




Ministry of Environment
and Food of Denmark
Coastal Authority

Building with Nature: Systems Description of Skodbjerg

August 2018



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1 Introduction

1.1 Building with Nature

The objective of the Building with Nature EU-InterReg project is to improve coastal adaptability and resilience to climate changes by means of natural measures. As part of this project the Danish Coastal Authority (DCA) carry out research into different aspects of using natural processes and materials in coastal laboratories on Danish coasts.

Through the EU InterReg project “Building with Nature” a better understanding of the interactions within the coastal system is sought.

The Building with Nature project is a combination of six different work packages, see Figure 1.

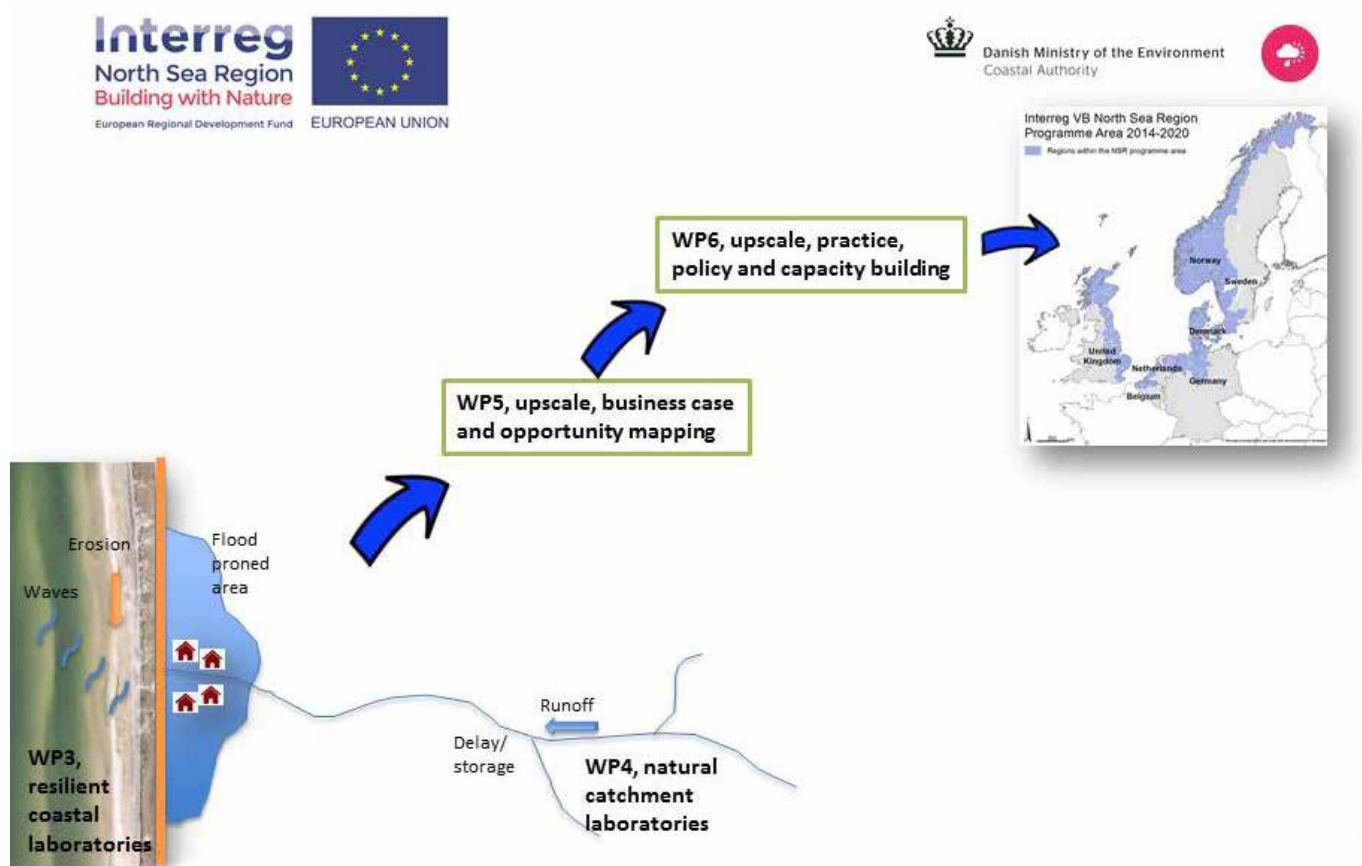


Figure 1: The connections between the 6 work packages in the Building with Nature project. WP1 - Project Management, WP2 - Communication Activities, WP3 - Resilient Coastal Laboratories, WP4 - Natural Catchment Laboratories, WP5 - Upscaling, Business Case and Opportunity Mapping, WP6 - Upscaling, Practice, Policy and Capacity Building.

The Danish Coastal Authority is mainly active in Work Package 3: Resilient Coastal Laboratories. This project comprises two living laboratories: Krogen and Skodbjerg. Each location will be monitored and examined with regards to erosion, nourishment and aeolian transport throughout the duration of the project.

The Danish Coastal Authority has an in-depth knowledge of coastal dynamics along the Danish North Sea coast; the Danish Coastal Authority has been engaged in coastal protection since 1872 and has collected measurements of the coast since 1876.

1.2 The Joint Agreement (on the North Sea coast)

After a severe storm in 1981 it became apparent that the structural coastal protection established, mainly consisting of groins and dikes were not enough to safeguard the Danish North Sea coast. This is due to the fact that the coast line is subject to chronic erosion, which means that the natural retreat of the active coastal profile will vary between one and eight meters per year, see Figure 3. In this area, the combination of substantial natural coastal retreat, a relatively high water level during storms, a narrow dune belt and low hinterlands along long stretches of the coast create a serious flooding hazard; and in case of dune penetration homes and property would be destroyed. See Figure 2.

