

# INTELLIGENT BEACH NOURISHMENT: THE FUTURE OF SOUTHERN BALTIC COASTAL PROTECTION

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## AREA OF INTEREST - THE HEL PENINSULA

The Hel Peninsula is a unique and distinctive geographical feature of the Southern Baltic Sea region. A long, narrow and forested sandbar, it is a popular tourist destination thanks to its beautiful beaches, but also an object of high scientific interest. As a transitional environment between the Baltic and the sheltered waters of Puck Bay, it is a biodiversity hotspot of the region, providing a home for a wide range of flora and fauna, with some species being unique to the place.



Figure 1 - The Hel Peninsula. Source: Landsat 2000.

## EROSION PROCESSES OF THE PENINSULA

Over the past several thousand years, the Hel Peninsula has been freely shaped by the alongshore sediment transport. The sediment material that supplied the peninsula came from eroding coastlines. Over the last thousand years, the peninsula has witnessed the formation of local and randomly occurring inlets and channels, which were created during very strong storms (Uścińowicz 2003). These gaps would appear for several weeks or months and then they would get filled in with sand, only to reappear in different locations.

Starting from the 19th century, the Hel Peninsula began to implement the first methods of protection, such as the construction of coastal barriers and groins, which relatively stabilized the coastal zone of the peninsula. Channels were no longer forming, but there was still some minor coastal erosion occurring.

In the 1987, a severe flooding and erosion event occurred on the Hel Peninsula. The continuity of the peninsula was disrupted (Ostrowski et al. 2013). As a consequence, the Polish government implemented a strategy for protecting the peninsula's coasts. This strategy involved regular artificial beach nourishment, the modernization existing and construction of new groins, and the incorporation of coastal barriers into the dunes, serving as the last line of defense against further breaks in the peninsula. This strategy has been in use for almost 40 years. However,

taking into account the local conditions, the effectiveness of groins, and the small and inhomogeneous dune system, artificial beach nourishment is considered crucial for the protection of the Peninsula's shoreline.

However, nourishment is fundamentally a temporary resolution of the problem, as it does not affect erosion rates and the supplied material is eventually worn away through coastal processes. Intensification of those processes is poised to make beach nourishment projects more frequent and, subsequently, costly. Adaption to the changes requires these projects to be performed in a more efficient manner, with consideration for the effects of climate change.

## CHANGES IN HYDRODYNAMIC CLIMATE

There are several ways in which climate change affects the Baltic Sea. Storm surges are big drivers of erosion, and an intensification of their severity and frequency directly leads to greater erosion rates. Next, the rise of sea level, due to global temperature increase, is particularly dangerous to low-lying and vulnerable areas such as the Peninsula (Stronkhorst et al. 2018). Increase in sea level is directly related to temperature increase, which can also negatively impact the Peninsula due to its geology: harsh hydrodynamic climate coupled with mild winters can expose layers of finer sediments, in this case peats and other organic soils, which erode at an even faster rate than sediments on the outer layer (Różyński, Lin 2021). As a result of all these issues, the key to understand the changes happening in the Peninsula is to perform an analysis of past hydrodynamic climate of the region and subsequently follow it up with an estimation of future conditions.

## HYDRODYNAMIC DATA ANALYSIS

An examination of a 61-year period from 1958-2018 has been performed for wave parameters (significant wave height, peak period, wave direction) based on two databases, the HIPOCAS program and CMEMS' Baltic Sea Wave Hindcast. Both of them utilize the numerical model WAM and, after extensive comparisons with observational buoy data, have been verified to be suitable for the Southern Baltic region. Furthermore, water level values for the 1958-2018 period have been studied based on observational from the Władysławowo mareographic station, as well as additional CMEMS model data. The area of analysis extends from Władysławowo, located at the root of The Peninsula, to the town of Kuźnica.

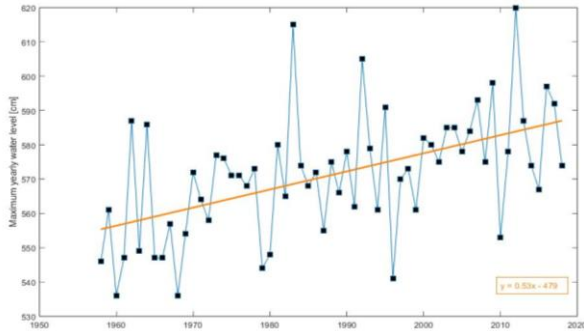


Figure 2 - Maximum recorded water level values at the Władysławowo station. 1958-2018.

### CALCULATION OF FUTURE CONDITIONS

The next step of the research involves calculating hydrodynamic conditions for the years 2018-2100. The modeling is performed utilizing Delft3D, a three-dimensional modeling suite that allows for hydrodynamic, morphodynamic and sediment transport analysis. The simulation is performed based on most probable climate change scenarios predicted within a set of Regional Climate Models. This leads to a comparison of patterns in extreme events occurring in the period of 1958-2018 and the period of 2018-2100.

### EFFECT OF CHANGING HYDRODYNAMIC CLIMATE ON EROSION PROCESSES

In the first step of this analysis, based on historical technical reports from past artificial beach nourishment projects, the effectiveness of these projects was assessed in relation to the hydrodynamic conditions at the time. Starting from 1987, the average lifespan of artificial nourishment for each subsequent 5-year period was determined. In the next step of the analysis, anticipated future hydrodynamic conditions were taken into account, and it was determined whether, if artificial beach nourishment projects were to be carried out in the future according to the same characteristics.



Figure 3 - The process of beach nourishment. Author: Adrian Diack/CC.

In this way, it was demonstrated that due to the expected intensification of climate change, adjustments should be made to the currently existing strategy. Simulations, utilizing programs XBeach, CSHORE, SAND94 (Bugajny

et al. 2015; Szmytkiewicz et al 2016; Szmytkiewicz et al. 1998) were conducted for the reconstruction of the seabed and coastline in the area with the highest and most frequent erosion occurrences for different scenarios of depositing the same amount of sediment in various locations. It was found that the most effective approach (the ratio of the amount of deposited material to the first moment when the dune starts to erode) occurs when artificial nourishment complements the characteristic natural seabed deepening that occurs in the offshore area of the most significant coastal erosion on the Hel Peninsula. Thus, a new, intelligent method of reconstructing the shore of the Hel Peninsula was developed - taking into account climate related shifts, as well as the shape of the sea bottom in the area of analysis, which are factors that had not been taken into account before.

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