CHAPTER 223

BAR MIGRATION AND DUNEFACE OSCILLATION ON DECADAL SCALES

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Abstract

While structural erosion or accretion of a coastal stretch is of primary concern to coastal management, knowledge of coastline oscillations on larger time scales relative to the erosional or accretional trend would allow for a more efficient management practice. Our analysis of more than thirty years of observations of dune, beach and nearshore evolution reveals some of the typical oscillatory behaviour in time and space on a decadal scale. We have focused on the behaviour of the duneface and analyzed the possible relation between the duneface behaviour and that of the nearshore morphology. Amongst our results are the findings that the demeaned oscillatory duneface evolution on a decadal scale is not only correlated with the recurrence frequency of the migratory bar system, but also with a cumulative measure of episodic wave events.

Introduction

Moderate rates of structural erosion or accretion only become apparent on larger time and space scales, because of the dominance of shorter scale oscillations caused by natural processes. Most evident is that due to episodic wave events, which can cause strong erosion and associated steepening of the duneface, while the eroded sediment is deposited on the beach and nearshore profile, resulting in a more weakly sloping and wider beach. After these events a

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restoration may occur due to aeolian and hydrodynamic processes. Our interest is typically into the scales intermediate to the short term, event related, behaviour and the long term, structural trend of erosion or accretion associated with gradients in cross-shore and longshore directions over a coastal stretch.

These intermediate scales concern the temporal behaviour on decadal scales, leading to duneface amplitude oscillations of magnitudes comparable to those of the structural trend. Our objective has been to develop an understanding of the mechanisms behind this behaviour, based on the "working-hypothesis" that a relation may be expected between the bar dynamics and the duneface behaviour. The JARKUS data-set, comprising more than thirty years of field observations of the duneface, beach and nearshore profile along the central Netherlands coast, has revealed typical and unexpected properties of subaqueous bar morphodynamics on a decadal scale. Amongst the most recent analyses is that of Wijnberg and Terwindt (1995) pointing towards the existence of four distinct morphodynamic regimes, each characterized by their own particular bar dynamics. These regimes occur in four coastal stretches, each constrained by coastal engineering structures. While the precise physical interpretation and explanation remains to be resolved, our objective (stimulated by the findings of Guillen and Palanques, 1993) has been to investigate and explain the possible relation between the above described bar behaviour and the duneface dynamics.

It is clear that the dune system and the bar system interact throught the dynamic processes of the coastal area; they are both subject to the same wave and tidal forcings and, at same time, they are part of an interconnected system. We recall the fact that not only tides have clearly defined astronomic cycles with a periodicity ranging from hours to decades, but also wave climate has at least a seasonal cycle and, on a long term basis, longer cycles linked to climate oscillations. These are still active subjects of investigation; think for instance to the so-called Bruckner cycles, basically consisting of the recurrence in northwester Europe of periods of cold and damp alternating with warm and dry years, the average interval between successive maxima being 34.8 years (as calculated by Bruckner in 1890), though individual cycles vary from 25 to 50 years. However there is an increasing evidence that, when looking at large scale and long term evolution of the coastal system, we need to highlight the long term character of the forcing factors.

Study area

Our study area is the Holland coast (Fig. 1), bounded by Rotterdam harbour and the port of Den Helder. It is characterized by an almost uninterrupted dune system, without barrier islands and tidal inlets. The main human interventions along this stretch of 120 km are the harbourmoles of Scheveningen and IJmuiden, the sea dike of Petten and the dike of Den Helder.

During the last three hundred years this coast is erosive in the north (approx. 1 m/yr), and the south (approx. 0.3 m/yr) and accretive in the centre (approx. 0.2 m/yr). Sediment grain sizes are 200 to 250 microns in the dunes and 250 to 300 microns on the beach. The tide ranges from 1.7 m near Scheveningen to 1.4 m near Den Helder. Mean wave heights and periods are 1.2 m and 5 s respectively, with approaches from south-west and north-northwest mainly.