The Danish Government and the local municipalities therefore signed a joint agreement to protect the coast in the future. The Joint Agreements are financial agreements usually covering a five year period. This means that the agreement will be up for renegotiation every 5 years.

Since 1982, thanks to these agreements, protection of the 110 km stretch of coast from Lodbjerg to Nymindegab has been carried out as a joint effort by the local municipalities and the Danish government, see Figure 2. The basis for the agreement is a safety level objective as expressed in the average volume of sediment in the coastal profile.

Since the first agreement, 28 km of slope protection have been laid out, 145 breakwaters have been built and the coast has been nourished with some 59 million m³ of sand.

The current five year joint agreement will expire in 2018.

Since the 1990s, the coastal protection of the coast stretching from Lodbjerg to Nymindegab has primarily consisted of sand nourishment and slope protection in front of sand dunes and sand dikes. However, today the protective efforts almost solely consist of nourishment.

The building of solid constructions, only, reduced the retreat of the coastline, but not until a nourishment scheme was introduced, was the retreat brought to a halt. The annual coastal protection scheme of the Danish West Coast is planned on the basis of surveys, measurements and analysis of previous coastal developments, and the Danish Coastal Authority is continuously optimizing the coastal protection effort on the western coast of Denmark

In the current Joint Agreement covering the period from 2014 to 2018 two objectives have been implemented based on assessment and categorization of the impact of coastline retreat. The categorization serves as a means of prioritizing the resources of the joint agreement:

Stretches without slope protection, where homes and infrastructure are at risk and/or where there is risk of a dune breach during a storm, and this incident could lead to a flooding of the hinterland, the goal is to stop the coastal retreat.

At Havvig and Skodbjerg, where the dunes have a small, extra sand buffer, the objective is to reduce coastal retreat to a maximum of one meter per year.

On stretches with slope protection, the objective is to reduce coastal retreat as much as possible with the remaining amount of sand for nourishment. Based on a calculation of the amount of sand available for nourishment, the coastal retreat can be limited to 3.2 m/year on the stretches where the natural retreat is above this objective.

