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Adell, Anna; Kroon, Aart; Almström, Björn; Larson, Magnus; Hallin, Caroline

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MORPHOLOGICAL EVOLUTION OF A SMALL-SCALE BEACH NOURISHMENT IN A NON-TIDAL AREA

ANNA ADELL[1,2], AART KROON[2], BJÖRN ALMSTRÖM[1], MAGNUS LARSON[1], CAROLINE HALLIN[1,3]

1. *Department of Water Resources Engineering, Lund University, Box 118, S-221 00, Lund, Sweden.* anna.adell@tvrl.lth.se; bjorn.almstrom@tvrl.lth.se; magnus.larson@tvrl.lth.se.
2. *Department of Geosciences and Natural Resource Management, University of Copenhagen, Øster Voldgade 10, 1350 Copenhagen.* ak@ign.ku.dk.
3. *Department of Hydraulic Engineering, Delft University of Technology, PO box 5048 2600 GA Delft.* e.c.hallin@tudelft.nl.

Abstract: Combining hard and soft costal protection solutions can be an appropriate measure to enhance structure lifetime. This study aims to quantify the morphological evolution of the nourished stretch and adjacent coastlines. A small-scale beach nourishment has been performed in front of a rock revetment at site in Faxe Ladeplads in Zealand, Denmark. The overall objective is to learn more about the dynamics of small-scale nourishments in low energy environments. Monitoring techniques include repeated topographic (Trimble RTK-GPS, drone surveying) and bathymetric (single beam) measurements. To measure the hydrodynamic conditions two surface acceleration buoys deployed at -4 and -7 m water depth were used. Sediment volumes from nourishments of size 70,000 m^3 and 20,000 m^3 redistributed relatively quickly. The nourished material built up the cross-shore profile and a longshore bar in this area, and distributed sediments in the direction of the dominant littoral drift (SW). Results suggest that the morphological evolution of the nourishment is dependent on local hydrodynamic conditions and local geomorphology. These findings have implications for the main objectives of preventing wave overtopping onto an adjacent coastal road during extreme events and restoring a beach for recreation.

Introduction

Performing nourishments in areas where hard coastal protection structures exist is appropriate to reduce erosion pressure on structures and limit wave overtopping on the coastal roads (Steetzel et al., 2017). The dissipation of wave energy over the increased seabed level in nourishment areas means that the revetment or dike located more landward does not have to be heightened or strengthened. Thereby, a combination of hard and soft coastal protection measures is often cheaper and can result in more benefit in form of e.g., recreation, and nature values.

Recent beach nourishments performed at Faxe Ladeplads in Zealand, Denmark were established with the objectives to prevent wave overtopping onto an adjacent coastal road during extreme events and to restore wide beaches for recreation (Ramboll, 2017). The first nourishment was placed in 2018 and a second one in the same area in 2021. The objective of the present study is to learn more about nourishment dynamics of small-scale nourishments in low energy environments.

Case study site

The study site in Faxe Ladeplads is located in eastern Denmark, about 60 km south of Copenhagen, and faces Faxe Bay in the southwestern part of the Baltic Sea. Faxe Bay has a sedimentary coastline, and the bay is relatively shallow (Figure 1). Seabed sediments mainly consist of sand, muddy sand, and till (GEUS, 2014).

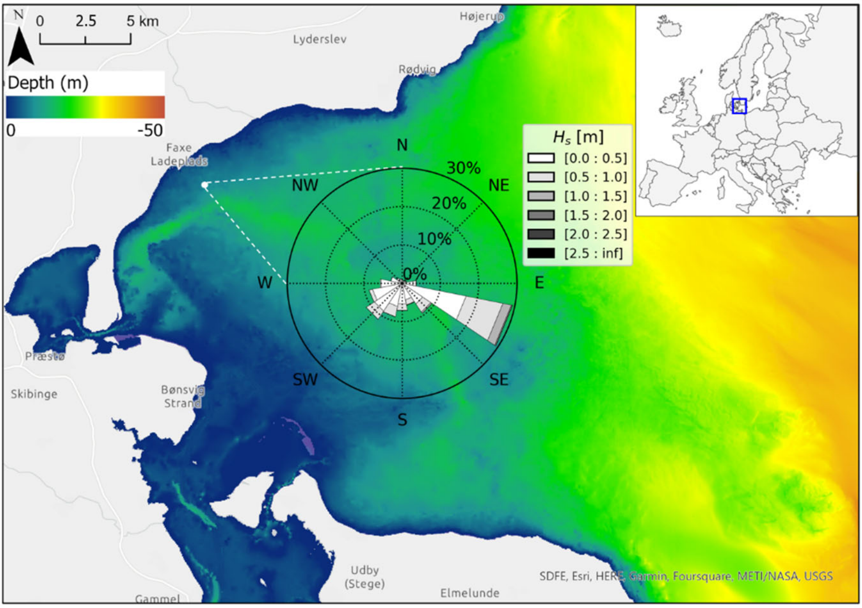

Figure 1: Map of Faxe Bay, including bathymetry (Massetti et al., 2022). Wave rose presents the hindcast wave climate conditions 1959-2021 at Faxe Ladeplads.

