15. BELGIUM

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GENERAL NATURE OF THE COASTLINE

Belgium's sandy, rectilinear, and macrotidal coastline is about 65 km long (Fig. 1). It borders the southern North Sea in a southwest to northeast direction, showing a gentle southward deflection east of Wenduine. It is situated a short distance from the large Rhine-Meuse-Scheldt Delta and near to the entrance of the Westerscheldt, a 5 km/wide estuary. Beside the mouth of the small river Ijzer, a few canal outlets (the harbours of Ostend, Blankenberge, and Zeebrugge) and the inlet of the Zwin tidal creek, the only remnant of the large 12th Century Zwin estuary, no more entrances breach that coastline.

Prevailing winds and waves coming in from southwest to northwest and eastward longshore peak flood currents provoke a residual eastward littoral drift, and some sediment sorting. This is shown by the westward coarsening of the beach sands and by sediment differentiation on both sides of the Zeebrugge breakwaters, under construction since 1980. Prevailing winds cause a dominantly eastward longshore, wind transport and little landward eolian sand migration. A 14th Century landward dune migration near Koksijde has been the most spectacular exception.

Seaward the fore-shore continues in a broad and shallow sublittoral zone. The -5 m isobath (below M.L.L.W.L.) runs at about 1,500 m in front of the low water mark. Further offshore extend several fields of sandbanks and subtidal channels with maximum depths up to 30 m, the nearest of which run parallel to the coastline (Fig. 1). The tide is semidiurnal. The mean tidal amplitude reaches 4 m with a slight decrease from west to east. Fetches of more than 200 km occur only toward the north so that northwest to north storms are the most devastating ones.

The coastal zone itself comprises a beach, backed by a continuous dune belt commanding a low coastal plain, adjacent to a slightly uprising land developed in Pleistocene and in Tertiary deposits.

The beach is of a very gently sloping and fine sandy runnel and ridge type. Its average slope varies from one to 2.5% from the west to

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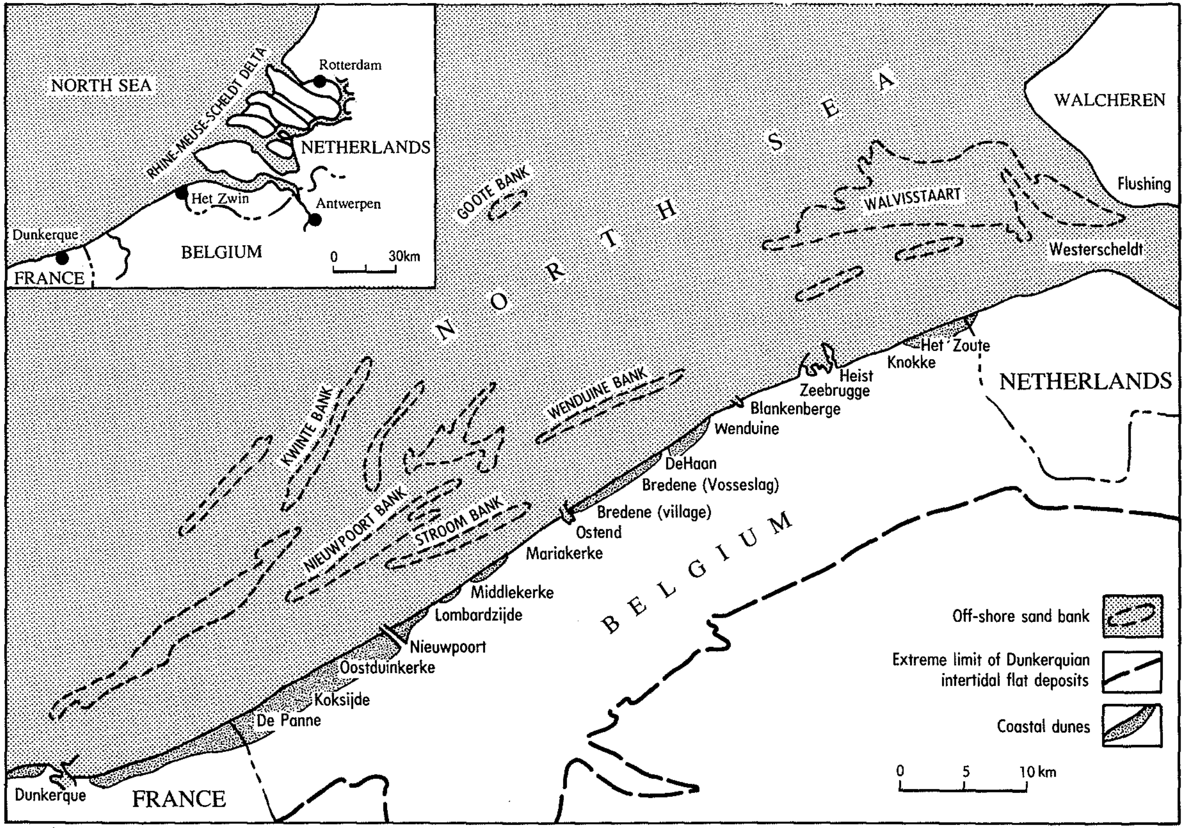

