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TIME-DEPENDENT EFFECTS OF NOURISHMENTS ON SHOREFACE BAR BEHAVIOUR

Tommer Vermaas[1], Edwin Elias[2], Ad van der Spek[3] and Rena Hoogland[4]

Abstract

In 2011/2012 a shoreface nourishment was placed at Heemskerk, the Netherlands. The nourishment consisted of two parts, separated by a c. 500 m wide gap, which were placed on the offshore slope of the outer breaker bar. Half-yearly bathymetric measurements show that both nourishment parts developed differently and had a different influence on the natural bar behaviour. In this paper, we show that the "phase" (Ruessink and Kroon, 1994) of the bar system during the moment of nourishing explains the differences in the response of the system. Understanding this mechanism and the consequences are essential for effective employment of shoreface nourishments.

Key words: breaker bar behaviour, shoreface nourishment, bar migration cycle, coastal morphodynamics, North-Holland

1. Introduction

Since 1990, the coastal policy in the Netherlands is to fight structural erosion through sand nourishments. These nourishments were initially used to maintain the coastline at its 1990 position (Van Koningsveld & Mulder, 2004), which required c. 6 million m^3. Since 2001 a second objective is to also compensate loss of sediment in the deeper part of the shoreface. As a result the yearly volumes increased to 12 million m^3, to also.

While initially nourishments were placed on the beach, with increasing sediment volumes needed, the more efficient and cost-effective shoreface nourishments became common practice. Shoreface nourishments are usually placed directly seaward of the outer breaker bar, with their top at a depth of c. 5 m below MSL.

Shoreface nourishments showed to have a significant influence on the natural bar behaviour (e.g., Van der Spek and Elias, 2013). The natural behaviour of the bar systems at many locations along the Dutch coast shows a repeating pattern of offshore migration. This bar migration 'cycle' is described in a conceptual model by Ruessink and Kroon (1994). They described three phases of this cycle, being (1) bar generation near the intertidal zone, (2) offshore migration of this bar, and (3) decay of the bar at the outer nearshore. The key factors controlling the behaviour of the inner bar(s) are the position and crest depth of the outer bar. Ruessink and Kroon (1994) found that as long as the crest of the outer bar lies above -5.5 m MSL, the inner bar remains within the first phase.

Studies by e.g. Grunnet and Ruessink (2005), Ojeda et al. (2008), De Sonneville and Van der Spek (2012), Van der Spek and Elias (2013) all indicate that shoreface nourishments influence the cycle of bar migration. Often reported effects are an interrupting or blocking of the offshore migration of bars, inducing bar switching, and stabilization of the outer bar. The differences in response have been attributed to the volume of the nourishment, the ability of the nourishment to connect with existing bars and their shore-parallel length.

The shoreface nourishments were described to have to effects that contribute to restoring the beach

[1] Deltares, Department of Applied Geology and Geophysics, P.O. Box 85467, 3508 CB Utrecht, The Netherlands. tommer.vermaas@deltares.nl
[2] Deltares USA, 8601 Georgia Ave, Silver Spring, Maryland, 20910. USA. edwin.elias@deltares-usa.us
[3] Deltares, Department of Applied Morphodynamics, P.O. Box 177, 2600 MH Delft, The Netherlands. ad.vanderspek@deltares.nl
[4] Rijkswaterstaat, Water Verkeer en Leefomgeving, Zuiderwagenplein 2, 8224 AD Lelystad, The Netherlands. rena.hoogland@rws.nl

profile, a feeder effect and a lee effect (e.g., Van Duin et al., 2004; Grunnet and Ruessink, 2005). The feeder effect refers to the onshore sediment transport of the nourished sediment by wave asymmetry and slow onshore currents. The lee effect is the increase of wave dissipation due to the shallower coastal profile which leads to less energetic conditions at the water line and an increase in sedimentation from alongshore sediment transport.

