upper beach but also westward and eastward of the brushwood structures. This means that along this portion of the beach, brushwood efficiency was reinforced by a net positive sediment budget. In reality, the difference in accumulation between the area equipped with brushwood and the surrounding areas was minor.

This study shows that the success of fencing in enhancing foredune development or foredune protection is largely dependent upon the available sand supply from the beach-shoreface system. Where a deficit prevails, as in Wissant beach, dune growth may not occur at all as fencing placed on the upper beach can easily be washed away under storm tide conditions. Although the erosive action of such storm events is usually conditioned by coincidence with large spring tides (Cooper et al. 2004, Pirazzoli et al. 2007), a context that may render unpredictable the timing of such potentially erosive events, retreat cannot be mitigated in the face of a negative sand budget. In contrast, a context of net sediment supply from foreshore to dune has certainly been the primary factor in enhancing sand accumulation and foredune development on Leffrinckoucke beach.

The results from these two surveys also clearly show that brushwood efficiency is dependent on site and location relative to the upper beach-foredune contact. In many areas where such fences are used to enhance aeolian dune accretion, particular attention is given to the way they are positioned, and this is usually above storm surge levels (Feilberg & Jensen 1992). Our study shows that the local sediment budget and the time span between individual storm events are crucial for the efficiency of dune fencing. A coastal compartment with a negative sediment budget will be much more sensitive to moderate storm surges than one where the sediment budget is balanced or positive. In this case only episodic large storm surges will induce dune retreat and scarping. Therefore, fences installed at the upper tidal limit will have enough time to accumulate sand, favouring foredune development.

Acknowledgements

Funding for work at the Leffrinckoucke site was provided by the INTERREG IIIA project "Beaches at Risk" and by the Dunkerque Urban Community. We thank the "Gardes du Littoral" of the "Conseil Général du Nord" for installing the sand fences at the Leffrinckoucke site. We also thank Denis Marin for preparing the illustrations. Hervé Regnauld and Derek Jackson provided constructive reviews.

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