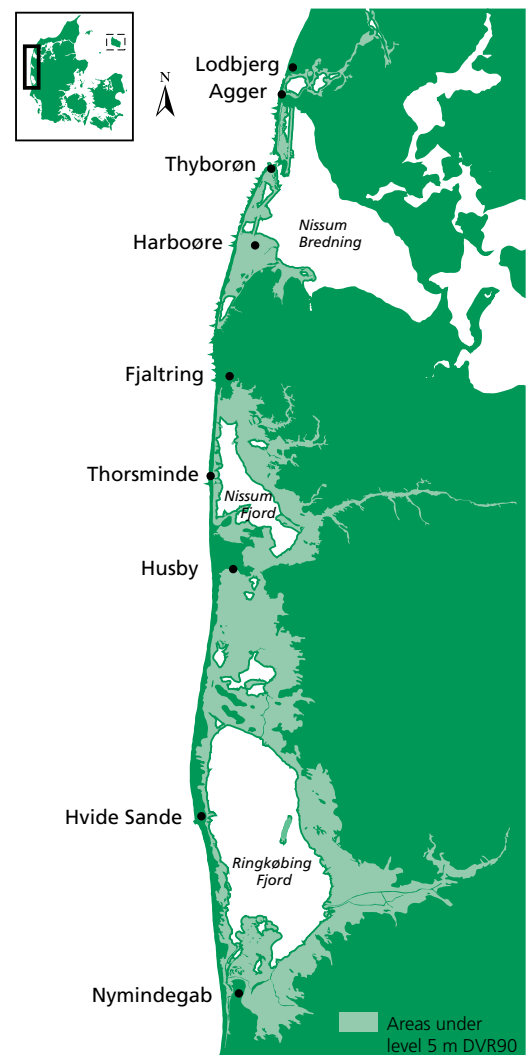


Figure 2 The 110 km stretch from Lodbjerg to Nymindegab. The map shows areas below 5 m DVR90.

The objective of the joint agreement for the period 2014-2018 is illustrated in Figure 3.

