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Confronting coastal morphodynamics with counter-erosion engineering: The emblematic case of Wissant Bay, Dover Strait.

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2 **Confronting coastal morphodynamics with counter-erosion engineering: The**
3 **emblematic case of Wissant Bay, Dover Strait.**
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11 **Abstract**

12 Wissant Bay is a picturesque and highly frequented French coastal resort comprising beaches,
13 dunes, marshes, and bold capes facing the Dover Strait. Situated at the southern approaches to
14 the North Sea, the 8 km-long bay has, arguably, the most rapidly eroding shoreline in
15 metropolitan France. Retreat has largely affected much of the bay shoreline west of Wissant
16 town, with parts of this sector having lost up to 250 m in the last fifty years, whereas a much
17 smaller sector east of the town is a zone of accretion. Various dune, beach and nearshore
18 morphodynamic studies conducted over the last decade have identified chronic sand bleeding
19 from the western sector and longshore transport to the east, within a framework of what
20 appears to be an ongoing shoreline rotation process within a dominant longshore sediment
21 transport cell between the headland of Cape Gris Nez to the west and the bold chalk cliffs of
22 Cape Blanc Nez to the east. Retreat of the narrowing beach-dune barrier poses a threat in the
23 coming years, as there is a likelihood of it being breached by storms. The seawall protecting
24 Wissant town has also been repeatedly damaged since 2000 due to the chronic sand deficit.
25 These changes involve interactions between a nearshore sand bank, a complex macrotidal
26 beach comprising multiple subtidal to intertidal bars and troughs subject to strong longshore
27 sand transport especially during storms, and aeolian dunes. The nearshore bank acts as a
28 dissipater of incident storm wave energy and as a sand source for the multi-barred beaches
29 and dunes, and has been strongly impacted by past massive aggregate extraction. The bank is,
30 in turn, part of a larger system of mobile banks reworked by storms and tidal currents within
31 the framework of a sand circulation system between the eastern English Channel and the
32 southern North Sea. The aim of this work is to confront knowledge acquired on the
33 morphodynamics of the bay with an engineering plan proposed to counter erosion and
34 reestablish shoreline stability. The plan is based essentially on the creation of an 'equilibrium'
35 beach profile, capable of withstanding storms, comprising an enlarged upper beach berm, and
36 constructed through beach nourishment from a nearshore source located 20 km east of
37 Wissant Bay. The plan has not been implemented because of cost. Even if it were to be
38 implemented, its efficiency seems very doubtful because the beach profile simulations on
39 which it is based neglect the complex multi-barred morphology and the overwhelming
40 dominant longshore transport over bars during storms. The plan is also geared towards
41 resolving a local problem of erosion that is embedded in the larger and rather complex
42 spatiotemporal morphodynamics and sediment transport mechanisms evoked above. Wissant
43 Bay is emblematic of the problems of erosion facing many communes in France, and
44 elsewhere. The fight against shoreline erosion generally starts with the commonly
45 insurmountable hurdle of fund-raising for costly engineering proposals that are not always
46 based on a clear grasp of the embedded scales of change affecting the coast.
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56 **Keywords:** Coastal erosion, coastal engineering, coastal morphodynamics, macrotidal coast,
57 beach nourishment, beach rotation, Wissant Bay.
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Introduction

1 One reason for the failure of many operations aimed at countering shoreline erosion is that
2 their conception and implementation are commonly not based on a sufficient knowledge of
3 processes shaping the coast at various morphodynamic scales. In many situations, the links
4 between short- to long-term geomorphic change in small segments of coast and the way these
5 are embedded in, and controlled by, larger-scale aspects of coastal change, are not always
6 well apprehended (Gelfenbaum and Kaminsky, 2010). From a coastal management point of
7 view, a first step towards a better understanding of this scale relationship has been the coastal
8 cell concept, commonly used in a sediment budgetary framework in which process gradients
9 may or may not be ignored, the emphasis being on definition of each coastal cell and on the
10 net gains and losses of sediment within each cell (e.g., Bray *et al.*, 1995; Cooper and Pontee,
11 2006; Patsch and Griggs, 2008; Anfuso *et al.*, 2011; van Rijn, 2011). This is a useful
12 approach but even where coastal cell definition may appear simple, the task of simply
13 delineating the shoreline and constraining the processes operating both across shore and
14 alongshore in such cells may turn out to be difficult (Kaminsky *et al.*, 2010). In particular, the
15 sediment dynamics of alluvial coasts subject to large tidal ranges can be quite complex
16 because of potentially strong tidal currents, modulation of wave action by tides, and large
17 variations in the 'shoreline' controlled by tidal range. This situation can be even more so
18 where large stocks of loose mobile sediments are available and constantly reworked by
19 processes generated by waves and currents over large shorefaces, as in the English Channel,
20 the southern North Sea and some of the marginal seas in Asia. The ensuing morphodynamic
21 adjustments between such sediment stocks and the forcing agents can lead to particularly
22 complex situations where sediment cells are hard to define and where apprehension of coastal
23 change requires crossing short- to long-term series of observations at various spatial and
24 temporal scales. In such situations, sound solutions to problems of local coastal erosion
25 require taking into account the complex, larger-scale morphodynamic background.