In this research, we show that also the phase of the bar system at the moment of nourishing is important for the development. Analysis of a recent nourishment at Heemskerk, the Netherlands, shows that the phase during the moment of nourishing explains differences in the response of the system. Understanding this mechanism and the consequences are essential for effective employment of shoreface nourishments.

2. Site and data description

The town of Heemskerk is located on the North-Holland coast, located in the central part of the Holland coast. This part of the coast is a relatively straight sandy coast, only interrupted by the harbour moles of IJmuiden, about 5 km south of Heemskerk (Figure 1). The nearshore morphology of the coast near Heemskerk is wave-dominated with a two bar system. The median grain size of the sediment at the North-Holland coast lies between c. 150 μm on the beach to c. 250 μm at about 1 km offshore (De Sonneville and Van der Spek, 2012).

The harbour moles of IJmuiden were constructed in the period 1867-1876 and extended between 1962 and 1967 to 2800 m (south) and 1850 m offshore (north). Their presence locally affects the hydrodynamics, resulting in net sedimentation close to the moles (first c. 3 km) and erosion some distance away (following c. 5 to 6 km). This effect was strongest directly after construction and is closer to an equilibrium state today (Schalkers and Visser, 1978).

De Sonneville and Van der Spek, 2012 describe the wave climate at North-Holland as governed by westerly storms. They report an offshore significant wave height with an annual return period in the order of 6 m and with a peak wave period of about 10 s, and a yearly averaged offshore significant wave height of about 1 m, with a corresponding peak wave period of 6 s. The spatial variation of the offshore wave climate is small (Wijnberg, 2002). The mean tidal range at Heemskerk is about 1.6 m, leading to shore-parallel peak flood and ebb currents in the order of 0.4 m/s (Wijnberg, 2002).

The coast at Heemskerk has been nourished sporadically with beach nourishments. The nourishment of 2011/2012 was the first shoreface nourishment south of km 40.