Foredunes are regressive, stable or progressive over the last decades, with widths ranging from 500 to 2500 m. The subaerial beach averages 43 m in width, with a mean slope of 1:15 (Short, 1991). The bar-beach system commonly consists of a beach-bar, attached to the beach as a ridge and runnel system, an outer bar, highly rhythmic and rip-dominated and a longshore bar (Short, 1992). Their temporal and spatial behaviour has been analyzed by Wijnberg (1995). A common characteristic is that of a cyclic two or three bar system, initiated

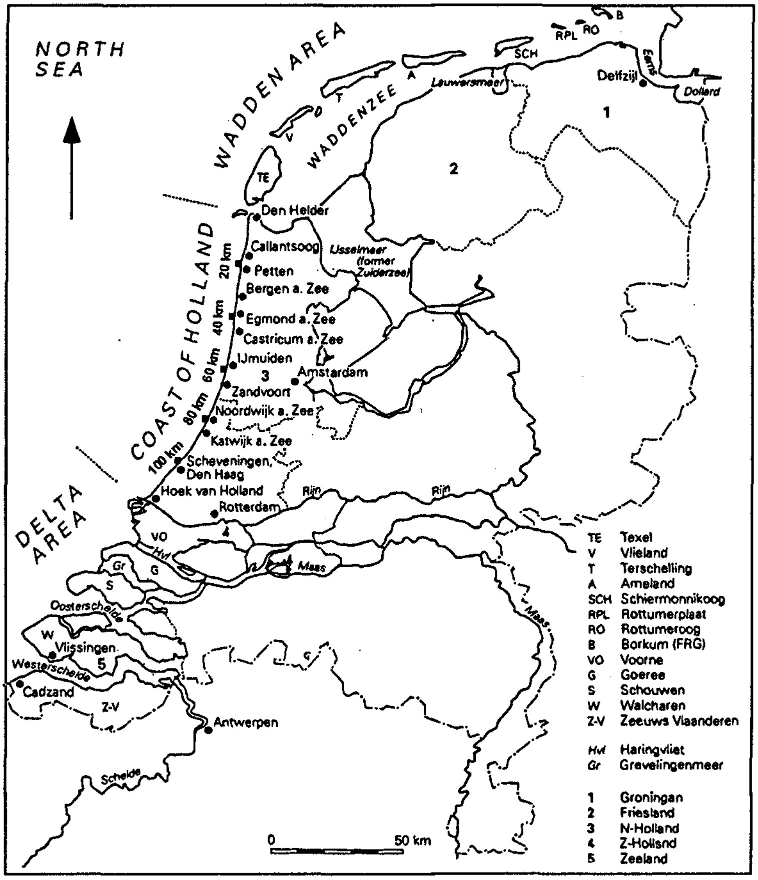


Figure 1 Study area

nearshore, migrating and growing through the surfzone and then decaying offshore. Apparent return periods range between 4 and 15 years.

Methodology

The medium-term dune, beach and nearshore profile evolutions were analyzed using the JARKUS data-set. It consists of (about 3,000) fixed measuring rays extending along the Dutch North Sea coast. The distance between the profiles is 200-250 m and yearly profiles approximately from the foredune to 1,000 m seaward are available since 1964. Profiles are usually surveyed between early April and late September. It is expected that the biased sampling does not affect a decadal analysis of the shapes of the profiles (Wijnberg and Terwindt, 1995).

Our morphometric analysis of the dune and beach system concerns first the determination of temporal and spatial oscillations on decadal scales in the dunefoot, and second the possible relation of this behaviour with the shoreface slope and the behaviour of bar and trough systems. Our parameters are the dunefoot position, the duneface slope and the beachface slope.

Qualitatively it is clear that the shoreface slope plays a fundamental role in the dynamics of the coastal system. Firstly, in the sense that in the steeper slope area, the bar system needs longer return period waves to be moved offshore. Second, in the steeper slope area, the dunefoot is subject to larger wave impact under storm conditions. In addition, residual tidal currents will determine a relatively larger speed of motion for the shallower part of the bar system with respect to the deeper part, which is a clear mechanism of introduction of a "structural modification" in the coastal system. If we consider two adjacent zones with different profile slope, this is clearly a mechanism for the introduction of a longshore mechanism of motion.