26 These issues are examined here using the example of Wissant Bay, a highly frequented resort
27 in the Dover Strait (Fig. 1a), set in a particularly complex environment in terms of coastal
28 processes. The bay shoreline has varied significantly over the last half century, with certain
29 sectors, hitherto prograding, now in a particularly critical condition in terms of erosion. A
30 detailed plan has been set up for the implementation of engineering solutions. Meanwhile,
31 numerous studies conducted over the last decade have progressively highlighted the complex
32 patterns of shoreface and shoreline change at both the small-scale level of the Wissant town
33 front, where erosion poses a direct hazard, and at the larger bay scale. This larger scale is
34 embedded in the hydrodynamic and sediment circulation system of the Dover Strait. In this
35 paper, we will briefly summarise the recent findings on the morphodynamics of the bay,
36 confront these with the proposed engineering solutions, and then discuss why Wissant Bay is
37 emblematic of many communes, in France, and elsewhere, where the fight against erosion is
38 commonly stalled by fund-raising for costly engineering proposals that are not always based
39 on a clear understanding of the embedded scales of change affecting coasts.

Wissant Bay

Beach, dune and shoreface morphology

40 Wissant Bay is, in terms of setting and morphological diversity, commonly considered as one
41 the most picturesque sites on the southern North Sea coast, occupying an 8 km-long mild
42 embayment between bedrock cliffs. Wissant town has functioned as a resort since the 19th
43 century. It is extremely popular, and its beaches, dunes, marshes, and bold capes facing the
44 Dover Strait offer a variety of tourism-based recreation and leisure activities. The bay is also
45 part of a protected site. The dunes in Wissant Bay form a linear barrier 100 to 300 m wide and
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1 with a maximum inland height of about 20 m. They impound marshes of ecological value.
2 The beach is characterised by multiple intertidal to subtidal bars and troughs (ridges and
3 runnels). In this transition zone between the eastern English Channel and the southern part of
4 the North Sea, the gently sloping shallow shoreface extending seaward of the beach bars and
5 troughs is characterized by prominent tidal sand banks and ridges that are particularly well
6 developed as the narrow Dover Strait opens up on the epicontinental southern North Sea (Fig.
7 1a). These banks are up to several kilometres long and have heights of up to 10 m. They
8 practically impinge on the beach in places. These elongated sand bodies are commonly
9 oriented WSW-ENE, roughly parallel to sub-parallel to the coastline. One of these tidal
10 banks, the Line Bank, lies just off Wissant Bay (Fig. 1b). The importance of these nearshore
11 banks for coastal stability in the southern North Sea has been emphasised in a number of
12 recent studies (Anthony *et al.*, 2007, 2010; Héquette and Aernouts, 2010; Anthony, 2013).
13 Sand banks modulate both wave dissipation patterns and onshore sand supply for coastal dune
14 accumulation. They are consequently involved in longshore variations in shoreline accretion
15 and erosion, the latter occurring where bank sand supply and protection from waves are
16 lacking. The banks can also weld onto the coast, leading to locally important coastal accretion
17 at multi-decadal timescales. Aernouts and Héquette (2006) showed, from differential
18 bathymetric analysis, that the Line Bank underwent erosion during the 20th century, losing
19 over 1 million m³ of sand over a 90-year period. This loss has been due essentially to massive
20 aggregate extraction, especially in the western sector of the bank closest to the coast. This
21 practice was prohibited in the 1980s but the damage had already been done. The lowering of
22 the Line Bank by seabed mining not only curtailed sand supply to the western part of Wissant
23 Bay, but may also have induced a process of erosion that became self-maintained following
24 the prohibition of extraction. The dynamics of the Line Bank are likely to be embedded in a
25 process of longer-term larger-scale storm- and tide-controlled sand migration from the eastern
26 English Channel towards the Dover Strait and the southern North Sea, a process that could
27 explain a west-east gradient of decreasing bank lowering.
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33 Hydrodynamic context