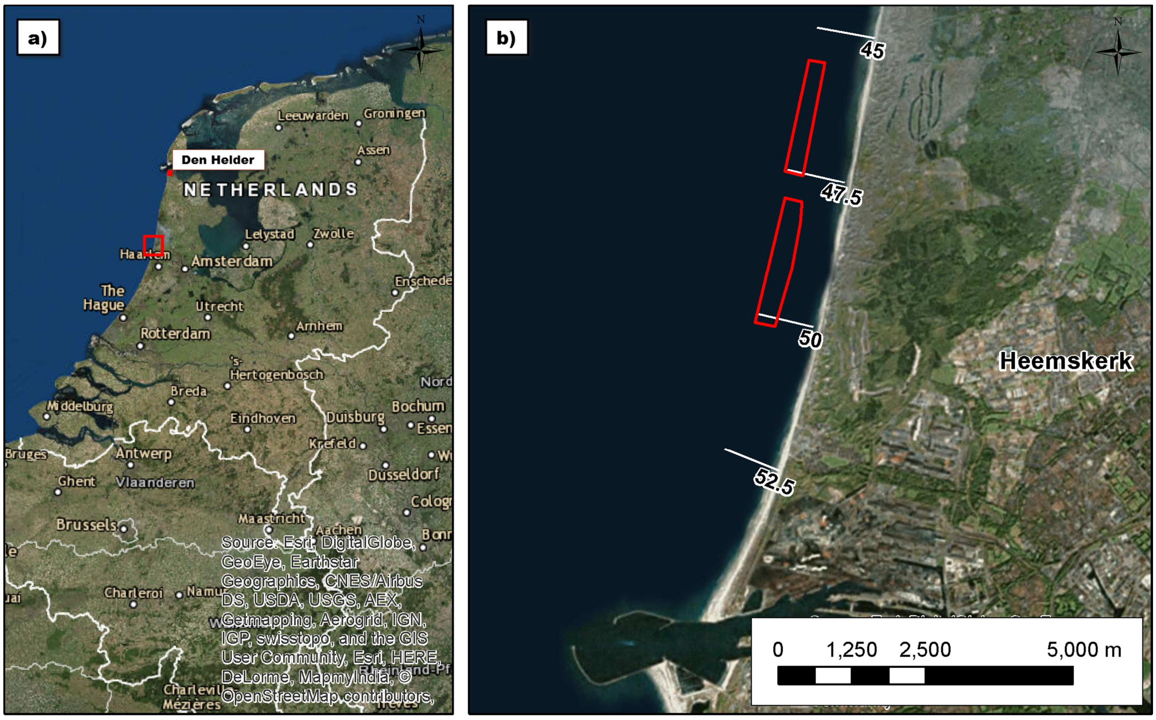

Figure 1. a) location of the study area in the Netherlands, indicated by red rectangle; b) location of shoreface nourishments, indicated by red rectangles, at the town Heemskerk. Numbers indicate alongshore position.

The analysis in this study is based on three bathymetrical datasets: (1) yearly JARKUS surveys (2) half-yearly local JARKUS surveys with higher resolution alongshore and (3) local surveys of the nourishment during placement.

The first two datasets are collected by Rijkswaterstaat, the Dutch Department of Waterways and Public Works. The yearly JARKUS surveys consists of cross-shore transects with an alongshore spacing of c. 250 m, covering the area from the dunes up to 800 to 3000 m offshore and reach an offshore depth of 10 to 15 m. These transects are available from 1965 onward. The alongshore position of the transects at this part of the coast is relative to the town Den Helder in the north, with increasing distance to the south. The cross-shore distance is indicated relative to a fixed position. Interpolated grids based on the JARKUS transects are available with a resolution of 20 m. These datasets are used to analyse the long-term autonomous behaviour.

The second dataset consists of similar transects as the JARKUS dataset, but with an alongshore spacing of c. 125 m. These transects have been surveyed between spring 2011 and spring 2016. This dataset is used to analyse the development of the nourishment in detail.

The last dataset are local bathymetric grids collected by the contractor during placement of the nourishment. In total 14 surveys, collected between July 2011 and November 2012 covering the nourished area or a part thereof, are available. These data are used to analyse the way the nourishment was placed.

3. Results

3.1. *Natural bar behaviour*

Based on the analysis of the individual transects, one can conclude that in a natural state the breaker bars migrate offshore in a 10 to 15 year cycle and decay at a depth of 5-10 m below MSL (Figure 2), as also described by De Sonneville and Van der Spek (2012). In top view, this behaviour is more complex. The decay of the outer bar does not occur simultaneously along the stretch of coast, but shows a distinct pattern.

The decay of the outer bar starts around km 50 and propagates from there both to the north and south

(Figure 3). The offshore migration of the inner bar follows this alongshore propagation, starting at km 50, and in a later state at the more northern and southern locations. At a certain moment in time, even on this scale of a few kilometres, the bar system can be in different phases of evolution. For example, in 1999 the outer bar at km 48 had almost entirely disappeared and the inner bar was migrating offshore, while 2 km to the north at km 46 the outer bar was still clearly present and the inner bar had just formed.