Fig. 1. The coast of Belgium.

the east and its width from 500 m in the west to hardly 200 m in the east. In several places the coast has been hit by strong erosion extending over a few 100 to a 1,000 m, lasting a few years to a few decades, locally followed up by a new natural residual sand supply and by beach and dune-foot restoration. This natural cycle of erosion and accretion, however, has locally been turned into a permanent erosion situation, mainly because of works executed for the construction of and approachability to harbours.

The dune ridges, mostly stabilized by vegetation, are generally less than 20 m high. The width of the dune belt varies from a few kilometres in the westernmost and easternmost parts to hardly 100 m in other places (Fig. 1). They are the site of numerous seaside resorts which in summer time have to support several 100,000 tourists.

The adjacent coastal plain lies at a mean level of about 3 m above low-tide sea level and extends over 5 to 10 km in width. It shows a distinct microrelief mainly because of differential sedimentation and differential settling induced by reclamation and drainage. It corresponds to intertidal flats of Dunkerquian Age which developed behind a more winding coast with barrier islands and large tidal creek inlets. The flats were reclaimed in different steps mainly between the 9th and the 13th Centuries, when the present-day dune belt developed as well.

The breached and winding early Dunkerquian coastline was regularized mostly before the 14th Century. In 1304 a rectilinear ditch (Count John ditch), still partially existing today, backed the entire coastline. The regularization is proven by the existence of remainders of older dune ridges either cut by erosion and exposed on the present-day beach (De Haan-Vosseslag) or by subboreal peat exposed on the beach (Mariakerke), by tidal creek inlets choked by downdrift sands (Dunkerquian II tidal creek inlet at Bredene), by the silting of large tidal creeks due to decreases in tidal flat storage potential (Zwin inlet in the 12th Century), and by the findings of drowned settlements in a present-day offshore position. It is known that at least 2 settlements, Scarphout (offshore of present-day Blankenberge) and Ter Streep (offshore of present-day Mariakerke) were swallowed by the sea during the St. Clemensday tempest on 24 November 1334.

The Westerschelde Estuary, on the contrary, which today extends up to 100 km inland in the middle of large reclaimed marine and perimarine tidal flats, developed only gradually since the 13th Century (1241), because of regressive erosion by a tidal creek system cutting into a large peatland and capturing the river Scheldt.

TYPES OF ARTIFICIAL STRUCTURES

Many types of artificial structures have been used along the coastline and in the reclaimed polderlands; including:

1. Reclamation ditches and defence ditches in the reclaimed intertidal flats.
2. Longshore seawalls, mostly consisting of a dune foot protected by a concrete layer, covered by stoneblock masonry.