34 Wissant Bay lies in a typical mixed storm-wave- and tide-dominated environment subject to a
35 complex pattern of time-varying influences of tides and storms, in addition to wind-forced
36 flows (Héquette *et al.*, 2008). Winds are dominantly from southwest and northeast, but the
37 strongest winds mostly originate from west to southwest. The hydrodynamic context is that of
38 a short-fetch, storm-wave environment, characterised by marked short-term (order of days to
39 weeks) fluctuations in wave height (Fig. 2a). The dominant waves are from southwest to west,
40 originating from the English Channel, followed by waves from the northeast to north,
41 generated in the North Sea. Breaking waves are essentially from a north-northeast to
42 northwest window, although the dominant deepwater directions are from both north and west.
43 The tidal regime in the region is semi-diurnal and macrotidal, the tidal range in Wissant Bay
44 being about 6.5 m during spring tides. In calm weather, current directions are closely
45 conditioned by the tide, with dominantly longshore eastward-directed flood directions and
46 westward ebb directions (Fig. 2b). Strong winds enhance ebb or flood current speeds when
47 blowing in the same direction, or limit, and even prevent tidal reversal when blowing in the
48 opposite direction in the bay (Sedrati, 2006), but flow is more commonly flood-dominated.
49 During conditions of significant wind stress (sustained wind speeds $> 10 \text{ m.s}^{-1}$), the peak
50 current speeds can be two to three times higher than 'normal' (tide-generated) peak spring
51 tide speeds ($\sim 0.45 \text{ m.s}^{-1}$). Longshore currents, especially setting east, can become particularly
52 strong during storms as a result of direct wind stress (Sedrati and Anthony, 2007) and
53 reinforcement by longshore gradients in radiation stress that divert, alongshore, offshore mean
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1 currents generated as waves pass over or break over the sand banks (Anthony, 2013). Storms
2 may add up to 1 m of surge above high-tide swash excursion levels.

3 Morphodynamic sectors

4 Wissant Bay comprises three sectors (Fig. 1b): a 6 km-long strongly eroding western sector,
5 comprising Dune du Châtelet and Dune d'Aval, where the foredune has retreated by up to 250
6 m between 1949 and 2000 (Fig. 3), following an early period of stability and even
7 progradation (Aernouts and Héquette, 2006; Chaverot *et al.*, 2008), a short central sector,
8 Wissant town, fronted by a seawall that has held the shoreline, and an equally short accreting
9 eastern sector, Dune d'Amont. Sedrati and Anthony (2008) showed that a retreat rate of the
10 dune front of up to 4 m in the eroding western sector can occur in just 24 hours during severe
11 storms associated with high surge levels (up to 1 m) and high spring tides. This value is
12 equivalent to the annual mean shoreline retreat rate calculated for the Dune d'Aval sector by
13 Aernouts and Héquette (2006). This suggests a highly rhythmic foredune retreat that depends
14 on the right combination of storm waves, spring tidal range and storm surge conditions. This
15 erosion has led to the cropping out of peat on the beach representing former backbarrier
16 vegetation. Erosional in the past, the eastern sector of the bay is now a zone of deposition,
17 characterised by significant foredune growth and active formation of embryo dunes (Anthony
18 *et al.*, 2006). In terms of the overall shoreline dynamics, the western and central parts of the
19 bay constitute a long updrift erosional sector linked to a short downdrift depositional sector in
20 the east.

21 Figure 4 shows unpublished beach profiles that summarise these three sectors. The first and the
22 last of these three profiles start from the dune front. The Wissant profile starts from the seawall
23 protecting the town. The Dune d'Aval profiles show a typical system of bars and troughs the
24 changes of which reflect both cross-shore beach mobility and longshore bar mobility. Two
25 significant aspects associated with the profile changes at this site are the low elevation of the
26 beach close to the dune front and the marked retreat of the latter (Fig. 4a). At a distance of 100
27 m from the survey origin point, the beach profile fluctuations occur within an envelope of
28 nearly 4.5 below the high water neap tide level. The dune front shows nearly monotonous
29 retreat over the survey period, exceeding 20 m. The Wissant townfront profile shows much
30 larger fluctuations than the previous profile (Fig. 4b). The bar and trough morphology is,
31 consequently, much more pronounced. At a distance of 100 m from the survey point on the
32 seawall, the beach fluctuations are up to 4.5 m below the level of high neap tides. The envelope
33 of fluctuations at the foot of the seawall attained up to 3 m during the survey period. The Dune
34 d'Amont profile shows a system of more subdued bars with a milder envelope of fluctuation
35 (Fig. 4c). The envelope below the mean high water neap tide level within the 100 m distance is
36 about 2 m.