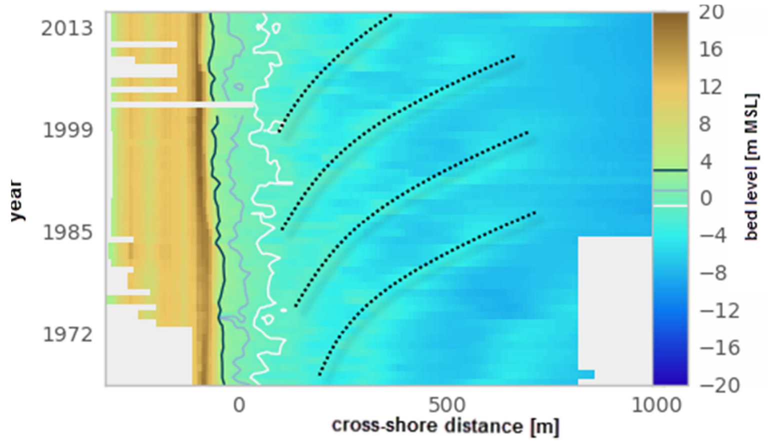

Figure 2. Timestack of transect 48.25 showing the natural offshore bar migration

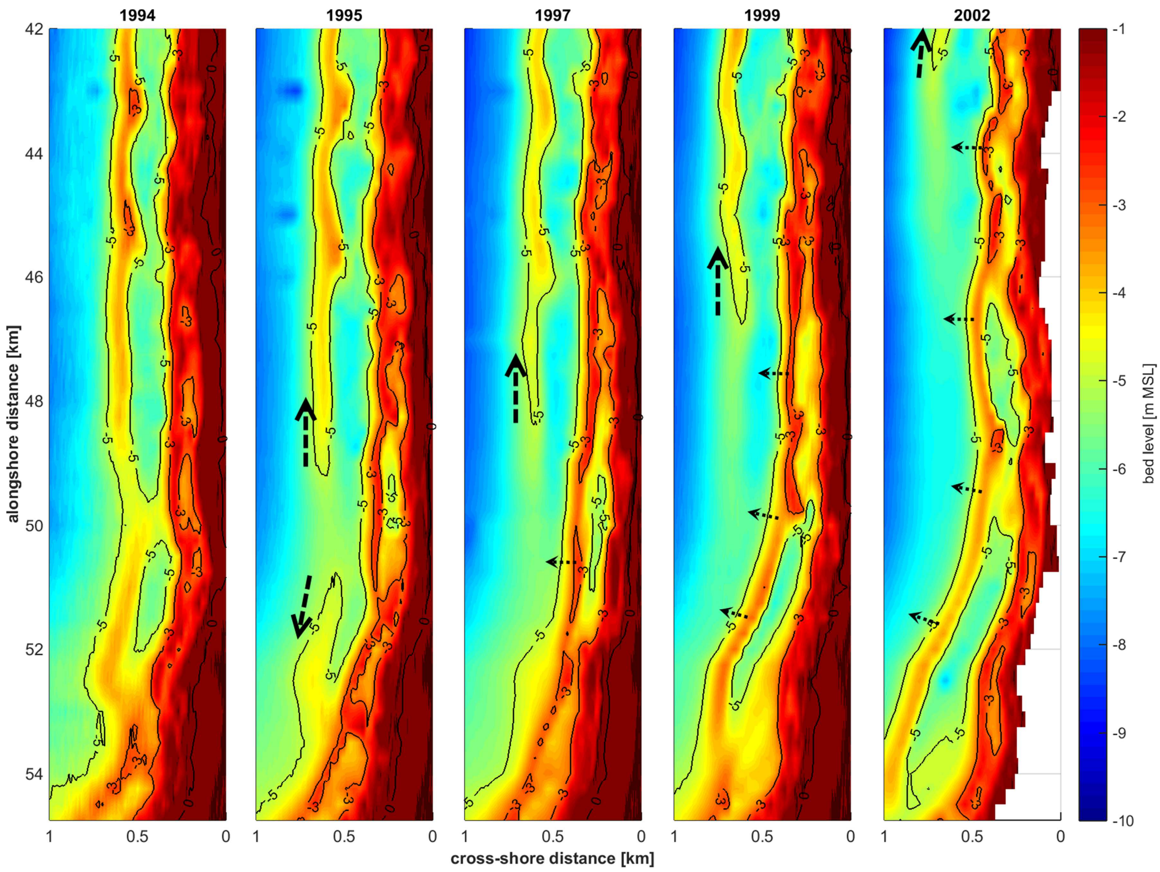

Figure 3. Bathymetry of the area north of IJmuiden between 1994 and 2002, based on JARKUS cross-shore profiles. Decay of outer bar begins around km 50 and propagates along the coast to the north and south (dashed arrows). Offshore migration of the inner bar only starts after decay of the outer bar, following in north and south direction (dotted arrows).