3. Groynes up to several 100 m in length. Older types are made of masonry often with a twig bundle core, or of stone blocks fixed with wooden pegs or fixed with wooden poles. More recent types are made of a concrete debris core covered by block masonry. All groynes are perpendicular to the shoreline and to the longshore drift.
4. Beach nourishment and bulldozing.
5. Beach nourishment with sandbag frame (Longard system).
6. Sand fences from different materials (wooden slat fences, plastic mats, osier hedges) and in different patterns (longitudinal, transversal, and oblique rows, networks) have been used to trap wind-blown sands, especially on the sea-side flank of the dunes above the high water mark.
7. Vegetation plantings for dune sand fixation (especially ammophila).
8. Fencing of dunes to reduce passage and occupation.
9. Walkways in dunes.
10. Jetties either made by wooden or concrete piles (Nieuwpoort, Oostende, Blankenberge) and open to the longshore drift.
11. Breakwaters either consisting of a massive concrete construction (Zeebrugge 1870), or made of dumped stone blocks (e.g., the new ones since 1980) under construction for the new outer-harbour of Zeebrugge and extending up to 3.5 km offshore.

DEVELOPMENT AND IMPACT OF ARTIFICIAL STRUCTURES ALONG THE BELGIAN COAST

Historical documents allow us to reconstruct reclamation since the Dunkerquian II inundations.

Very little, however, is known about the construction of coastal defence structures earlier than 1850. It is known that already in the 15th Century vegetation plantings have been carried out and that in 1502 small sea groynes were constructed at Blankenberge. Before the 18th Century, no stone material had been used and all defence structures were of wooden poles and twig mats.

Today very little of the Belgian Coast is devoid of any defence structure. Only a 2.5 km stretch between Wenduine and De Haan, a 1.5 km stretch between Nieuwpoort Harbour and Westende, a 5 km stretch between Oostduinkerke (Groendijk) and Koksijde, and a one km long stretch at the eastern border are without any defence structures or, at least, without any known one. Today a total 46 km of beaches, about 70% of the total coast length, are backed by seawalls.

Reclamation Ditches

Reclamation ditches, defence ditches, and drainage devices have been built in the Belgian coastal plain at least since the end of the Dunkerquian II inundations (9th Century). Construction has proceeded in the areas flooded by the Dunkerquian III inundations since the 13th Century. They consist of earth ditches, generally still visible but without a real function today, because of coastal damming by the dune belt. Their height generally decreases with age, but interpretation in relation to a sea-level rise is very debatable.

There is very little pumping because of the relative narrowness of the polderland and the importance of the tidal range.

Seawalls and Groynes

In 1885 an important 500 m long stone seawall was built on the waterfront of Ostend, partly for the defence of the developing town, partly for the development of its touristic function, and partly for the improvement of its harbour facilities. Before the end of the 19th Century another 3 km were already added at Ostend and seawalls were constructed on the waterfront of developing seaside resorts such as Middelkerke (1898), Nieuwpoort (1897), Wenduine, Blankenberge, Zeebrugge (1870), and Heyst.

The development of transportation possibilities, especially the construction of the first railway system, certainly played an important role as well. Indeed the Belgian coastal zone is completely devoid of any form of rock outcrop and all construction material had to be brought in from brick yards and from limestone or microdiorite quarries situated at least 100 km inland.

In 1912 the central part of Belgium's coastline between Westende and Ostend was already covered by a continuous stone seawall over a distance of 17 km. Discontinuous seawalls extended east of the knickpoint of Wenduine over a total length of 11 km, at Wenduine (1.5 km), Blankenberge (2 km), Zeebrugge (2.5 km), Heyst (3 km), and Knokke (2 km). Moreover there were a few small seawalls at De Haan (1 km), at Nieuwpoort (0.3 km) west of the harbour entrance, and at Oostduinkerke (0.7 km). With the exception of Heyst, Ostend, and Mariakerke, all were situated far from the village centers which were generally located at the landward edge of the dune belt.

Documents attest that some time before 1912 several stretches of the coastline were subject to beach erosion, especially at De Haan, where a concrete seawall was built (De Haan to Golf) which later completely disappeared under new natural sand drifting and which was not uncovered before 1976 when another erosional phase hit the coast in that stretch and exhumed for the first time the sand covered seawall and other defence structures. Near Oostduinkerke the 1912 coastline was situated 100s of metres behind its present-day position, as shown by a contemporaneous map.