37 The net sand budget changes of the three profiles over the survey period are depicted in Fig. 5.
38 Dune d'Aval and Wissant town front show a fluctuating but strongly negative sand budget over
39 much of the survey period, whereas Dune d'Amont beach shows a fluctuating but net positive
40 budget with a single negative value in 1998. The three profiles in Wissant Bay show envelope
41 patterns and net budget changes that reflect the west to east gradient in shoreline mobility
42 highlighted by Chaverot *et al.* (2008). The profile of the beach in the eroding western sector of
43 the bay is significantly lower than in the accreting sector in the east. This difference in
44 elevation also goes with much larger bar and trough fluctuations in the eroding sector, which
45 clearly incorporates Wissant town front. Photographs of the town front shoreline in 1952 and
46 1986 show a much more accreted beach with sand covering the seawall, which is clearly
47 visible in the earlier 1909 photograph (Fig. 6a). This suggests that sand was still accumulating
48 in this central sector nearly 30 years ago, a situation that contrasts with the beach lowering and
49 repeated damage to the seawall since 2000 (Fig. 6d-f).

Proposed management solutions to erosion

The investigations summarised above have thrown light on the large-scale processes involved in sediment movements in which are embedded shorter-term changes such as those depicted by the beach profiles (Fig. 4). To summarise these findings, we note active sand transfer over the shoreface of the bay from west to east within at least the last three decades, resulting in sustained erosion of the western bay foredunes and lowering of the beach. The retreat constitutes a threat in the coming years, because of the likelihood of storm breaching of the narrowing dune barrier. In essence, this entails eventual failure of the retreating dune front in the west, leading to marine invasion of a backbarrier marsh (Fig. 1b) of high ecological value. Wissant town is also becoming increasingly vulnerable to submersion.

At the scale of the entire bay shoreline, the only sector where efforts at containing erosion have been deployed is the town front with its seawall. Figure 6a shows an inclined seawall in 1906 that served as a coastal defence structure in replacement of the mobile dunes and as a seafront promenade as the town prospered essentially from winter tourism. The wall assumed a military defence function during World War 2 when the Atlantic Wall was built along large parts of the French coast, including Wissant Bay, by the German army. Much of this Atlantic wall has been eroded. Remnants still subsist on the beach in the western sector, whereas remnants in the eastern accreting sector have been largely buried by aeolian dune accretion. Since 2000, the seawall fronting the town has been damaged on several occasions by storms, and undermined by beach lowering at its base (Fig. 6d-f). The difference in profile morphology between Dune d'Aval and Wissant town (Fig. 4) appears to reside essentially in the presence of this seawall, which has acted as a rampart against shoreline retreat, notwithstanding the progressive beach lowering. Hence the exclusion of this sector (Fig. 3) from the multi-decadal shoreline mobility survey conducted by Chaverot *et al.* (2008).

The fight against erosion in Wissant Bay has been mainly focussed on maintaining the seawall. Damages have been repaired in piecemeal fashion following severe storm attacks (Fig. 6), as the wave of erosion, largely ignored as long as it concerned only the uninhabited Dune du Châtelet and Dune d'Aval sector, started affecting the town front more actively. Wissant Bay is a protected site of natural value, and this drastically reduces the possibility of implementing heavy defence structures such as breakwaters and concrete or rock groynes. The installation of a low-cost but more ecologically 'friendly' defence system of wooden dykes was envisaged but rapidly abandoned by the communal authorities because it was viewed as nefarious to tourism and recreation. The most comprehensive management options have been proposed by CETMEF (2004), a state-run agency in fluvial and coastal engineering expertise, and by SOGREAH (2006), a private hydraulic engineering firm. In a global study that recommended beach nourishment as the primary solution, CETMEF (2004) stipulated that a policy of 'no intervention' constituted a threat to the commune. This report also recognised the limited utility of reinforcing the seawall by emplacing rock armouring because of the rampant erosion and the high cost of this defence option, as well as the relatively low potential efficiency of wooden groynes, and the problems such structures will pose for various beach activities such as kiting, kite-surfing, sand yachting and speed sailing. CETMEF (2004) proposed sand nourishment over a distance of 2.5 km covering the central sector (Wissant town front) and extending 200 m west of the seawall. This solution was subsequently also retained by SOGREAH (2006). Much of the expertise proposed was based on defining an 'equilibrium' beach profile to be attained through nourishment using a variant of the SBEACH (Storm-induced BEACH Change) Model of the US Army Corps of Engineers (Larson and Kraus, 1989; Rosati *et al.*, 1993) that simulates cross-shore beach, berm, and dune erosion produced by storm waves and high water levels. SOGREAH (2006) proposed an initial renourishment to the

