Coastline Evolution as a Result of Three Decades of Dynamic Coastal Preservation

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Abstract. The coastline is pro-actively maintained in the Netherlands to prevent negative effects of erosion. Since the 1990's significant nourishment efforts have been carried out for this purpose. Here, the beach topography of a relatively undisturbed stretch of coast, with the exception of nourishment efforts, was investigated to understand the effect of three decades of coastal preservation. The evolution of the beach volume, coastline position, and coastline orientation were compared before and after the implementation of the coastal preservation policy. Structural erosion of the coastline was put to a halt thanks to regular nourishments. On average, the coastline built out, which was proven necessary to maintain the most erosive parts of the coast. Especially adjacent to breakwaters/groynes and nourishments hotspots an expansion of the coastline can be observed. It can thus be concluded that coastline maintenance is achieved with regular nourishments and that sediment accumulates in the beach zone at certain locations along-shore.

Keywords: sand nourishment impact · coastal management · coastline orientation · beach morphology

1 Introduction

Coastal erosion threatens flood safety and other functions of the coast globally. A dynamic coastal preservation policy was implemented in the Netherlands in 1990. This policy aims to prevent chronical land loss while, given the coastal functions, allowing for coastal dynamics where possible [1]. Sand nourishments were adopted as the primary means of maintaining the coast [2]. It has often been concluded that sand nourishments are an effective solution to coastal retreat [3]. The cumulative effect of repeated nourishments, however, is lesser studied and poorly understood. In this study, the effect of three decades of nourishments on the coastline position, coastline orientation, and beach volume is evaluated for a stretch of the Dutch coast. This practice-based evidence helps understanding the relation between coastal dynamics and nature based coastal maintenance strategies.

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2 Approach

Beach volume, coastline position and coastline orientation were calculated from yearly cross-shore topographic transects [4]. The beach volume is calculated as the volume around the mean low water line, from the dune foot to the same elevation difference below the low water line (i.e., approximately from 3 m above to 5 m below mean sea level) [5]. The coastline position is the weighted average of this volume and thus represents the low water line. The coastline orientation is the angle in the coastline position between neighbouring transects. Variability in the coastline position was determined to understand the effect of local protrusions of the coastline on the coastline evolution. This variability was calculated as the standard deviation in coastline orientation over 1.5 km of coastline.

Indicators were compared for 1970, 1990, and 2020 to understand the effect of the nourishment strategy that originates from 1990. Indicators were averaged over three years (e.g. 1989, 1990, and 1991) to exclude short-term variations, such as the effects of individual nourishments.

In this study, we focus on only a part of the Dutch coast: a stretch of the straight coast (Scheveningen to Den Helder) and one of the barrier islands (Texel), which are separated by a tidal inlet. This part of the coast is relatively unaffected by large-scale morphological developments and is therefore suitable for the aim of this study.

3 Evolution of the Coast

Small-scale nourishments were already implemented before the start of regular coastline maintenance in 1990, which resulted in an stable coastline position with a median change of 0.1 m/year (Fig. 1). Without these small-scale nourishments, the coastline would have shown a net retreat [6]. Regardless, 25% of the coast showed significant coastline retreat of 2.0 m/year or more. Since the start of coastline maintenance, the coastline builds out with 1.6 m/year on average (1990–2023). Nowadays, only 0.5% of the coast shows significant coastline retreat of 2.0 m/year or more.

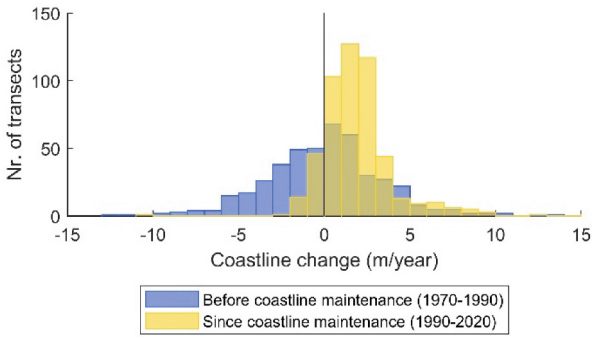

Fig. 1. Histogram of the net coastline change in the period before and after the start of the national nourishment policy.