Seventy years later (1986), after new constructions at Koksijde and Nieuwpoort, seawalls extend almost continuously along the coat from Westende to the Dutch border, with the exception of a 9 km zone between Bredene and Wenduine surrounding the De Haan seawall, a 2 km beach between Blankenberge and Zeebrugge, and a one km wall near the Zwin mouth.

The seawall at Koksijde was extended toward the west after the violent February 1953 storm surge. East of Ostend the existing seawall has been elongated in order to back the new groynes. West of De Panne a provisional seawall has been constructed to the French border (1978) in order to counteract the strong dune erosion related to the flood current downdrift position of this section in relation to the Dunkerque breakwaters and the approach channel dredgings to that port. More intensive beach restoration works are envisaged here.

It is not quite clear the extent to which the important lengthening of the seawalls was a response to beach erosion or to the promotion of the early development of sea side resorts, nor how much the seawalls themselves destabilised the beach budgets. Anyway, seawalls have been built to prevent the coastline from further regression. On eroding beaches with predominant longshore transport, such defences have not altered the longshore transport and beach erosion in front of the seawall often continued. The latter increases the wave attack on the seawall and the offshore transport, resulting in overtopping and scouring of the seawall and more erosion.

Groynes have a more strictly defence function. Groyne construction in front of the Ostend seawall did not begin before 1900. In 1912, 75 groynes (as much as 250 m long and more or less regularly spaced), some of which were backed by existing seawalls, were constructed over a distance of about 18 km along the beaches east of the knikpoint of Wenduine. No groynes existed west of Wenduine, with the exception of 13 groynes in front of Ostend and 4 more in front of the adjacent Mariakerke.

The whole groyne pattern seems to indicate that at the beginning of the 20th Century beach erosion was active east of the knikpoint of Wenduine, and the place where the earliest seawalls had been built. This erosion seems to confirm the negative impact of seawalls upon the beach evolution. The latter is explained by the fact that the seawalls are installed as a dune revetment, leaving no sand supply available for beach nourishment during storms and impeding the deposition and fixation of compensating new longshore sand supplies. Moreover, seawall slopes do not dissipate wave energy but instead reflect it, increasing the sand back wash and toe scour.

The strong erosion east of Wenduine has been much debated. One main hypothesis suggests a relationship with further enlargement of the Westerscheldt entrance and with a further regularization commanded by the coastal head position of Wenduine where a mid-eocene sandstone and clay scarp which is locally outcropping offshore (as proven by sandstone fragments brought in regularly on the beach) provides a sea bed more resistant against tidal currents. On the other hand the erosion east of Wenduine has also been related to the impact of the construction of both the harbours of Blankenberge (1865) and Zeebrugge. Especially the long (one km) 1870 breakwater of Zeebrugge has been held responsible because it deviates the littoral drift and makes both longshore tidal currents that strike the coast to have a higher angle than otherwise would be the case, and because of its interruption of the longshore sand transport, especially after the closing of the claire-voie in the Zeebrugge breakwater and starting the approach channel dredgings.

Today, most of the groynes between Wenduine and Zeebrugge, west of the breakwater of Zeebrugge, are partly or mostly covered with beach sand. The exception is the stretch of beach downdrift from the Blankenberge Harbour entrance. Meanwhile east of Zeebrugge, downdrift of the stronger flood currents, erosion still continued, and even became stronger with the construction of the still larger 1980 Zeebrugge breakwater and the related sand dredgings in the approach channel. Sand supply on the beaches west of Zeebrugge was related to the beneficent effects of the groynes upon the beach erosion by decreasing the local longshore downdrift beach sand pickup and changing it into a residual deposition, favouring at the same time eolian nourishment. However, questions arise about possible changes in the hydrodynamic conditions of the foreshore, especially the deflection of the longshore current but also the periodic variation in the local transport capacities of the longshore current which causes an alternation of successive phases of erosion and deposition in a downdrift direction.

In any event, soil movement or sea-level variation are hardly invocable; a sea-level rise of hardly 8 mm having been recorded for this coast over the period 1945 to 1975. Neither is the setting of groynes a probable reason because no trace of distortion of the groynes has been observed and because the dune foot remained stable.