1 tune of 300,000 m³ in order to rebuild the upper beach lowered by erosion and to attain this
2 equilibrium profile, and examined the possibility of the adjunction of groynes to hold the
3 recharged sand against drift to the east, but this latter proposal was discarded on the grounds
4 evoked above. An alternative solution of complementary annual nourishment to the tune of
5 15,000 m³ was thus proposed. Another complementary option consisted in installing a beach
6 drainage system using the *Ecoplage*[®] procedure to help maintain recharged sand. The
7 nourishment project also recommended the dismantling of the last blockhouses subsisting as
8 part of the Atlantic seawall, and dune rehabilitation in the eroding Dune d'Aval sector. The
9 estimated cost of these operations ranged from 6.2 to 9.05 M€, depending on optional
10 adjunctions, maintenance and annual sand recharge over 20 years. The plan also highlighted
11 the numerous risks of failure and uncertainties related to the operations proposed.
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16 **Discussion: confronting engineering options with processes and scales of shoreline change**

17 Wissant Bay is an emblematic example of the problems facing many coastal communes in
18 France wherein several layers of difficulties have resulted in stalled shoreline protection and in
19 failure in the fight against erosion. A major problem, which is the focus of this paper, is that of
20 confronting such solutions with morphodynamics of the coast at various scales. Confronting
21 management options with the processes and scales involved in shoreline change is often a
22 major challenge. This is particularly well illustrated in Wissant Bay, arguably the most
23 strongly eroding coast in metropolitan France. The engineering solutions proposed to stave off
24 erosion in Wissant Bay do not sufficiently take into account the complexity of the sediment
25 dynamics of the bay. This large tidal-range setting is subject to important tide-, wind- and
26 storm-wave-controlled fluxes that are embedded in a larger-scale sediment circulation system
27 between the eastern English Channel and the North Sea. The shoreline rehabilitation plan
28 proposed by SOGREAH (2006) is strongly centred around simulations of an equilibrium beach
29 profile (corresponding essentially to the Wissant town front sector (Fig. 4b)) that includes the
30 construction, via beach nourishment, of an enlarged berm, in front of the failing seawall,
31 capable of withstanding storm attack, and the stability of which will be further enhanced by the
32 *Ecoplage* operation. However, the maintenance of a complex multi-barred profile of the beach
33 in Wissant Bay is not considered in these simulations which are indeed unlikely to adequately
34 replicate such complex beach morphology. Storm wave dissipation is assured by: (1) the Line
35 Bank offshore, (2) inshore by the multiple subtidal to intertidal bars, and (3) the aeolian
36 foredune front, and not just by an enlarged beach berm and upper beach drainage. Furthermore
37 the main beach morphodynamic process during such storms is strongly hinged on longshore
38 sand transport over the bars, rather than on offshore sand losses. Figure 7 shows unpublished
39 calculated sand transport rates over the multi-barred beach using the formulation by van Rijn
40 (1990), based on wave and current data acquired in 2005 (Sedrati, 2006). The results highlight
41 the overwhelming importance of longshore transport relative to cross-shore transport. Sedrati
42 and Anthony (2007) showed from high-resolution beach topographic changes that these
43 longshore transport conditions are considerably reinforced during storms. Anthony (2013) has
44 recently suggested that this longshore transport may be reinforced by longshore gradients in
45 radiation stress generated by 3D changes in the morphology of the Line Bank from west to
46 east. These gradients divert offshore storm flows alongshore, hence preventing sand loss
47 offshore but strengthening sand transfers from west to east.
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55 The large-scale interactions encompassing the Line Bank offshore clearly illustrate here the
56 difficulty, predicted by Sipka (1997), of using the cell concept as a management tool on the
57 macrotidal coasts of the Dover Strait and the southern North Sea where cell boundaries are
58 hard to delimit both alongshore and seaward. It seems very likely that the progressive erosion
59 affecting Wissant Bay is part of the long-term (multidecadal) shoreline response to the
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1 lowering of the Line Bank, diminishing both its capacity to dissipate storm waves and to
2 supply sand to the beaches and foredunes in the west. As lowering of the Line Bank has
3 occurred, storm wave energy dissipation has been largely transferred to the bar-trough beach
4 and the foredune front, notably in the deeper western sector. Aernouts and Héquette (2006)
5 showed from a SWAN wave propagation model simulation that incident wave energy over the
6 bank had increased in 2002 relative to 1977 due to the lower bank surface. The beach and
7 dunes adjacent to the deeper western end of the bank have, therefore, been rapidly retreating.
8 Although the thrust of the anti-erosion plan proposed by SOGREAH (2006) is on cross-shore
9 dissipation of storm wave energy, the plan does recognise the need to contain longshore sand
10 transport but only via a short-term (with costs exponentially increasing from five to 20 years)
11 renourishment plan. There is no vision of what may happen beyond this period. The past
12 changes in shoreline retreat and advance that have affected Wissant Bay have been viewed in
13 terms of a multidecadal to secular shoreline rotation process (Sedrati and Anthony, 2008).
14 There appears to be little scope for reversal of this sand transfer process in the future, given the
15 effectively strong large-scale residual drift to the east. Rotation is generally reversible, but also
16 operational on shorter timescales of seasons (e.g., Norcross *et al.*, 2002; Jeanson *et al.*, 2013)
17 to years (Thomas *et al.*, 2012). The strong drift to the east that reinforces the destabilisation of
18 the western sector of the bay is also due to combined wave, tide and wind-induced currents,
19 thus differentiating the Wissant Bay system from many of the beach rotation examples
20 described in the literature, driven by changes in combined incident wave energy and direction.
21 Since one of the two trailing edges of the Line Bank is close inshore in the Dune d'Amont
22 sector, it probably provides sand for the coastal dunes and shelters the shore from the larger
23 storm waves. The loss of sand by this bank and the scale of longshore sand transfer to the east
24 may suggest that even an expensive long-term renourishment solution based on constant
25 truckload transfers to the western beach sector of sand accumulating feeding foredune
26 accretion in the east may not be tenable in terms of cost, nor given the ecological status of the
27 bay dunes. Without a consideration of the rehabilitation or renourishment of the Line Bank
28 sand source and wave energy dissipater, such a renourishment solution may also not be enough
29 to counter the progressive retreat of the dunes in the west of the bay. The anti-erosion and
30 rehabilitation plan proposed by SOGREAH (2006) does not concern aeolian dune
31 rehabilitation in the eroding western sector.