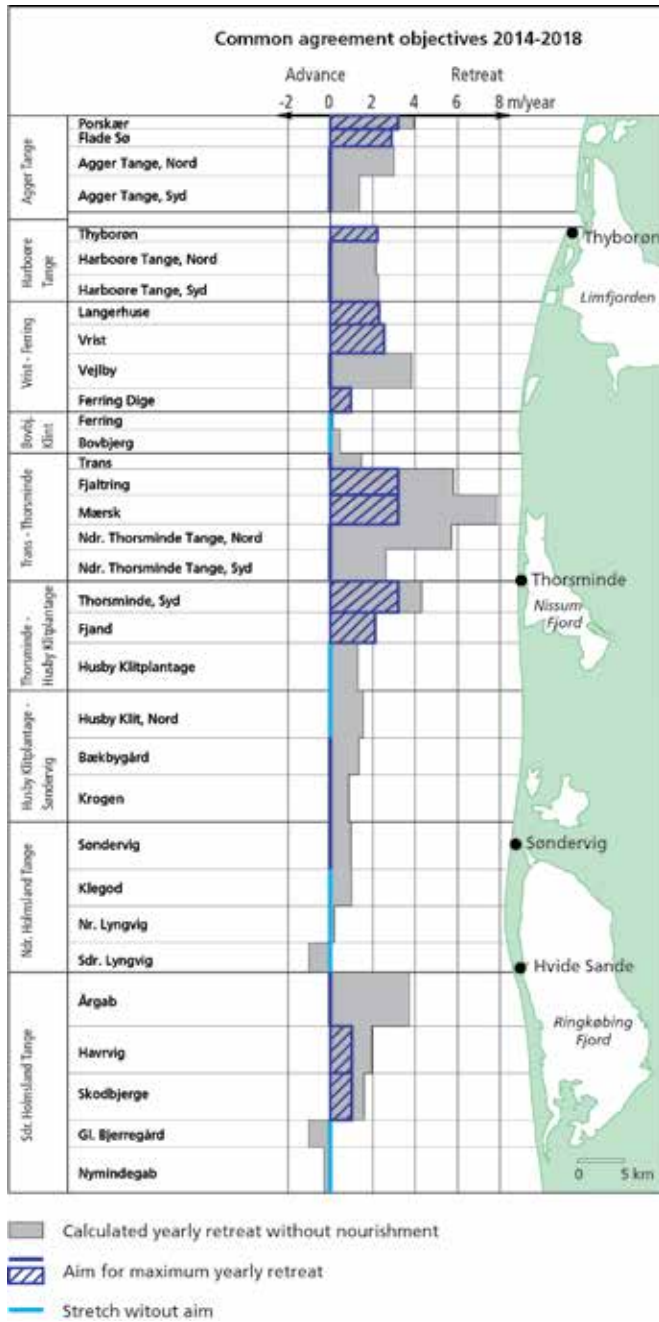


Figure 3: Joint agreement objectives 2014-2018

1.3 Safety Level in the Joint Agreement from Lodbjerg to Nymindegab

The overall purpose of the Joint Agreement is to ensure that at the beginning of each winter season the dunes on this stretch of the coast will be resilient enough to withstand the erosion and prevent a breach during a storm with a 100 year return period. The only exception is Thyborøn where the objective is protection against a 1000 year storm event. The Joint Agreement for the coastline between Lodbjerg and Nymindegab specifies a safety level for erosion, which includes a protection level against dune breach and floods. This means that the dunes must have a minimum height and a minimum width based on the surveys and analyzes made by the Danish Coastal Authority.

Table 1 An overview of the different dune safety criteria on the coast between Lodbjerg and Nymindegab.

Stretch	Minimum dune height	Minimum dune width
Agger By	3.5 m	40 m ¹
Agger Tange	3.5 m	30 m
Thyborøn By	4.0 m	50 m
Harbøre Tange	3.5 m	30 m
Langerhuse til Bovbjerg	3.5 m	40 m
Bovbjerg to Husby Klitplantage	4.0 m	40 m
Husby Klitplantage to Nymindegab	4.5 m	40 m

Table 1: Dune safety criteria

This systems description will focus on the living laboratory Skodbjerge which is found on the stretch Husby Klitplantage to Nymindegab.

This systems description will describe the area around Skodbjerge, including coastal protection, local safety criteria and the factors affecting the area. The coastal system from the ocean to the hinterland will also be described.

¹ Minimum dune width 30 m where slope protection is placed

2 The area of Skodbjerg

There are several interesting characteristics about the area of Skodbjerg, which contributed to the decision to make the area a Building with Nature living laboratory. The living laboratory of Skodbjerg is located along that part of the Danish North Sea coast which is governed by the Joint Agreement under which the Danish Coastal Authority is responsible for meeting the agreed safety objectives. There are no hard coastal protection installations in the area, a dune enhancement has been established behind the dunes and nourishments have been performed several times over the last decades. This means that studying the system at Skodbjerg can lead to a better understanding of the effects of beach and shoreface nourishments.



Figure 4: Location and photos of the living laboratory Skodbjerg (© SDFE).

Skodbjerg is located on the southern part of the narrow spit Holmsland tange which encloses Ringkøbing Fjord, Figure 4. The main road, Sønder Klitvej, is the only road connecting the southern part of the spit with the northern Holmsland Tange at Hvide Sande. Along Sønder Klitvej there are several areas with vacation homes in the dunes; as is also the case in Skodbjerg. The road runs parallel to the coast only about 1 km inland, which makes it important to maintain the safety level and safeguard the coastline position. The dunes are generally steep and the naturally developing dunes are backed by a plateau formed by a dune enhancement. The hinterland is protected by dunes and a dune enhancement. The dunes at Skodbjerg have several wind-scoured blowouts resulting in increased sand drift inland.

2.1 The landscape at Skodbjerg

The illustration in Figure 5 conceptualizes some of the important elements in the system at Skodbjerg. During the last decades, The Danish Coastal Authority have performed dune enhancements, as well as beach and shoreface nourishments. In the following the geological setting, the coastal system, the land use and the infrastructure are described.