In 1938 defence structures appear to have changed very little since 1912 suggesting only small demands for stabilization of the beach budgets during this period. Nevertheless there had been some groyne construction especially around Ostend (30 groynes over a distance of 7 km).

In 1986 groynes extend, without interruption, from Westende to Bredene (Vosseslag) and from Wenduine to Knokke (Zoute). East of Ostend groynes have been constructed or prolonged from Bredene (Village) to Bredene (Vosseslag) especially between 1965 and 1975. New ones have been constructed between Middlekerke and Mariakerke upon subboreal peatlayers exposed as an abrasion platform (1978 to 1984), in front of Duinbergen and from Knokke to Het Zoute. In this last section defence-structure construction went on especially after the 1953 storm surge and during the 1975 to 1980 period, because of increased beach erosion, even before the construction of the new 1980 to 1985 Zeebrugge breakwater.

More to the west of Ostend, new groynes appear in front of the Koksijde seawall where, after an erosion attack in 1960 to 1965, the seawall now stands in retreat with regard to the surrounding dunes, and at Nieuwpoort where, west of the harbour entrance (1980 to 1982), groynes provoked a considerable beach accretion.

Sea groynes, constructed to cope with the negative effects of seawalls and to stop the dune-foot regression and beach lowering, are considered to have a positive impact along the Belgian Coast. This is because they break incoming waves, thus quenching the wave energy responsible for erosion and offshore sand transport. The main effects of groynes are the reducing of the longshore sediment transport (due to their impact upon the longshore bottomdrift), a seaward displacement of the high and low water marks, a possible decrease of the erosive action of the waves on the backshore area and duneflank, and a micro-regularization by the development of Zeta-type beaches between the groynes, and as well, a decrease of the runnel and ridge mobility. The recent groyne construction at Middelkerke, Nieuwpoort, and Westende provoked distinct beach nourishment. Their impact upon the slope of artificially refilled beaches seems to be very slight, as shown by the erosion of the sand filling at Bredene (1978to 1986). Moreover little is known about their impact upon the near-shore depth.

Beach Nourishment and Bulldozing

Beach nourishment has been established recently in several coastal sections under erosion stress in order to increase the beach area for touristic use or as a defence measure for the dune foot or the seawall, by raising the beach level. As this involve a steepening of the beach profile, coarser sands have been used to counter the harsher wave attack on the steeper beaches. Moreover the higher, new backshore areas and duneflanks have had fences built or been planted with hedges or other vegetation in order to trap eolian sands and to prevent wind erosion.

In 1956, a first attempt at nourishment without any solid frame was put on the beach in front of Knokke. Over a distance of about 2 km a volume of about one million m^3 was pumped on the beach supplied by the dredging of an artificial lake in the backing dune belt (Knokke to Zegemeer).

In 1978, a sand fill with sand bag frame (Longard system) was put on the beach east of Bredene over a length of about 2 km, using 560,000 m^3 of sand dredged from an offshore sand bank, the Stroombank in front of Ostend (435,000 m^3), and in the New Fisherydock of the Ostend Harbour (125,000 m^3). Later, in 1980 this nourishment has been prolonged over 2.0 km towards De Haan in a flood downdrift direction, using the same Longard system and a supply of another 700,000 m^3 coarse sand, dredged from the Kwinte Bank.

In 1977 to 1979, a new 8.4 million m^3 sand supplementation was executed on the 8 km/long beach stretch east of the new Zeebrugge breakwaters (Knokke to Heyst), the sand being dredged from the Gootebank.

The recent beach nourishment of Knokke to Heyst was intended to compensate the predicted sand losses and coastline regression due to the building of the new Zeebrugge breakwaters, as well as to cope with the existing severe erosion of this beach stretch.

In 1981 there was a less important sand fill (90,000 m^3) (Longard system) at Lombardzijde over a length of 1.25 km. Because of the harbour extension at Zeebrugge, annual beach erosion on the order of 800,000 m^3 a year was forecast. In 1984, 5 years after the main beach nourishment, the evolution can be described as follows: dune area = +207,000 m^3, backshore area = -106,700 m^3, and foreshore area = -558,000 m^3. Thus, the real loss was less than predicted. In order to compensate the assessed losses a new nourishment of 1 million m^3 of sea sand was completed in 1986.