32 Two other problems facing the fight against erosion in Wissant Bay are a clear definition of
33 responsibilities in coastal management and in the implementation of engineering solutions
34 against erosion, and finding funds to finance such engineering solutions. Lobbying against
35 erosion has been spearheaded by the landowners' association in Wissant Bay. A French law of
36 1807 stipulated the setting up of landowner associations that had to bear, proportionately to the
37 interests of each landowner, all costs of defence or maintenance works carried out on the shore
38 or along river banks. Exceptions concerned sectors where government interests were
39 concerned, thereby providing a source of state subsidy for such works. Enforcement of this law
40 was never really assured and under the continuing pressure of coastal urbanisation, generally
41 spurred on by large-scale lucrative estate acquisition and development, the state decided, in the
42 Law of 1973, to allow individual communes or unions of communes to undertake coastal
43 defence works where this was deemed necessary to preserve the common interest. This is
44 presently the situation in France, where the municipality or commune bears the costs of local
45 defence operations, with the possibility of additional funding by the Regional Council.
46 Authorisations concerning the implementation of defence works on urbanised coasts, and
47 decisions as to whether state funding is appropriate, are taken by a regional engineer delegate
48 of the state directorate responsible jointly for matters of environment, territorial management,
49 and housing. State funding is exceptional. The problem is compounded in Wissant Bay by the
50 high costs involved in even implementing a plan such as that proposed by SOGREAH (2006).
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1 van Rijn (2011) indicated as an acceptable cost a range of 100-150 € per metre of coast per
2 year over a 20-year period for 100 km of the Holland coast, a country where the fight against
3 coastal erosion is as much a tradition as a national priority. The cost of the proposed Wissant
4 Bay plan is 125-362 € per metre of coast over a 20 year period depending on options and
5 effective maintenance operations, a cost well beyond the possibilities of the commune.
6 Effective implementation of the plan has been delayed by lack of funds and it is doubtful
7 whether the plan will be ever implemented. Hence the continuing erosion and the piecemeal
8 repairs to the seawall.
9

10 11 **Conclusion**

12 The case of Wissant Bay illustrates a common situation in France, and in many other countries,
13 where problems of shoreline defence and rehabilitation are considered in a short-term,
14 piecemeal perspective that is often hinged on local problems that are not viewed within the
15 larger context of spatiotemporal shoreline change and the processes involved. In France, there
16 has generally been lacking an overall view of management practice in terms, for instance, of
17 coastal sediment cells, although this situation has been changing in the last few years. As a
18 result, the spread of beach erosion has commonly been aggravated by individual communal
19 efforts lacking a common view of what exactly is happening, and the effects on downdrift
20 sectors, of engineering structures implanted in updrift sectors. The problem has been
21 exacerbated by the high costs involved in implementing a plan against erosion. The
22 implementation of the anti-erosion operations proposed by SOGREAH (2006) has been
23 delayed by lack of funds and it is doubtful whether these operations will ever see the light of
24 day. Should one conclude from this that the cost of defending Wissant is too high relative to
25 the value of the resort? This raises the delicate issue of considering other management options
26 such as set-back lines (e.g., Ferreira *et al.*, 2006), options that may not be readily accepted by
27 the communal authorities of Wissant.
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41 **References**