3.2. *Nourishment at Heemskerk*

The nourishment at Heemskerk was placed in several stages, between July 2011 and November 2012. The nourishment consisted of two separate parts: a northern part with an alongshore length of c. 1750 m and a volume of c. 600.000 m^3 (c. 340 m^3/m), and a southern part with a length of c. 2000 m and a volume of c. 800.000 m^3 (c. 400 m^3/m); see Figure 1 for location. The two sand bodies were separated by a c. 500 m wide gap.

The various stages of nourishment placement are shown in Figure 4. The southern nourishment (Figure 4, right-hand panel, light blue line) was placed with its top at the conventional depth of 5 m on the offshore slope of the remains of the outer bar. At this time, the outer bar had already a low crest height below -5 m MSL (dark blue line). Between August 2011 and June 2012, the nourished sediment had been reworked in a more pronounced, new outer bar with its crest well above -5 m MSL (yellow line). The location of the new bar crest is about 150 m more seaward compared to the original crest. After the second stage of nourishment, from June 2012 till August 2012, the sediment was placed on the offshore slope of this newly formed outer bar, again at a depth of c. 5 m.

The northern nourishment (Figure 4, left-hand panel, light blue line) was placed between July 2011 and September 2011 with its top at a larger depth of 6 m, also on the offshore slope of the outer bar. The outer bar at this location (dark blue line) had a crest position still above -5 m MSL. After the second stage of nourishment, from July 2012 till November 2012, the outer bar had moved c. 75 m landward and got a deeper crest depth (red line). The nourishment is present as a small plateau at -6 m MSL.

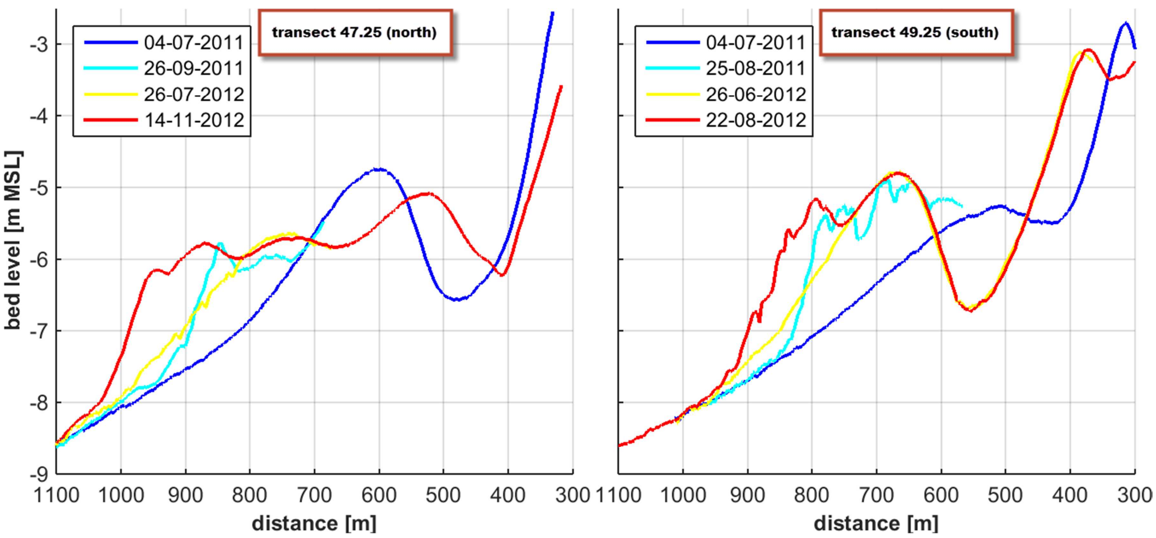

Figure 4. Cross-shore profiles, based on the contractor surveys, showing the placement of the shoreface nourishment in two stages for the northern (left) and southern part (right)