Meanwhile most of the sand fill on the Bredene to De Haan foreshore has already been eroded leaving only the backshore area of the beach untouched and even. Because of the trapping of wind-blown sands, this area was more nourished than at the time of the original sand fill itself.

The effects of nourishment are ambivalent. In most places a more or less rapid renewed depletion of the lower beach is observed progressing in a flood downdrift direction together with a duneward retreat of the high water line. With sand-bag armament, beach lowering is slowed down. Some effects, however, are harmful. For example, the exhumed sand bags form a dense grid-like ditching on the foreshore and local beach pitting, restraining the touristic use of the beach and causing local rip currents.

Along the Belgian Coast, at least, the effect upon the high beach and the dune foot is very positive. Eolian sand supply, especially if helped by fencing and osier hedges, causes sand accretion on the seaside of the dunes. This forms a sandbuffer in front of the existing dunes and increases the safety of the dune zone with respect to possible break-through of the sea into the adjacent coastal plain.

For about 10 years bulldozing of beach sands towards the seawall foot shortly after the winter beach depletion, is used as a means of providing beach facilities, more rapidly than would be the case with the natural refilling of the higher parts of the beach by the slow beach ridge upslope movement processes or by eolian longshore supply.

Fences and Plantations

Fences for trapping wind blown sands have been used in many places and for a long time. Different types such as wooden slat fences, perforated plastic mats, and rows of osier hedges, among others, and different patterns, such as arranging them transversal or longitudinal to prevailing winds, have been tested.

All have shown high efficiency for residual trapping of sand, especially on the backbeach above the high water mark (Zeebrugge and others) and on the upper part of sand fills (Bredene, Knokke, and others). Although insufficient for a progradation of the beach, they proved to be useful for a storage of sands allowing to buffer more or less the losses by normal winter storm activity. On the Bredene to De Haan sand fills they induced a storage of important sand masses along the dune foot and a back beach heightening, retarding the retreat of the high-water line erosion cliff. In Knokke however, downdrift and downwind of the large 1980 Zeebrugge breakwaters and the approach channel, the sand gain by fencing was less important, partly because of the coarseness of the supplied sands. Furthermore, this beach was deprived of natural beach nourishment by littoral drifts.

Vegetation plantings (mainly with ammophila), fencing of walkways in dunes, and construction of different walkway pavements have been used to decrease sand deflation in the dunes.

Jetties, Breakwaters, and Port Approach Channels

Pile jetties for harbour approaches have been constructed at Nieuwpoort, Ostend, and Blankenberge where they are partly fixed on massive groynes. Their impact on beach dynamics is more due to the port access channel than to the open-work structure itself.

Distinct beach erosion has been observed over a certain distance as well east of the Ostend entrance as of that of Nieuwpoort, that of Blankenberge, and that of Zeebrugge, due to trapping of downdrift sands in the entrance channel and their evacuation by its dredging, so that immediately downdrift of the channel the longshore current became more aggressive. Erosion is possibly counteracted by the spreading of the sand and silt dredged from the channels, on the downdrift side of the entrance channels. During periods of no dredging, choking of the entrance channel is rapid and a hooked spit develops at the westside top of the breakwater at Blankenberge.

Because the dune belt has been cut for entrance channels, wind loses its sand transportation capacity especially on the prevailing wind updrift westside. Thus, eolian sand deposition and even channel choking occurs (Blankenberge). In addition, chronologic variations in the intensity of longshore sand supply occurs.

The erosion east and west of the 1870 Zeebrugge breakwater began early in relation to several factors already discussed. The erosion on the flood downdrift side continued after closing the claire voie which was done in order to decrease the silting of the harbour. The sand catch function of the dredged approach channel has been important.

In 1980, the Zeebrugge breakwater provoked considerable sand deposition and beach progradation on the west side of the new western breakwater. In addition, it caused silty deposition at the east base of the new eastern breakwater. That construction intensified the erosion along the eastern, flood downdrift beaches because of the higher impact angle of the flood longshore current which lost its load in the approach channel. There was a small sand supply in the flood downdrift side of the eastern breakwater because of a consolidated eocene clay substratum.