- 42 Aernouts, D., Héquette, A., 2006. L'évolution du rivage et des petits fonds en Baie de
43 Wissant pendant le XX^e siècle, Pas-de-Calais, France. *Géomorphologie : relief,*
44 *processus et environnement*, 1, 49-64.
45 Anfuso, G., Pranzini, E., Vitale, G., 2011. An integrated approach to coastal erosion problems
46 in northern Tuscany (Italy): Littoral morphological evolution and cell distribution.
47 *Geomorphology*, 129, 204-214.
48 Anthony, E.J., 2013. Storms, shoreface morphodynamics, sand supply, and the accretion and
49 erosion of coastal dune barriers in the southern North Sea. *Geomorphology*, 199, 8-21.
50 Anthony, E.J., Mrani Alaoui, M., Héquette, A., 2010. Shoreface sand supply and mid- to late
51 Holocene aeolian dune formation on the storm-dominated macrotidal coast of the
52 southern North Sea. *Marine Geology*, 276, 100-104.
53 Anthony, E.J., Vanhée, S., Ruz, M.H., 2006. Short-term beach-dune sand budgets on the
54 North Sea coast of France: sand supply from shoreface to dunes and the role of wind
55 and fetch. *Geomorphology*, 81, 316-329.
56
57
58
59
60
61
62
63
64
65

- 1 Anthony, E.J., Vanhée, S., Ruz, M.H., 2007. Embryo dune development on a large actively
2 accreting macrotidal beach: Calais, North Sea coast of France. *Earth Surface Processes
3 and Landforms*, 32, 631-636.
- 4 Bray MJ, Carter DJ, Hooke JM., 1995. Littoral cell definition and budgets for central southern
5 England. *Journal of Coastal Research*, 11, 381-400.
- 6 CETMEF, 2004. Approche qualitative du fonctionnement hydrosédimentaire de la baie de
7 Wissant et son application pour la définition de solutions. Rapport du Centre d'études
8 techniques maritimes et fluviales. Ministère de l'Équipement, des Transports, du
9 Logement, du Tourisme et de la Mer. 72 p.
- 10 Chaverot, S., Héquette, A., Cohen, O., 2008. Changes in storminess and shoreline evolution
11 along the northern coast of France during the second half of the 20th century. *Zeitschrift
12 für Geomorphologie* 52, Suppl. 3, 1-20.
- 13 Cooper, N.J., Pontee, N.I., 2006. Appraisal and evolution of the littoral 'sediment cell'
14 concept in applied coastal management: Experiences from England and Wales. *Ocean
15 & Coastal Management*, 49, 498-510.
- 16 Ferreira, O., Garcia, T., Matias, A., Taborda, R., Alveirinho Dias, J., 2006. An integrated
17 method for the determination of set-back lines for coastal erosion hazards on sandy
18 shores. *Continental Shelf Research*, 26, 1034-1044.
- 19 Gelfenbaum, G., Kaminsky, G.M., 2010. Large-scale coastal change in the Columbia River
20 littoral cell: An overview. *Marine Geology*, 273, 1-10.
- 21 Héquette, A., Aernouts, D., 2010. The influence of nearshore sand bank dynamics on
22 shoreline evolution in a macrotidal coastal environment, Calais, Northern France.
23 *Continental Shelf Research*, 30, 1349-1361.
- 24 Héquette, A., Hemdane, Y., Anthony, E.J., 2008. Sediment transport under wave and current
25 combined flows on a tide-dominated shoreface, northern coast of France. *Marine
26 Geology*, 249, 226-242.
- 27 Jeanson, M., Anthony, E.J., Dolique, F., Aubry, A., 2013. Wave characteristics and the
28 morphology of pocket beaches fronted by a coral reef-lagoon system, Mayotte Island,
29 Indian Ocean. *Geomorphology*, 182, 190-209.
- 30 Larson, M., Kraus, N. C. (1989). Sbeach: Numerical model for simulating storm-induced
31 beach change. Report 1: Empirical foundation and model development. Technical Report,
32 CERC-89-9. 266 p.
- 33 Norcross, Z.M., Fletcher, C.H., Merrifield, M., 2002. Annual and interannual changes on a
34 reef-fringed pocket beach: Kailua Bay, Hawaii. *Marine Geology*, 190, 553-580.
- 35 Patsch, K., Griigs, G.B., 2008. A sand budget for the Santa Barbara Littoral Cell, California.
36 *Marine Geology*, 252, 50-61.
- 37 Rosati, J. D., Wise, J.D., Kraus, N.C., Larson, M. (1993). Numerical model for simulating
38 storm-induced beach change. Report 3: User's Manual, Technical Report, CERC-93-2,
39 65 p.
- 40 Sedrati, M., 2006. Morphodynamique transversale et longitudinale de plages à barres
41 intertidales en domaine macrotidal et en conditions de forte agitation : Baie de Wissant,
42 Nord de la France. Thèse de Doctorat, Université du Littoral Côte d'Opale, Dunkerque.
- 43 Sedrati, M., Anthony, E.J., 2007. Storm-generated morphological change and longshore sand
44 transport in the intertidal zone of a multi-barred macrotidal beach. *Marine Geology*,
45 244, 209-229.
- 46 Sedrati, M., Anthony, E.J., 2008. Sediment dynamics and morphological change on the upper
47 beach of a multi-barred macrotidal foreshore, and implications for mesoscale shoreline
48 retreat: Wissant Bay, northern France. *Zeitschrift für Geomorphologie* 52, Suppl. 3, 91-
49 106.
- 50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

