GUIDELINES FOR DESIGNING SAND NOURISHMENT ON LOW TO VERY EXPOSED COASTS

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MOTIVATION
Laws in Denmark gives every citizen in Denmark right to access the beach and walk along it, even though beaches often are privately owned. The law also states that coastal protection may not hinder this. Therefore, sand nourishment must be a part of every coastal protection scheme against erosion. Sand nourishment can be designed in numerous ways depending on the objectives. As a part of the European Interreg project, Building With Nature (BWN), guidelines will be developed by the Danish Coastal Authority (DCA) in mid-2020. This abstract presents these with special focus on the coasts in Denmark.

METHODOLOGY
Special emphasis will be on establishing knowledge of the coasts natural variability, because it is vital for both designing the most effective coastal protection scheme and for evaluating the impact of the nourishment. In this project, the pathway along which the sediment is being transported spans from offshore at the outer bar to the coastal cliff.

10 beach nourishments in Denmark and Sweden, and 8 shoreface nourishments in Denmark was analyzed during the project. The nourishment volumes range from 4,000 to 2,000,000 m³. Results from the co-analysis in BWN on nourishments in Belgium, Netherlands and Germany will also be included.

It is the aim to be able to determine the along- and cross-shore paths on which the nourishment sand are transported, the diffusion velocity of the nourishment and the impact on the surrounding coasts. Based on the results of the multiple analysis, it is the primary objective to produce guidelines on how to use sand nourishment to counteract erosion in a sustainable and socioeconomically way.

ANALYSIS
In this abstract, the ongoing work and analysis of a shoreface nourishment at southern Holmsland barrier, a beach nourishment at Nørlev and a beach nourishment at Fredericia will be presented as they are located on highly different coastal stretches. Furthermore, they represent highly different nourishment designs, monitoring programs and results of the various analyses.

At Southern Holmlands Tange, shoreface nourishment of 310,000m³ was placed along a 775m coastal stretch in 2011. Multiple surveys have been conducted before nourishment and fig. 1 shows the variability in the active profile over a period of 10 years. Especially the bars are highly dynamic. Analyses showed relatively significant pattern in the long-, and cross-shore variability bar and the benefits of scaling the shoreface nourishments to the native morphology could potentially increase the benefits from the nourishments. The high frequency in profile measurements showed large variation, which had not been evident from yearly measurements.

Figure 1 - Natural variations 2005-2010, 14 surveys.

At Nørlev, beach nourishment of 18,000 m³ was placed along a 340 m stretch as a 10 m wide rectangular buffer in the duneface. The nourishment volume diffused into the profile and was redistributed along- and cross-shore after the first winter storm. Long-term variations and natural variability on the stretch was analyzed from orthophotos and profile measurement. Satellite images from Sentinel 2 was used to determine the variability of the bars over seasons, but also for before, during and after storm analysis of the beach nourishment development.

Figure 2 - Satellite images of breaker bar system.
Fig. 2 shows three RBG-images with a resolution of 10x10
m from the Sentinel-2 satellite. From these it was possible to determine the variability of the bar system and identify a depression in the outer bar just outside the location of significant dune erosion. Regular drone footage have contributed in determination of natural variability in the active coastal zone, and for analysis of temporal diffusion of nourishment sediment.

At Fredericia, beach nourishment of 18,000 m³ was placed along an 800 m stretch where most was pumped ashore from ship. The goal of the nourishment was to extend the shoreline to the same position as in 1954. The stretch was monitored with regular drone imagery by the DCA but no monitoring program was planned otherwise. Nourishment analysis was mainly based on imagery from the drone captured at comparable positions as seen in Fig. 3 and Fig. 4. Additionally modeled wave data, modeled and measured water levels and two national digital elevation models were included. Decrease in planform and volume was not unexpected and did not exceed the potential transport rates. After 1.5 year, the beach volume and width had still increased compared to before nourishment.

Firstly, the actual problem at the stretch must be addressed. In general, on eroding coasts, the sediment deficit is the main issue. In Fredericia this was handled by increasing the beach width and volume with the goal of extending the shoreline to the same position as in 1954. However, the lifetime of the nourishment was not considered in the planning and the intended goal of the nourishment was achieved the day the nourishment was finished. The general sediment deficit and natural beach width for such a coastline was not considered in the original plans. The diffusion of sediment and reduction in planform was an excepted development, considering the natural behavior of such a system, but an outside viewer might consider this development as unexpected and see the nourishment as pointless.

To improve future designs and effects of nourishments it is a general recommendation to analyze the effects and the migration of sediment. Nourishment sediment does not vanish, the position of the sand grains does though shift. Coastal protection schemes should include evaluations or analysis of nourishment development and effects, as this contribute to increase the knowledge for both stakeholders and planners. This will undoubtedly benefit planning of future protection. A questions in this respect could be; "What had the natural development been if the nourishment had not been conducted?"

To analyze nourishment development and effects, a pre-planned monitoring program is essential for gathering information and data. When planning such a program the natural morphology and knowledge on the variability of the system comes into play. Planning could benefit from gathering knowledge on already available data on the stretch. Profile measurements, orthophotos, DTMs, imagery, etc. could potentially be available, and monitoring methods should try to emphasis the present data so that analysis of nourishment development can be based on data comparable to those used for analysis of the natural development of the stretch. Low-budget data acquisition could be as simple as drone imagery captured from the same position once a month. This data can be utilized not only in analyzing the stretch but also for informative campaigns to the stakeholders. Monitoring with drones can also be extended to the acquisitions of imagery for construction of both DTMs and orthophoto if there is a need for detail. This naturally also comes with a slightly higher cost.

CONCLUSIONS
The use of frequent data (survey, satellite, orthophoto and drone images) to quantify the natural variation on erodible coasts has improved the ability to assess and quantify the effects of sand nourishments. The planned and ongoing further analyses are expected to result in statistically significant results which will be used to make guidelines on the design on nourishments that are improvements to the present ones.

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