CONCLUSION

During the last century, beach erosion has occurred on the Belgian Coast in different sections and over more or less long-time periods, making coastal defence gradually necessary along most of the coastline. Some of this erosion has a natural origin, some is man-made, and some results from the construction of defence structures themselves. Recent fears of an increase of the storm levels along the Belgian Coast insuring the decrease of the storage capacity due to damming in the Rhine-Meuse-Scheld estuary have not been confirmed by observations. Relating erosion to a mere sea-level rise seems improbable because most of the erosion has a local and temporary character and any recent sea-level rise is hardly observable.

Several types of coastal defence structures have been used with more or less variable results. Any evaluation of these techniques has to take in account the type of structure, the specific coast characteristics, the characteristics of currents and winds, the periods under consideration in relation to the duration of natural cycles commanding the coastal dynamics, as well as the impact of the structures themselves and the repercussion of human intervention on the coast and its near-shore morphology.

REFERENCES

Charlier, R. and Auzel, M., 1961. 'Geomorphologie côtière: migration des sables sur la côte belge.' Zeitschr. für Geomorphologie 5, 181-184.

Codde, R. and De Keyser, L., 1967. Mer du Nord. Littoral. Estuaire de l'Escaut. Atlas de Belgique 18A-18B. Bruxelles, Comité national de Géographie.

De Candt, P., De Meyer, C., Kerckaert, P., De Wolf, P., Wens, F., and Grobben, A., 1984. 'Beach nourishment. A soft method for coastal protection,' 26th Intern. Navigat. Congress, Brussels, 23-34.

De Moor, G., 1979. 'Recent beach erosion along the Belgian North Sea coast.' Bull. Soc. Belge Géol., Hydrol., Paléont. **88**, 143-157.

________, 1979. Premiers effects du rehaussement artificiel d'une plage saleuse le long de la côte belge. Colloque sur les Côtes atlantiques d'Europe Publ. du CNEXO, Actes de Colloques **9**, 97-114.

________, 1984. 'Belgium." In: Bibliography on Coastal Environment 1977-82, ed. J. Paskoff, Paris, IGU, Commission on Coastal Environment.

________, 1985. 'Shelf bank morphology off the Belgian coast. Recent methodological and scientific developments.' Recent trends in Physical Geography, Liber Amicorum L. Peeters, Brussel, V.U.B., Study series **20**, 47-90.

De Moor, G. and Ozer, A., 1985. 'Belgium.' In: World Shorelines, ed. R. Bird and M. Schwartz, New York, Van Nostrand Reinhold Company, 353-358.

Finkl, C. W., 1981. 'Beach nourishment, a practical method of erosion control.' Geo-Marine Letters **1**, 155-161.

Moller, J.T., 1984. 'Artificial structures on a North Sea Coast,' Aarhus, Geoskrifter **19**, 25 p.

Paepe, R. and Baeteman, C., 1979. 'The Belgian coastal plain during the Quaternary.' Acta Univ. Ups., Symp. Univ. Ups, Ann., Quing. Cel 2, Uppsala, 143-146.

Tavernier, R., 1947. 'L'évolution de la plaine maritime Belge.' Soc. Geol. Belgique, Annales **56**, 332-343.

Tavernier, R. and Moorman, F., 1954. 'Les changements du niveau de la mer dans la plaine maritime flamande pendant l'Holocene.' Geol. en Mijnbouw, N.S. **16**, 201-206.

Tavernier, R., Ameryckx, J., Snacken, F., and Farasijn, D., 1970. 'Côtes. Dunes. Polders.' Atlas de Belgique. Bruxelles, Comité national de Géographie.

Van Cauwenberge, C., 1985. 'Overzicht van de tijwaarnemingen langs de Belgische Kust, Periode 1971-1980.' Tijdschr. Openb. Werken Belgie 5, 437-457.

Van De Graaff, J., 1977. 'Dune erosion during a stormsurge.' Coastal Engineering 1, 99-134.