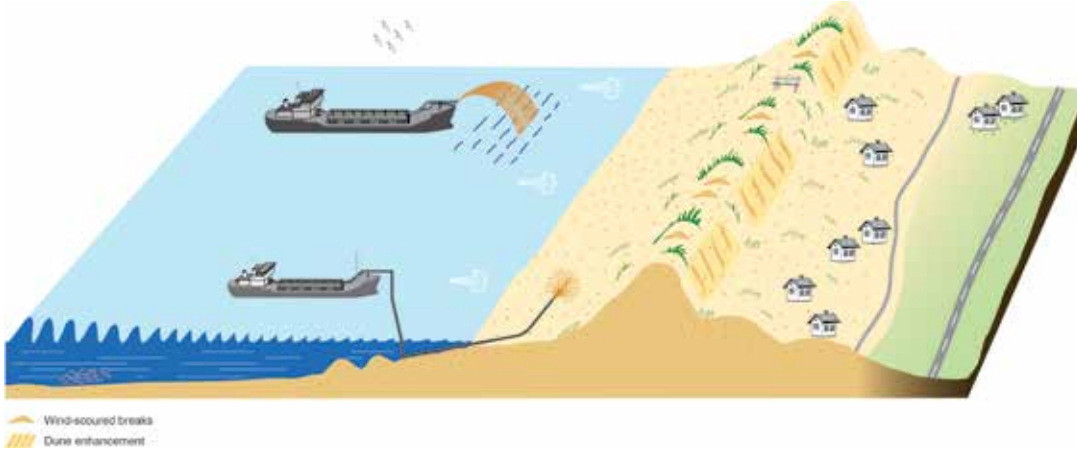


Figure 5: Schematic representation of the living laboratory at Skodbjerg

2.1.1 Geological Setting

The Danish landscape is primarily a glacial landscape; the coasts are predominantly made up from loose sediments/marine deposits. Ringkøbing Fjord was closed off by a spit development driven by southerly directed sediment transport. This has resulted in a straight coastline and a brackish lagoon. The spit, Holmlands Tange, is built upon the remains of one or several low-lying islands that have once stretched far into to the ocean. This is a fairly young marine foreland. Along the west coast the large amounts of available sand combined with consistent westerly winds have created dunes.