The shoreline orientation at Faxe Ladeplads is NE-SW. As presented by the wave rose in Figure 1, the dominant wave direction is ESE-SSE. The largest wave heights are generated in these directions due to the long fetch of about 230-300 km. All other directions are fetch-limited. Since the largest waves are from ESE-SSE directions they generate a net littoral drift towards the SW. There is a harbor and an operating marina, which enables both shipping industry, leisure sailing and fishing. Harbor moles are disrupting the natural sediment transport, which has led to rapid accretion up-drift the harbor and erosion at the lee side. Consequently, the down-drift area has been deprived of sediment for an extended period of time and this has caused steepening of the beach profile.

The tidal range in the enclosed Baltic Sea is only a few centimeters and is negligible. However, water level fluctuations by wind-set up during storm surges or by basin resonance in the Baltic Sea can be up to 100 cm (Baden & Aarosiin-Hansen, 2017).

Methods

The objective of the study is to quantify the morphological evolution of the nourishment site and adjacent shorelines. To then evaluate the coastal protection solution with respect to wave dissipation effectiveness and impact on longshore sediment transport rates. Monitoring techniques include repeated topographic (Trimble RTK-GPS, drone surveying) and bathymetric (single beam) measurements. The survey area is shown in Figure 2.

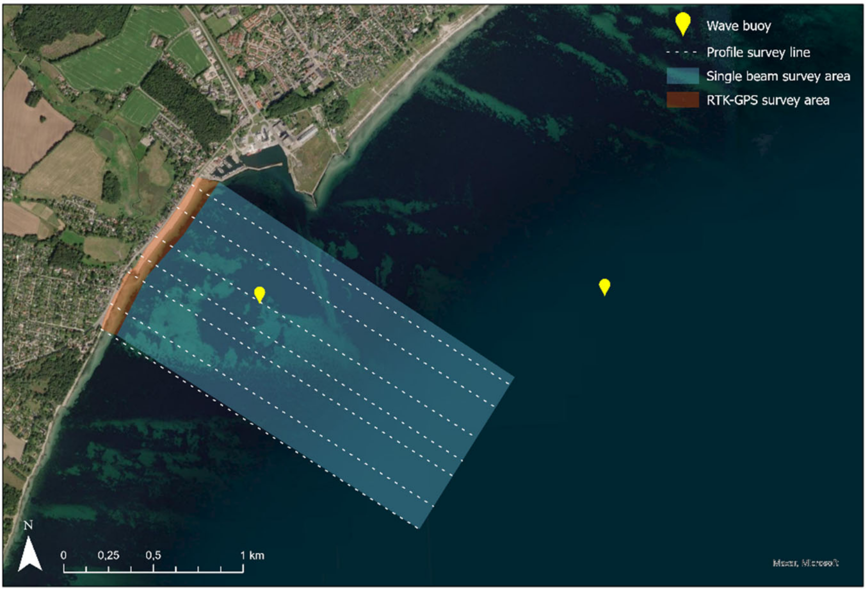

Figure 2: Map of the survey area and wave observation locations. Basemap: Maxar, Microsoft.

To measure the hydrodynamic conditions two surface acceleration buoys deployed at -4 and -7 m water depth were used, the locations are displayed in Figure 2. In addition, water level observations are available at Rødvig harbor station operated by the Danish Meteorological Institute (DMI). The monitoring is done with respect to identifying mechanisms that drive the redistribution of nourishment material. Accounting for both morphological and hydrodynamic conditions.

Results

The first results showed that sediment volumes from the first nourishment redistributed relatively quickly (Vinge-Karlsson & Soerensen, 2021). This nourishment had a size of 70 000 m^3. The nourished material built up the cross-shore profile and distributed sediments in the direction of the dominant littoral drift (SW). It also built up a longshore bar in this area (Vinge-Karlsson & Soerensen, 2021). At the same time, the beach width rapidly reduced and a second nourishment with a size of 20 000 m^3 was placed in 2021. The impact of this maintenance nourishment showed a similar re-distribution. However, the response was not as quick as the initial nourishment. The downdrift effects were still observed; the material bypassed the terminal groin (Figure 3) continuously supplying the down drift area. The cross-shore erosion rates along the stretch were not uniform along the shore. These different erosion rates were partly induced by longshore gradients in the longshore transport rates due to changes in shoreline orientation, and partly due to the result of a complex interaction with the hard structures.

Figure 3: Drone images of Faxe Ladeplads towards the NE. The nourished area is the stretch between the harbor and the terminal groin. (a) August 2018, before the initial nourishment, (b) December 2018, just after the initial nourishment, (c) March 2020, (d) July 2021, just after the re-nourishment, (e) May 2022, including down-drift area. (Images: (a-d) Danish Coastal Authority, (e) Authors.)

Conclusion

The morphological evolution of the nourishment is dependent on local hydrodynamic conditions and local geomorphology. Re-distribution of the nourishment material since the initial nourishment in 2018 has occurred both in cross-shore and longshore directions. From analysis of the hydrodynamic conditions, it is possible to identify events with simultaneously elevated water levels and large waves. Such events have the capacity to increase displacement of nourishment material and induce larger erosion rates.

Acknowledgements

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