Following Wijnberg (1995) we distinguish four distinct spatial sectors (Fig. 1), viz. (I) km 8-20, (II) km 28-52, (III) km 63-95 and (IV) km 104-114. These sectors are bounded by structures, the Hondsbossche dike (km 23) and the harbours of IJmuiden (km 55) and Scheveningen (km 102), and have been found to exhibit a uniform bar behaviour within them. In our analysis we further concentrate on Zones (II) and (III), which contrary to (I) and (IV), are virtually without human interference.

Our initial effort has been to derive a representative duneface and dunefoot definition, such that it is not affected by local and instantaneous processes occurring immediately before the survey. A heuristic procedure, based on hydrodynamic and morphologic considerations, using two constant planar surfaces and a sediment volume balance was chosen (Fig. 2). By using this procedure the temporal changes in the calculated dunefoot position indicate the changes in the volume of sediment stored in the dune-beach system between +1 and +5 m NAP heights, allowing a comparison between all the profiles in a coherent way. The choice of the +5 m NAP height as the upper boundary is based on the storm surge design level height for dune erosion in Holland.

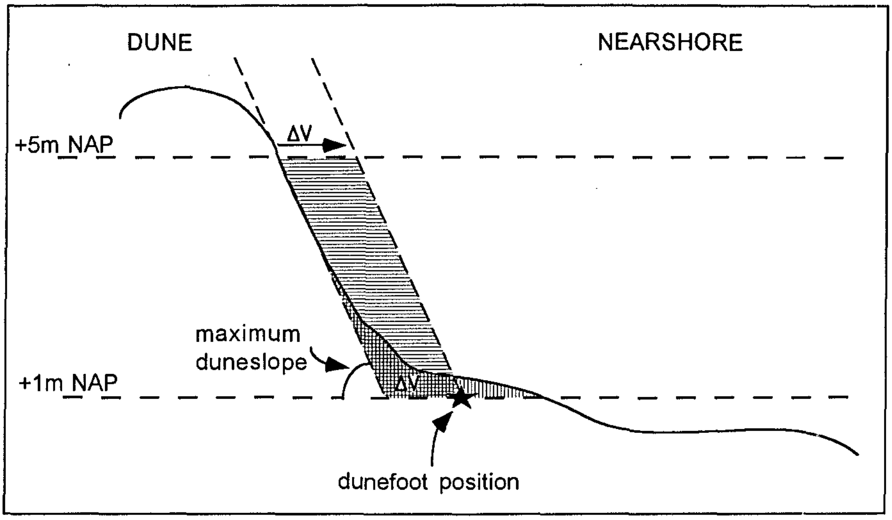


Figure 2 Dunefoot definition procedure

In the analysis the dunefoot and nearshore profile evolution has been based on space-time diagrams. Linear temporal trends were calculated in each profile and the "residuals" with respect to this trend were extracted. This approach has been complemented by application of Empirical Orthogonal Function (EOF) analysis techniques, the presentation of which has been omitted here because of space limitations. We have used the EOF's to derive periodicities more clearly.

In analyzing possible effects of wave forcing we have used a time history of 1,090 "storm events" during the period 1979-1991 (De Valk, 1994). They have been characterized by two parameters, viz.

$A = H_{m0}*SQRT(t)$, and

$B = SL*SQRT(t)$,

where H_{m0} is the average significant wave height during the storm event, SL the average surge level and t the duration of the storm event. Furtheron we have summed these parameters over the period in between soundings to account for the cumulative effect of storm events.

Results and analysis

Dunefoot data

Following our derivation of a morphologically equivalent and stable duneface profile, we find that the average maximum duneface slope is nearly constant along the different zones (tan b = 0.14 to 0.15). The average beach slope between the + 1 m NAP and the - 1 m NAP ranges from 0.025 to 0.030, implying a mean beachface width of 70 to 80 m.

The linear trend of the dunefoot position shows a high longshore variability (Fig. 3), but the average over several kilometres is less than 1 m/yr, while the accretional and erosional character is not very different from that over the last few hundred years. Standard deviations relative to the trend also show a high longshore variability (Fig. 4), while the average over several kilometres is between 5 and 10 m.