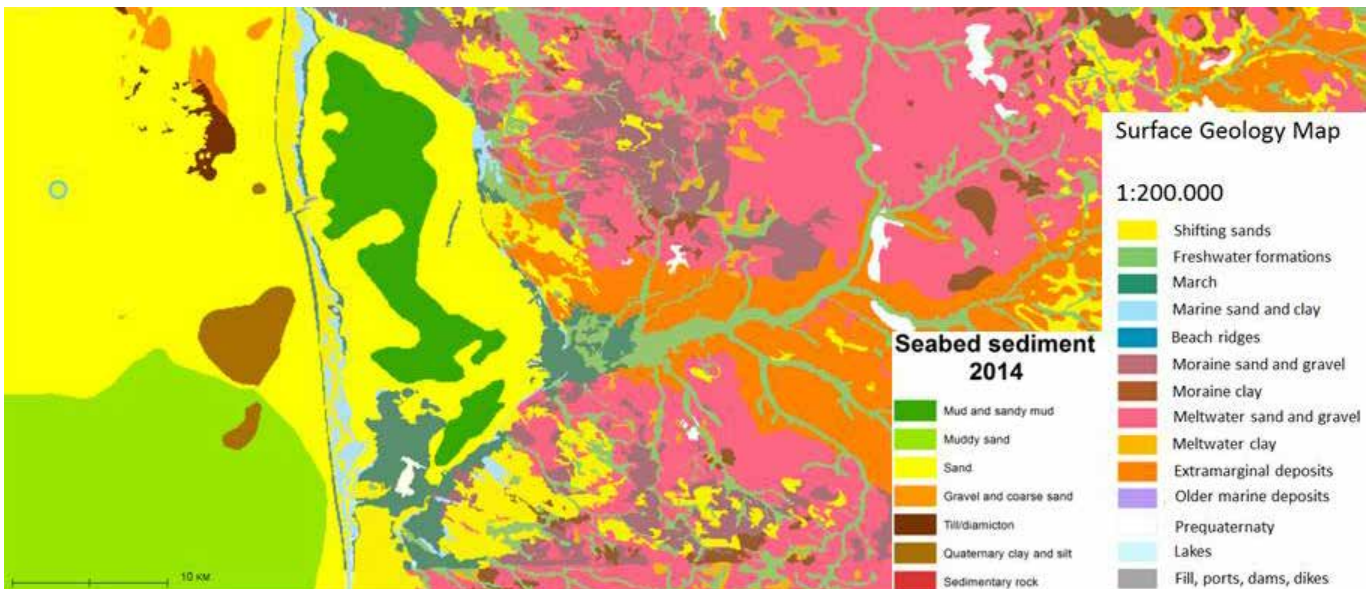


Figure 6: Map with seabed sediments and surface geology soil types (© GEUS)

The inland sediment is dominated by sand with a layer of clay. Where clay dominates, the coastline is less affected by erosion from the sea. The seabed sediment is also dominated by sand with muddy sand and small areas of clay and silt, see Figure 6.

2.1.2 The Coastal System

The Danish North Sea coast is a micro tidal wave dominated sandy coast. The coast is highly dynamic and the morphology changes responding and adjusting to climatic conditions. Large alongshore variations in the coastline have been documented along the Danish North Sea coast, rhythmic bar systems and separating rip currents create coastline perturbations and indentations, which migrate as the bar system migrates alongshore in the sediment transport direction, which is southbound. These coastline indentations, which are characterized by a narrowing of the beach, mark potential erosional hotspots. The number of bars, their size and position in the offshore direction change rapidly, especially during storms; the bars migrate offshore, and during calm weather conditions they will migrate towards the shore and in some cases well onto the beach, momentarily widening it. Skodbjerg is located at Holmsland Tange. The area is characterized by high dunes lining the spit. Along the lagoon, the coast develops under much calmer conditions with marsh forming.