At the time of the nourishment, the decay of the outer bar had already started south of the nourishment. The bar system shows the same development as in the period described in section 3.1, with the decay starting around km 50 and propagating north and south from that location (Figure 5).

During placement of the nourishment, the bar system in the northern part was in a different phase than in the southern part. At the location of the southern nourishment the outer bar had already almost disappeared, while at the northern part it was still present. The northward propagating decay of the outer bar only reached the location of the northern part of the nourishment but did not propagate any further north after the nourishment. The presence of the outer bar at the northern part of the nourishment prevented the inner bar from migrating offshore, while at the southern part the inner bar migrated offshore after decay of the nourishment. The northern outer bar connected with the offshore migrating southern inner bar, forming a new outer bar (Figure 5, right-hand panel, 2014).

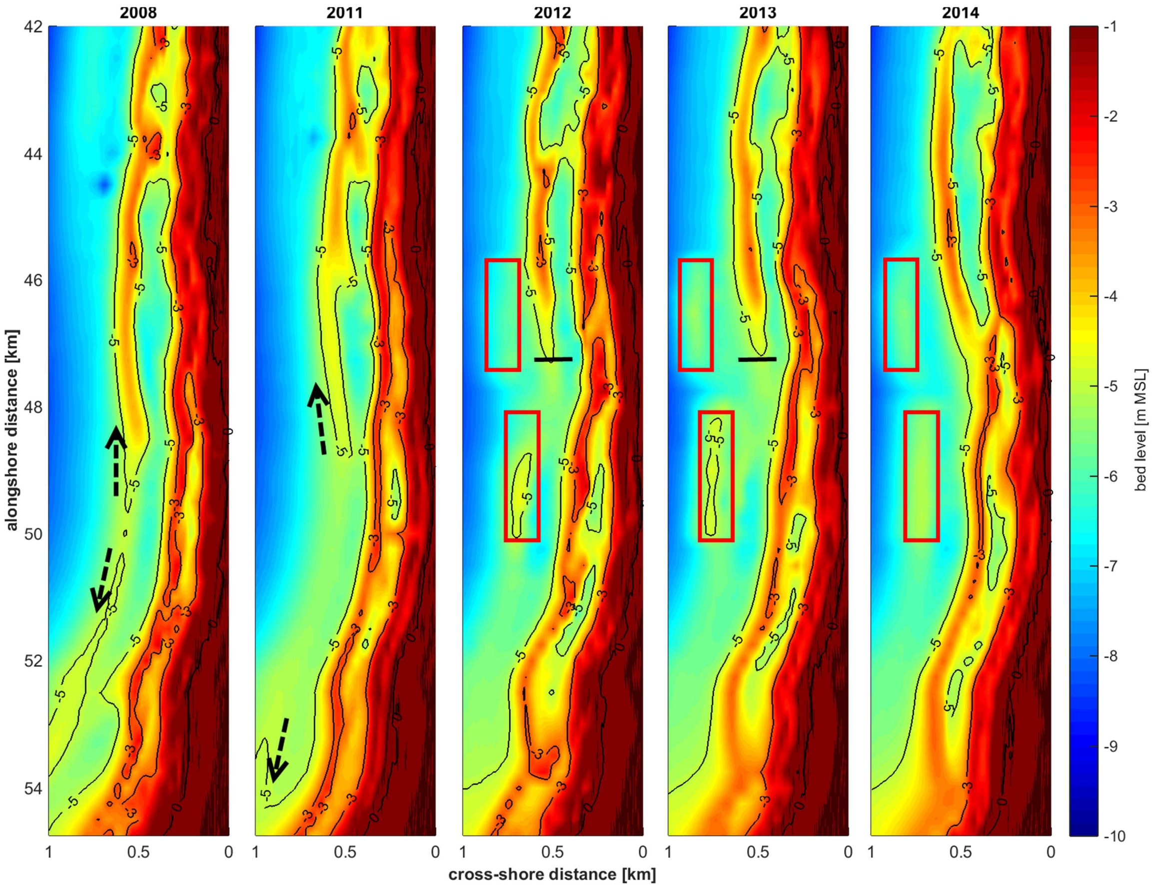

Figure 5. Bathymetry of the area north of IJmuiden between 2008 and 2014 based on JARKUS cross-shore profiles. Decay of outer bar begins at the same location as in 1994, around km 50, and propagates along the coast in north and south direction (dashed arrows). After the placement of the nourishment parts (red rectangles), the propagation of the decay stops around km 47.

The development around the nourishment is shown in more detail in Figure 6. At the location of the southern nourishment the outer bar had already fully disappeared, while at the northern part it was still present (Figure 6A). The southern nourishment took over the role of the decaying outer bar, temporarily stabilizing the seaward movement of the inner bar, which had already started just before the nourishment. As the nourishment decayed, the seaward migration of the inner bar continued (Figure 6B). After the nourishment had decayed almost entirely, the inner bar migrated to the outer bar position (Figure 6C). At the northern nourishment, the outer bar remained present and moved landward, still being the main outer bar (Figure 6B). With the decay of the nourishment, the bar moved seaward again, and connected to the new outer bar in the south (Figure 6C).