We now describe the behaviour of Zones II and III, showing a general erosive and accretive trend respectively, which are relatively untouched by human intervention.

The evolution of the residual dunefoot position in Zone II exhibits longshore and temporal oscillations (Fig. 5). Spatially, alternating accretional and erosional stretches of 2 to 3 km are observed alongshore. Temporally, this longshore rhythmicity may be viewed as a shoreline wave propagating towards the south with a propagation velocity of 150 to 200 m/yr. The amplitude of the oscillation is approximately 20 m and its periodicity 15 years.

In contrast the evolution in Zone III shows virtually no longshore oscillations (Fig. 6). Temporally, periods of relative accretion and erosion alternate simultaneously along the coast.

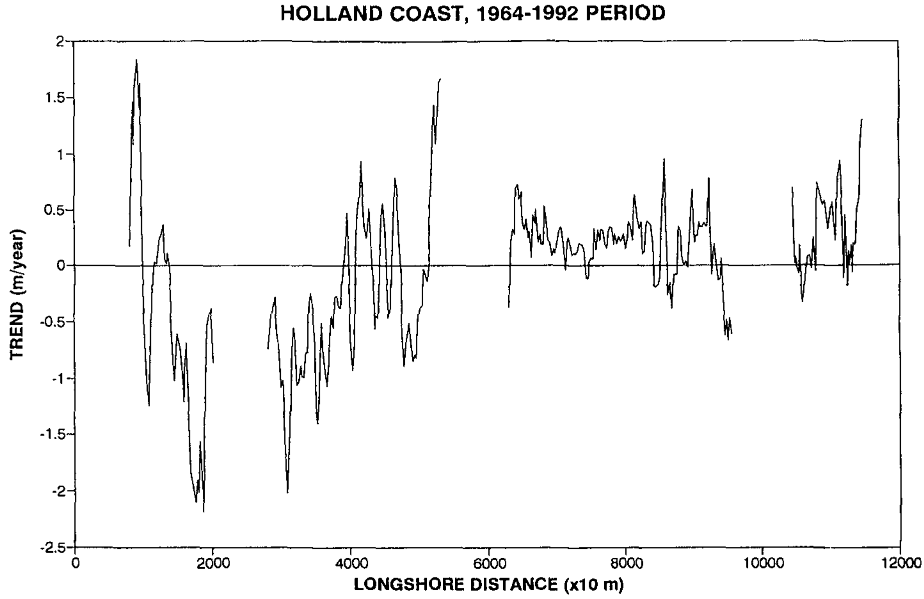


Figure 3 Trend in the dunefoot position (positive is seaward, negative is shoreward)