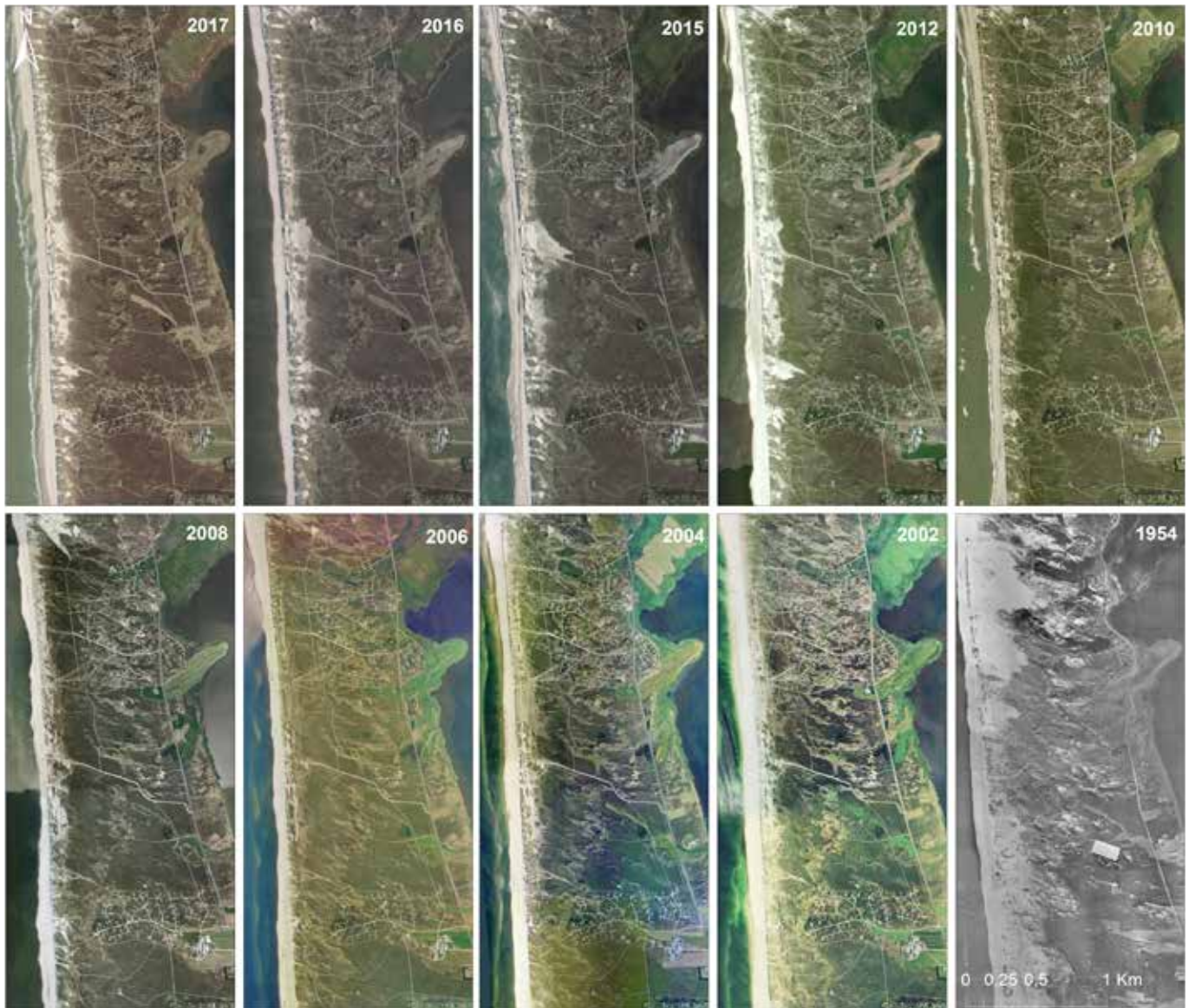


Figure 7: Aerial photos covering Skodbjerg from (© DDO 1954-2012, COWI), (© DDO 2015-2017, Geodanmark, SDFE).

The west coast of Denmark is generally flat, particularly around the area of Ringkøbing Fjord. The differences in elevation in the landscape are minor and the coast and hinterland are at risk of flooding. The morphodynamic changes on the exposed coastline are observed when comparing aerial photos, see Figure 7. The alongshore variations described above in coastline and bars are observed especially when comparing the photos from 2010-2015. In 2010 it seems that a bar is coming from the north and

ending in the middle of the map section. Just south of the bar there is an indentation in the coastline. The observed bar system is not visible two years later in 2012 when the coastline is more meandering. In 2015 a nearshore bar is present and it seems to have almost welded on to the beach creating a transverse bar and a beach system with rip channels. In 2006 it is possible to identify a rhythmic bar along most of the coastline section.

When examining the evolution of the coastline based on aerial photos the ongoing beach and shoreface nourishments in the area should be taken into account as they blend into the natural dynamics. Untangling the natural variations from the nourishment effects is one of the main challenges of this study. The living laboratory has at least one sandbar and the dynamics and influence of the bar system will be further examined in the project as they influence the evolution and effects of beach and shoreface nourishment.

2.1.3 Land Use and Infrastructure

At Skodbjerg the main road, Sønder Klitvej, is about 700 meters from the dune front. Behind the dunes, approximately 300 meters from the dune front but in some areas as close as 150 meters to the dune front, vacation homes have been built, see Figure 4. Along the lagoon coast there are areas used for grazing. Large parts of the area are governed by Natura 2000 legislation because of their great importance to migrating and nesting birds.

2.2 Threats to the Skodbjerg Area

Storm surges are recurrent in the winter season at Skodbjerg. A storm surge can be defined by the resulting water level during a storm. There is a connection between high water level due to storm surges and large waves generated by strong onshore wind. The combination of these effects will have a particularly strong impact on the dunes, with risk of overtopping, erosion, breaches of dikes and dunes and subsequently flooding of the hinterland. The vulnerability of the area at Skodbjerg is apparent when examining the local elevation. The LIDAR scan from 2017 shows the narrow dune ridge which borders on a more low-lying area which is then followed by a new dune system consisting of dunes as high as 16 meters, see Figure 8.