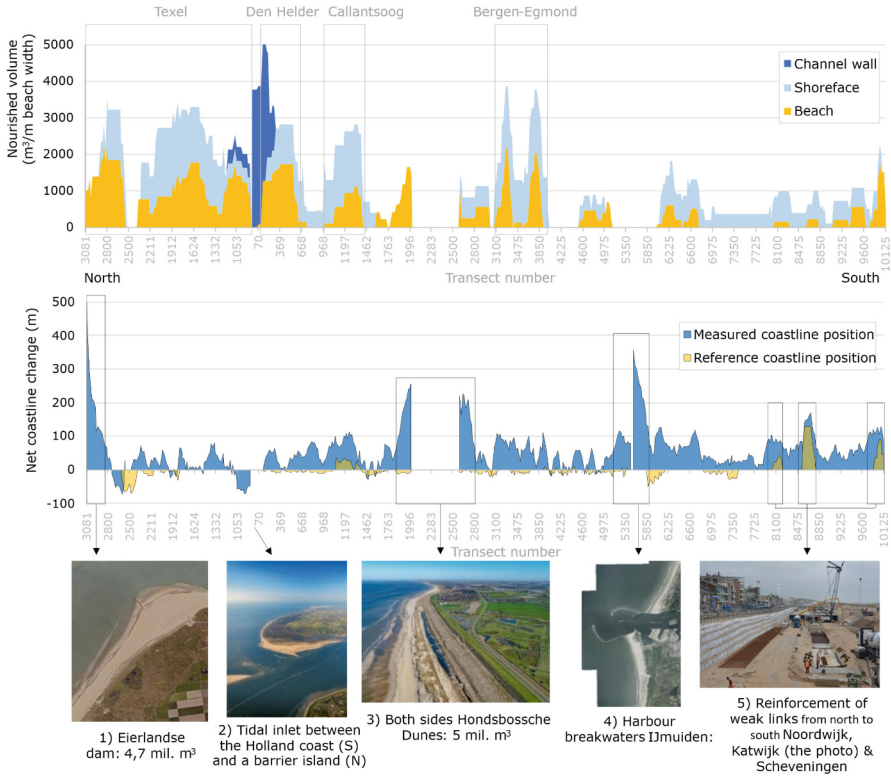

Fig. 2. Total nourishment volume between 1990 and 2020 (top) and changes in coastline position since the start of coastline maintenance (middle) from the north of Texel to Scheveningen. The most frequently nourished areas are indicated in grey. Important features are highlighted (bottom). Photo sources: 1 & 4 beeldmateriaal.nl; 2, 3 & 5 Rijkswaterstaat.

Coastline expansion occurs along the entire coast but the coastline evolution varies alongshore (Fig. 2). In total, 132 mln. m^3 of sand was added in the investigated part of the coast between 1990 and 2020, of which a part was added through reinforcements. After a reinforcement, the coastline is often maintained at a more seaward position to preserve the reinforcement (indicated in yellow, Fig. 2). The coastline expansion that can be observed at reinforced towns Noordwijk, Katwijk, and Scheveningen is thus intentional. A total of 45 mln. m^3 of sand has accumulated between 1990 and 2020 on the stretch of coast shown in Fig. 2. Approximately 10 mln. m^3 of this sand was trapped by the harbour breakwaters of IJmuiden and the large groyne 'Eierlandse dam' (Fig. 2), resulting in a coastline expansion of several hundreds of meters south of these dams.

The remainder of the nourished volume is transported to the dunes, alongshore, offshore, or into the Wadden Sea through the tidal inlet between Texel and Noord-Holland. In earlier studies this transport was estimated to be approximately 3.7 mln. m^3/year [7], resulting in a total of 111 mln. m^3 of sand that would be transported into this inlet in the period 1990–2020. It must be noted that not all of this sand is actually

nourished sand: even without the long-term nourishment strategy, sand would have been imported into the Wadden Sea, but without nourishments this would have resulted in coastal retreat of other areas.