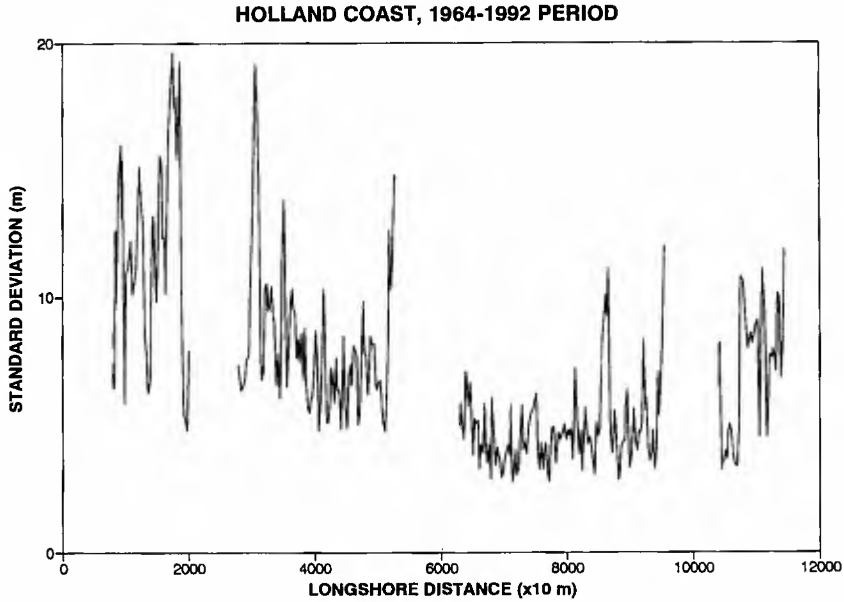
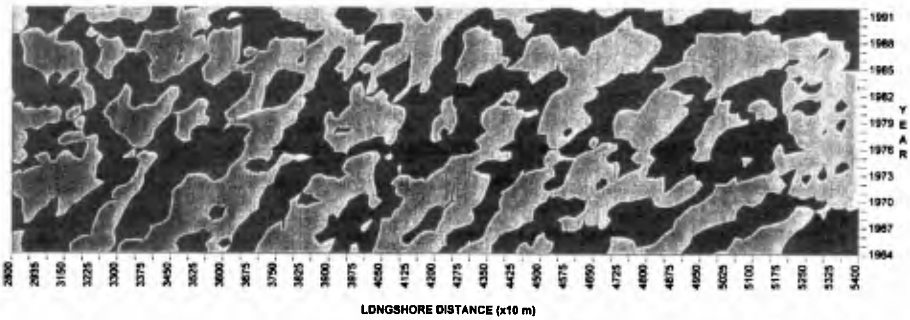


Figure 4 Standard deviation of the dunefoot position



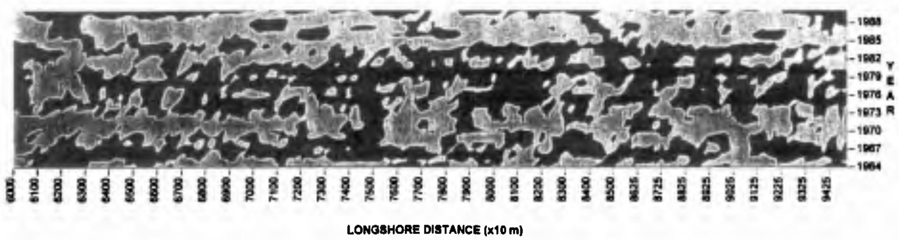


Figure 5 and 6 Residual dunefoot position relative to the trend for zones II and III respectively (dark shading is shoreward, grey shading is seaward)

Also, in spite of the above differences, inspection of Fig. 5 and 6 reveals some simultaneous occurrences of relative erosion and accretion. This may be more clear from Fig. 7, comparing the spatially averaged residual position over time in the two zones. Although our extreme event data only cover the period 1980 to 1991 (Fig 8), we note that we expect that these simultaneous occurrences are related to the decadal variation of the cumulative extreme events. For instance, the relative accretion between 1985 and 1988 appears to correspond to a relative minimum in the extreme events.

A preliminary analysis of the periodicity of the first empirical orthogonal function of the dunefoot position for the whole coast has also been performed. It consists of applying a simplified non-linear model as a reference concept. In practice the temporal evolution of the first and the second empirical orthogonal functions has been considered as determined by the sum of a linear (sinusoidal) term and two nonlinear terms related to the amplitude of the first one. Using empirical process-oriented considerations we assume that, under erosive conditions, the dunefoot is less mobile (composed by less mobile sediments), while under accretive conditions, the dunefoot is more mobile (composed by more mobile sediments). This way three fundamental periods have been identified: 51 years for the oscillation of the mean dunefoot position; 7.5 years for the oscillation of the dunefoot during erosive periods; 2 years for the oscillation of the dunefoot during the accretive periods. These results (see Figure 9) need to be further examined mainly because of the short duration of the dataset with respect to the longer period of oscillation. The results also need to be further examined with respect to the cycles in the forcing factors. We note that the dunefoot evolution is recovered by multiplying the "reconstructed" temporal orthogonal functions and the spatial temporal orthogonal functions. In case the results will be confirmed by further analyses, it is clear that, with a very simple modelling concept we are able to gain some predictive value.