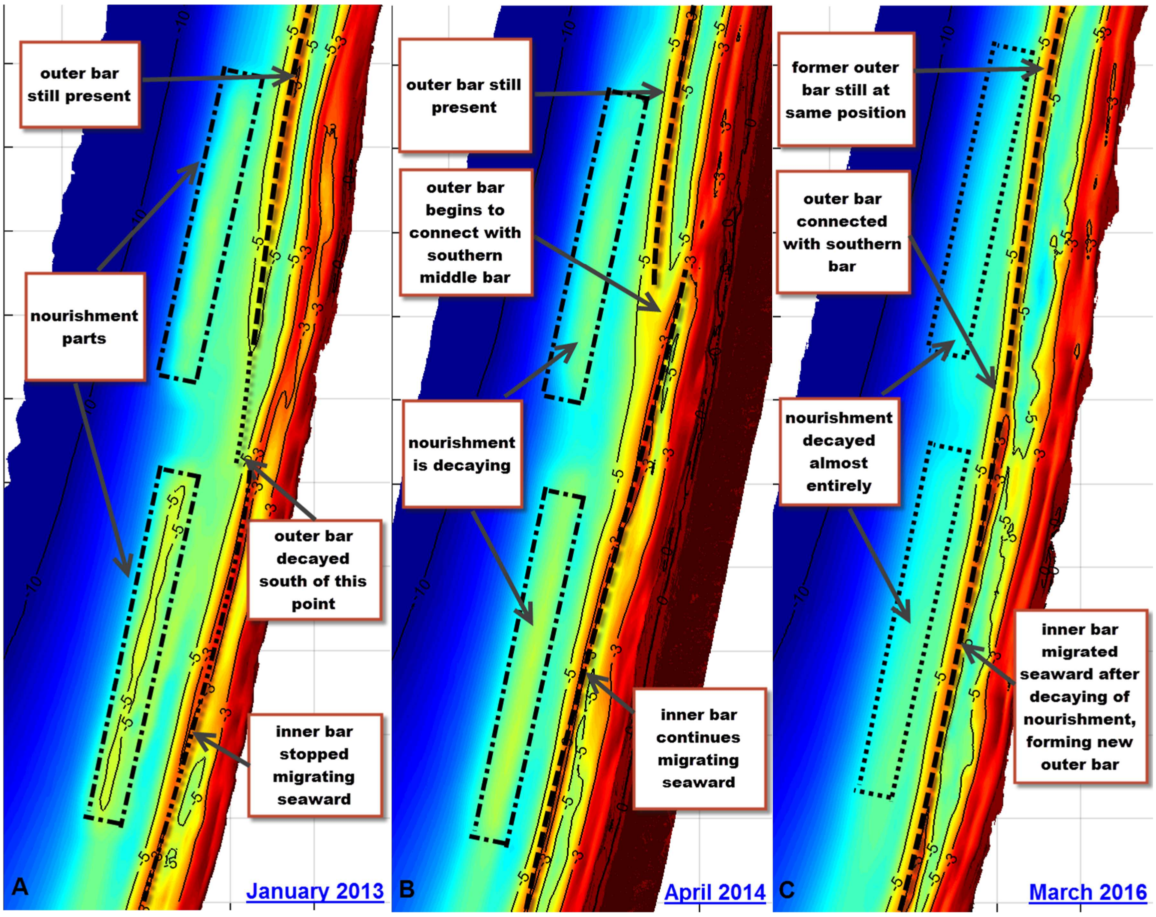

Figure 6. Development of the bar system at Heemskerk, after the shoreface nourishment of 2011/2012.

4. Discussion and conclusions

Despite almost the same size and volume, the northern and southern part of the nourishment had totally different effects on the bar dynamics. The southern part only delayed the on-going cycle of offshore bar migration and decay, while the northern one caused the outer bar to remain and not decay at all.

Van der Spek and Elias (2013) find that the volume of shoreface nourishments needs to be above a threshold to affect the natural bar behaviour. Shoreface nourishments with volumes of c. 1 million m^3 and smaller are taken up in the natural bar system shortly after their application. Larger volumes will interact with the natural breaker bars and change their natural behaviour.

The total volume of both nourishment parts at Heemskerk was large, c. 1.4 million m^3. However, their individual volumes were smaller than 1 million m^3 and both parts were taken up in the bar system in short time. Yet, the nourishment had a significant effect on the natural bar behaviour, blocking the decay of the outer bar and offshore migration of the inner bar and inducing bar switching.

The southern nourishment had dimensions similar to the decaying bar and was placed at -5 m MSL. This is above the critical outer bar depth of -5.5 m MSL (Ruessink and Kroon, 1994), above which the inner bar remains within the first phase. Consistently, the inner bar stopped migrating offshore, until the nourishment was decayed. We expect that if the nourishment had had a larger volume, it might have formed a new outer bar by itself, and possibly connect to the northern part, similar to what is observed by Van der Spek and Elias (2013).

The northern nourishment functioned very differently: instead of taking over the role of decaying bar, it acted as a sediment source for the existing outer bar, prolonging its lifetime. Because the original outer bar was still of significant size, it remained intact and connected with the newly formed outer bar in the south.

This effect might even had been stronger, had the nourishment been placed at the depth of -5 m instead of -6 m MSL, being a more effective sediment source.

Despite the smaller volume and larger depth, the northern part of the nourishment had a significant influence on the natural bar behaviour, while the southern nourishment only temporarily delayed the bar migration cycle. There were two differences between the two parts that played a role in their development: the phase of the bar system and the alongshore morphology of the outer bar.

We find that (1) 'isolated' or 'interrupted' outer bars decay faster than alongshore connected outer bars (2) the effect of shoreface nourishments on their development and the natural bar behaviour depends on the phase during the moment of nourishing. We hypothesize that in some phases also shoreface nourishments with volumes smaller than 1 million m^3 can have significant effect on the natural bar behaviour. Shoreface nourishments with larger volumes are expected to have an effect regardless of the phase.

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