- 1 Sipka, V., 1997. Les cellules sédimentaires du littoral du Nord Pas-de-Calais, Nord de la
2 France. Définition et applications. International Symposium Bordomer 97, Bordeaux,
3 Vol. 1: 61-70.
- 4 Thomas, T., Phillips, M.R., Williams, A.T., Jenkins, R.E., 2012. Medium time-scale
5 behaviour of adjacent embayed beaches: Influence of low energy external forcing.
6 Applied Geography, 32, 265-280.
- 7 SOGREA, 2006. Requalification du site de la Baie de Wissant – Réensablement de la partie
8 centrale. Rapport Final, Phase 3, Juillet 2006, 97 p.
- 9 van Rijn, L.C., 1993. Principles of Sediment Transport in Rivers, Estuaries and Coastal Seas.
10 Aqua Publications, Delft Hydraulics, Amsterdam, 673 p.
- 11 van Rijn, L.C., 2011. Coastal erosion and control. Ocean & Coastal Management, 54, 867-
12 887.
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17 **Figure captions**

- 18 Figure 1. Wissant Bay in the southern North Sea facing the Dover Strait (a); sketch showing
19 the shoreline status of Wissant Bay and the Line Bank offshore (b).
20
- 21 Figure 2. Offshore wave heights over a one-year period from the Sandettie lightship (UK Met
22 Office) (a), and a two-week record of wind conditions, inshore water levels, wave
23 conditions, and mean longshore and cross-shore currents in the eroding Dune d'Aval
24 sector, January 2005. From Sedrati, 2006.
- 25
- 26 Figure 3. Rates of shoreline change in Wissant Bay calculated for various time slices between
27 1949 and 2000, showing the strong fluctuations both alongshore and over time. From
28 Chaverot *et al.* (2008). The townfront seawall has acted as a rampart against shoreline
29 retreat. Note that longshore transect gaps in top figure are not reproduced in bottom
30 figure.
31
- 32 Figure 4. An 8-year dataset of beach profiles representing the three sectors of the bay: (a)
33 Dune d'Aval, (b) Wissant town front, (c) Dune d'Amont. The data reported here concern
34 monitoring between 1996 and 2005 at intervals of six months. Profile data are missing for
35 the years from 2001 to 2003. The profiles were surveyed using a high-resolution TC 407
36 Leica total station with errors within ± 3 mm for distance and elevation and $\pm 0.0015^\circ$ for
37 direction. An uncertainty margin of 5 cm, covering both field measurement and
38 interpolation errors and uncertainties, was applied in the treatment of the raw profile data.
39 All surveys were referenced to IGN 69 benchmarks of the French national datum.
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- 42 Figure 5. Profile volume changes over the 8-year survey for the three sectors of the bay: (a)
43 Dune d'Aval, (b) Wissant town front, (c) Dune d'Amont.
- 44
- 45 Figure 6. Photographs of the seawall fronting Wissant town: (a) 1906; (b) 1952; (c) 1986; (d)
46 2002; (e) 2007; (f) 2010. The synopsis shows a shift from a situation of relative sand
47 abundance in front of the wall, with sand even masking it (1952, 1986), to one of beach
48 erosion and damage to the seawall between 2002 and 2010. Note the rock armouring
49 emplaced to protect the front of the wall in the 2010 photograph.
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- 51 Figure 7. Sand transport rates calculated using the van Rijn (1993) formula, from data
52 obtained from current meters deployed in January 2005 over two bars submerged at high
53 tide in the eroding Dune d'Aval sector, with peaks expressing the dominant longshore
54 transport (a); the strong relationship between these rates and longshore current velocities
55 (b). From Sedrati (2006).
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