Profile data

A main morphological feature of the profile along the Holland coast is the existence of migrating breaker bars. A comprehensive analysis of their behaviour was recently made by Wijnberg (1995), using EOF analysis. In each of the four coastal stretches the bar behaviour is found to be temporally and spatially different, but internally (i.e. within a particular stretch) coherent. The explanation of this is as yet undetermined.

Zone II and III both exhibit an offshore migratory behaviour of the bars. The average number of bars is constant in time, where the offshore decay of the outer bar is followed by the appearance of a new bar at the shoreline. The temporal behaviour is thus similar, only the recurrence frequency is different, viz. approximately 15 years in Zone II and 4 years in Zone III. Their spatial behaviour is significantly different, however. Whereas in Zone III the relative

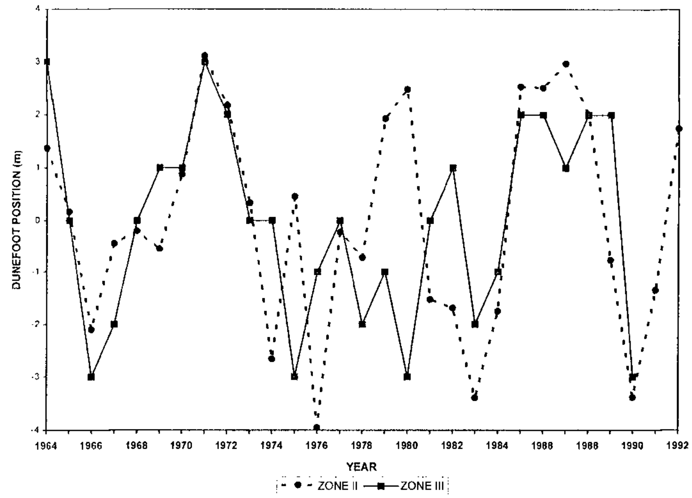


Figure 7 Longshore-averaged mean dunefoot position versus time

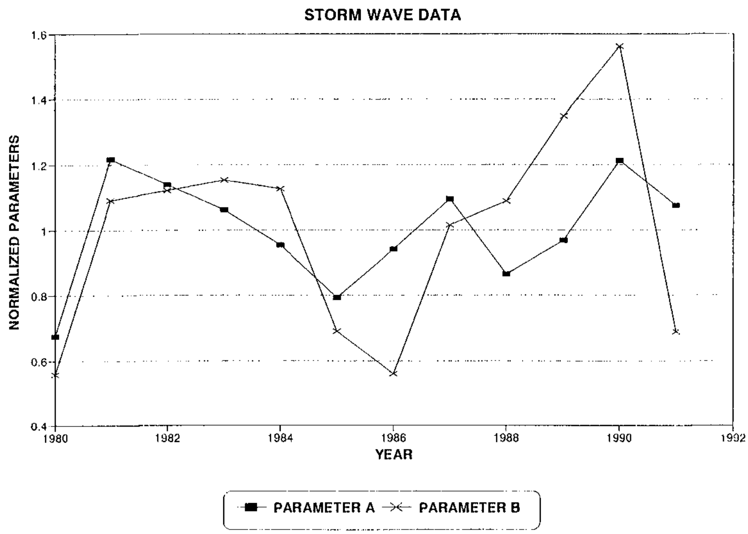


Figure 8 Normalized year-cumulative storm event parameters

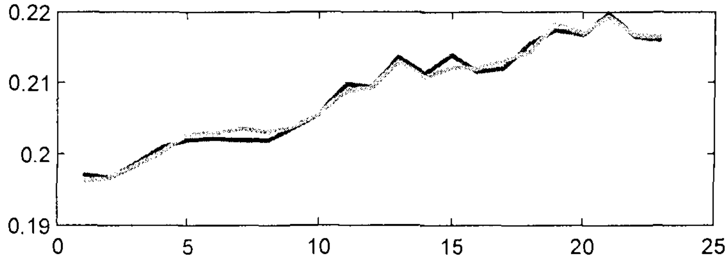


Figure 9 Normalized first temporal eigenfunction of the dunefoot displacement of all four zones (full line observed, grey line modelled)

position is homogenous alongshore, without any longshore rhythmicity, Zone II has two specific spatial features. First, at a large spatial scale, the bar migration is not in phase, exhibiting an obliquity relative to the shore. Apparently, the bar initiation first occurs in the south and this initiation propagates towards the north. The obliquity creates a discontinuity. Second, on a smaller spatial scale, longshore discontinuities (of a length of 2 to 3 km) in bar position exist, which are caused by the crescentic morphology of the bar systems here.

