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The Dynamics of Coastal Dunes Affected by Shoreface Nourishments and Storm Events

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Abstract. The dynamics of coastal dunes are often affected by a combination of environmental conditions and human interventions. During storms and calm periods, marine and aeolian flows cause sediment transport that results in sedimentation and erosion. Dunes typically grow due to aeolian transport of sediment and erode due to marine forcing by waves and currents. Shoreface nourishments can increase the sediment budget in the coastal profile which may influence the marine and aeolian sediment transport. To what extent shoreface nourishments influence sediment transport and the connected dynamics of coastal dunes is yet unknown. In this paper we investigate coastal dune volume change from yearly profile measurements and relate this to a shoreface nourishment program. The measured dune growth along the entire Dutch sandy coastline is characterized at most places by a break in slope where the dune growth increases after a specific ‘breakpoint’ year. The derived breakpoint years generally correspond with the start of the nourishment program with a delay of several years (1–5 years). These results provide a starting point for further elaborating on the relationship between the dynamics of coastal dunes and nourishments. The next step would be to delineate the potential influence of nourishments on either the growth of dunes through aeolian sediment transport or the erosion due to marine events.

Keywords: Coastal Dunes · Coastal Nourishments · Storm events · Data Analysis · JARKUS Analysis Toolbox

1 Introduction

The morphology of coastal dunes is dynamic on both short and longer timescales. Short term storm events in the order of days can cause coastal dunes to erode episodically. Long term sediment supply and aeolian wind forcing may cause dunes to grow gradually. Several quantitative studies have shown consistent linear trends in decadal dune growth rates at several locations (e.g. de Vries et. al., 2012; Strypsteen et. al., 2019). However, the spatially varying magnitude of these growth rates on decadal scales cannot be explained yet.

The offshore and beach sediment budget is connected to the erosion and sedimentation of dunes through mass conservation in a sediment sharing system. An increase in

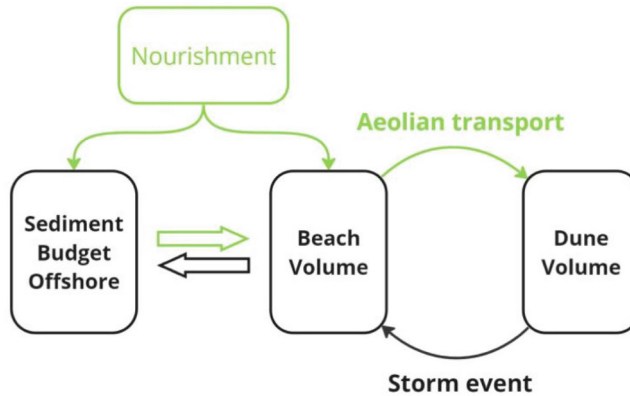


Fig. 1. The conceptual model of the links between the (nourished) offshore and beach volume and the dune volume. The dune volume may experience indirect effects of nourishments due to increased aeolian transport towards the dunes or reduced storm erosion.

sediment volume in the foreshore may therefore stimulate the growth of coastal dunes indirectly by reducing storm erosion and/or increase the sediment supply to the aeolian system (see conceptual Fig. 1). Decadal trends in dune growth rates could therefore be affected by the offshore and beach sediment budget.

Shoreface nourishments can influence offshore and beach sediment budgets (see Fig. 2). Along the Dutch coast, a sustained national nourishment program is in place since 1990 (Brand et. al., 2022). This national nourishment program aims to compensate for structural sediment erosion in the coastal profile. The program has involved the systematic nourishment of the coastal profile, in the order of 10 million cubic meters of sediment added to the coastal system on a yearly basis, for several decades.



Fig. 2. Photo shows an example of nourishments of the coastal profile feeding the offshore sediment budget (photo courtesy of Boskalis).

Measurements of the offshore, beach and dune morphology are required to analyze their interactions in the coastal profile. The extensive dataset of morphological measurements collected along the Dutch coastal zone (JARKUS; since 1965 to date) can be used to study sediment exchange between foreshore, beach and dune.

In this paper the decadal development of coastal dune volumes affected by shoreface nourishments and storms is investigated. The extensive dataset and the nourishment program in the Netherlands provide a unique opportunity to unravel the effects of shoreface nourishments and storms on decadal scale dune dynamics. The outcomes of this study may inform future nourishments and nourishment programs.

2 Methods

For this study the Dutch JARKUS dataset (JaArlijkse KUSTmeting) is employed. The JARKUS dataset consists of topographic measurements that include foreshore, beach and dune area along approximately 350km coastline collected yearly since 1965. All yearly data are interpolated to fixed transects that are spaced 200-250m alongshore. The JARKUS Analysis Toolbox is used to analyze the measured topographic profiles (see Fig. 3 for an example). Van IJendoorn et. al. (2021) describe the JARKUS dataset and ‘JARKUS Analysis Toolbox’ (JAT) in more detail. Dune volumes at 1033 transect locations are derived for every available year according to the procedure described by De Vries et. al. (2012). Only transect locations that contain more than 40 years of data are considered in the analysis. This attributes to over 47000 analyzed profile measurements distributed over time and space along the Dutch coast.