Nourishment hotspots (total nourished volume >2000 m^3/m) are marked in grey. At Texel and Den Helder the coastline position was maintained with regular nourishments. At Callantsoog and Bergen-Egmond the coastline was built out into the sea. Along the central Dutch coast there are several coastal towns where regular nourishments directly benefit the safety against floodings (Callantsoog) or socio-economic developments (Bergen and Egmond). Coastline maintenance happens more strictly at these coastal towns. Coastline expansion in these locations can likely be related to this strict maintenance of the coastline in the most critical transects. Expansion also occurs at the beaches surrounding these coastal towns due to the lateral spreading of nourished sediments.

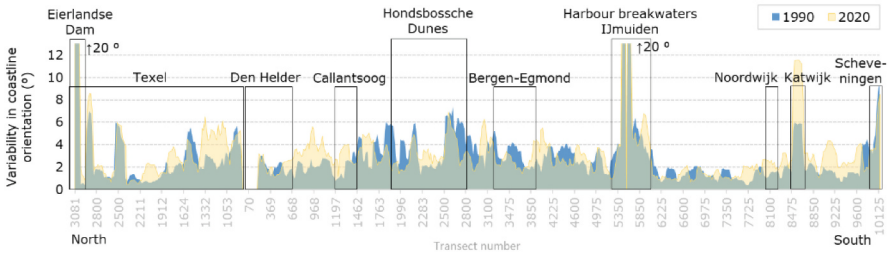

Fig. 3. Variability in coastline orientation pre- and post-coastline maintenance. Several coastal towns and important features are highlighted by the boxes.

It can be assumed that locations where the coastline protrudes further into the sea experience more erosion and thus require greater nourishment efforts. Due to lateral spreading of the nourished sediment, the coastline supposedly gradually becomes less protruded, possibly reducing nourishment efforts. Changes in the coastline orientation were investigated to test this assumption.

The most distinctive protrusions of the coastline are observed near breakwaters/groynes (Fig. 3). Furthermore, a protrusion of the coastline (>5° variation in coastline orientation over 1.5 km) is observed at some of the coastal towns (Katwijk, Scheveningen, Bergen, and Callantsoog). At others a seaward protrusion of the coastline cannot or can hardly be distinguished (Egmond and Noordwijk).

On average, the same amount of variation in coastline orientation is observed nowadays as in 1990 (Fig. 4). The assumption that the coastline tends to become straighter is partly true though. At original protrusions of the coastline, i.e. stretches of the coast with a relative high variability in coastline orientation (right side in Fig. 4) the coastline has become straighter. Here, a negative change in the coastline variability is observed in general (Fig. 4). However, at other locations the coastline is protruding seaward more nowadays than in 1990. At reinforcements that have occurred between 1990 and 2020 the coastline is often locally built out on purpose (e.g. Scheveningen and Katwijk). New protrusions can also be linked to repeated nourishment efforts that result in a seaward

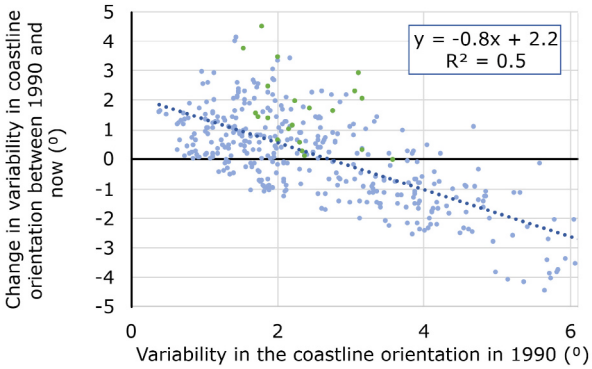

Fig. 4. Change in variability in coastline position compared to the original variability. The green dots represent sites with increased protrusion due to reinforcements or repeated nourishments.

migration of the coastline, such as observed at Bergen and Egmond. These specific sites are marked in green in Fig. 4.

4 Conclusions

With the current Dutch strategy of pro-active nourishments, structural retreat of the coastline was put to a halt in the investigated part of the Dutch coast. The coastline actually builds out on average, which was proven necessary to maintain the coastline in the most erosive parts. Coastline expansion is especially strong near breakwaters/groynes and adjacent to nourishment hotspots. Nourishment hotspots exist for example where the coastline is intentionally built out and maintained at a more seaward position for food safety. It can thus be concluded that coastline maintenance is achieved with regular nourishments and that sediment accumulates in the beach zone at certain locations alongshore.

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