Discussion and conclusions

The standard deviation of the mean shoreline position has been termed beach mobility (Dolan et al., 1978). Short and Hesp (1982) found it to be a function of the morphodynamic beach state: dissipative, intermediate and reflective beaches correspond to low-moderate, moderate-high and low beach mobility respectively. On Australian shores beach mobility ranges between 5 and 14 m from data taken over 1 to 5 years. Shoreline mobility along the Holland coast, averaged over several km (as inferred from the + 1 m NAP depth contour) over the period 1964-1992 amounted to some 20 m, suggesting an increase of mobility over longer time scales. On the other hand, dunefoot mobility, such as defined here, is approximately half that of the shoreline. Apparently, the shoreline evolution exhibits more "noise" than that of the dunefoot. Further, it is noted that the dunefoot mobility on shorter time scales, e.g. due to extreme events, can be nearly an order-of-magnitude larger, i.e. 25 to 75 m of duneface retreat (Steetzel, 1993). While longer term erosive or accretive trends are relevant for long term nourishment policy, our findings of mobility are relevant to medium term (decadal) coastline management.

While the order-of-magnitude of dunefoot mobility has been found the same along the Holland coast, its spatial and temporal nature is quite different in the two, virtually unmanaged, Zones II and III. Our findings suggest that the dunefoot behaviour is strongly influenced by the subaqueous bar behaviour, confirming earlier suggestions by Bruun (1954).

In Zone III, both the dunefoot and the subaqueous bar behaviour behave spatially homogeneous alongshore. Erosional-accretive oscillations appear to correlate with the cumulative parameters describing the storm events.

The latter effect is also found in Zone II, but here most interestingly is the occurrence of the longshore rhythmicity and of the recurrence frequency. It exhibits spatially the same scale as that of the crescentic bar morphology (2 to 3 km) and temporally the same recurrence frequency as that of the migratory bar behaviour (15 yr). Clearly, there exists a strong signature of the bar dynamics in the shoreline and dunefoot behaviour.

A comparison of earlier observed temporal oscillations and -if present- their alongshore propagation speed is given in Table 1. We note the study of Verhagen (1989), who interpreted from long term shoreline observations the presence of 'sand waves' along the Holland coast, moving northwards.

Author	length (km)	migration rate (m/yr)	amplitude (m)	period (yr)
Bruun (1954)	0.5-3	0-1,000	60-80	-
Morton (1979)	5-7	-	-	-
	2.5-3	-	-	-
Dolan & Hayden (1981)	>1	-	-	-
Davidson-Arnott (1988)	0.5-2.5	150-300	50-90	10
Verhagen (1989)	5.5	65	40-60	75-100
Pelczar et al. (1990)	5-9	100-200	70-110	50-60
This study	2-3	150-200	20	15

Table 1. Observed shoreline oscillations

Our final conclusion is that our interpretation of shoreline mobility on decadal scales for the Holland coast indicates that the dunefoot, according to our definition, shows an oscillatory amplitude of some 20 m. It is quite moderate compared to other studies, and its behaviour is clearly related to the dynamics of bar behaviour on the one hand and to the cumulative effect of extreme wave events on the other hand.

Acknowledgements

Part of this work is based on work in the PACE- and SAFE-projects, in the framework of the EU-sponsored Marine Science and Technology Programme (MAST-III), under contract no. MAS3-CT95-0002 and MAS3-CT95-0004. The second author would like to acknowledge his grant from the Ministerio de Educacion y Sciencia of Spain, allowing for his post-doctoral stay at Delft University of Technology in 1995. We thank Mark Voorendt of Delft University of Technology for his technical support.

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