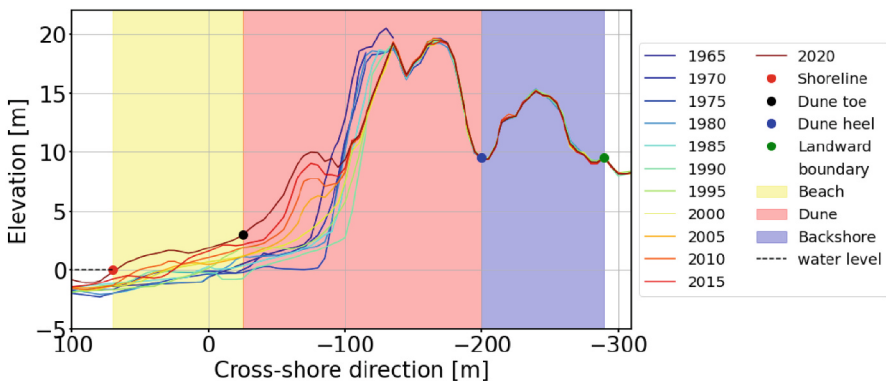


Fig. 3. Example of a JARKUS-transect showing the measured development of beach and dune topography. Elevation is normalized at 0 m NAP (about mean sea level). Dune growth is shown to be relatively large after 1990 compared with earlier years (transect ID 8009700).

For every transect location a piecewise linear relationship is fitted where it is hypothesized that after the start of the nourishment program a break in trend of dune volume development is caused. The year of the break in trend and the magnitude of the trends before and after the ‘break point year’ are the free fitting parameters that are optimized by minimizing the root mean square error of the piecewise fits combined.

3 Results

The extracted timeseries of the development of dune volumes indeed show a break in trend at most transect locations along the Dutch coast (see Fig. 4 for a clear example).

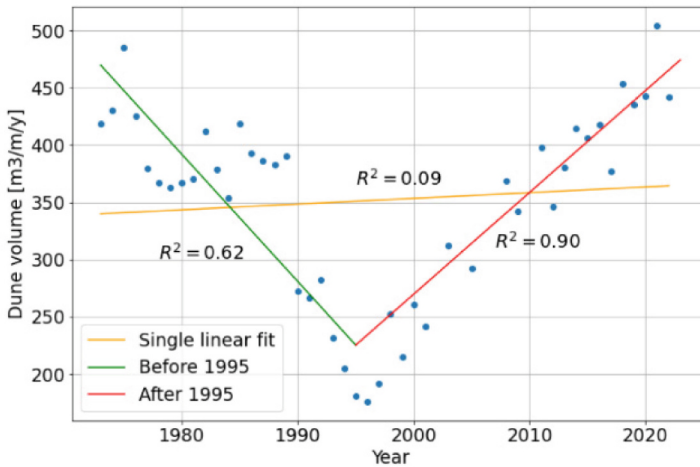


Fig. 4. The derived piecewise linear fit of dune volume development in time with a break in trend at 1995 (transect ID-7002965). Before 1995 the dune volume decreased by about $10 \text{ m}^3/\text{m}/\text{yr}$ and after 1995 the volume increased by about $10 \text{ m}^3/\text{m}/\text{yr}$

Applying the piecewise linear fit to the extracted dune volume timeseries at all 1033 transect locations leads to a generally large increase in fitting quality compared to the normal linear fit. The ‘break point year’ seems to occur mostly around 1995 when considering all 1033 transect locations (Fig. 5).

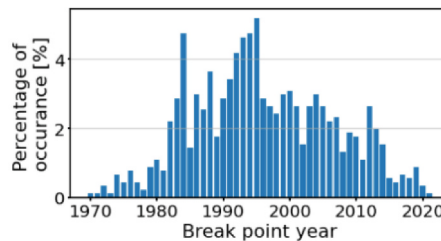


Fig. 5. The percentage of occurrence of the break point year when applying the piecewise linear fit to the 1033 considered transect locations. Most occurring break point years seem to be around 1990–1995.

4 Discussion and Conclusion

The current bulk-analysis of the dune volume development and the piecewise linear fits suggests that the nourishment program along the Dutch coast may have caused a break in trend of dune volume development. This break in trend seems to occur mostly around 1990–1995 at many locations. The break in trend may be explained due to the start of the national nourishment program in 1990. The nourishment program may have resulted in a shallower foreshore that could limit storm erosion and accretion of the beach which could have increased the sediment supply for aeolian sediment transport. The effects of individual storms and their aftermaths remain unclear. As the nourishment program may have stimulated dune growth, the results of this study have important implications for the integral management of dynamic coastal dunes as part of the sediment sharing coastal profile (foreshore-beach-dune).

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