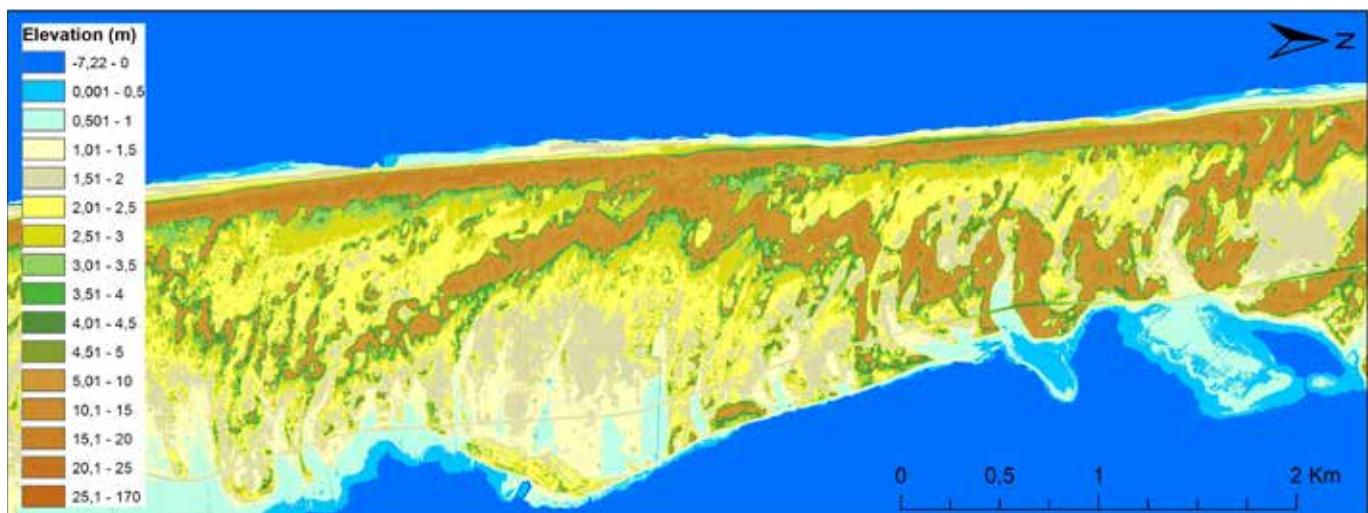


Figure 8 Map showing the elevation at Skodbjerg (© Digital Elevation Model, 2014, SDFE).

In the following sections the threats of erosion and flooding at Skodbjerg are presented.

2.2.1 Erosion

Erosion can be categorized as either chronic or acute. Chronic erosion is long term and is often induced by alongshore gradients of the sediment transport; along coastlines where, as sediment transport rates increase, a sediment deficiency occurs leading to erosion of the coastal profile and a gradual landside displacement of the coastline. Acute erosion is temporary and occurs during storms with high water levels and high wave energy conditions (Acute erosion is part of the chronic erosion). The higher water levels and waves displace the erosional processes onshore leading to erosion of sediment on the back of the beach and the dunes. The Danish North Sea coast is recognized as an erosional coast which is subjected to chronic erosion caused by the southbound alongshore drift but furthermore, large acute erosion events will take place during storms, see Figures 9 and 10.



Figure 9 Photo from Skodbjerge on January 12 2015 after the storm, Egon. The front of the dune has eroded back and is rendered almost vertical.

The chronic erosion at Skodbjerge is about 2m/yr. As such, this erosion rate is not high compared to other sections of the Danish North Sea coast, see Figure 3, but serious, in the light of the risk of acute erosion. At Skodbjerge large blowouts are scouring the dunes, see Figures 9 and 10.



Figure 10 Photo from Skodbjerge on January 7 2007. The dune front is eroded over a long stretch and there is a local breach.

Acute erosion has previously eroded long stretches of dunes at Skodbjerge. In 2007 part of the dunes in Skodbjerge retreated 10 meters during a storm in January. The maximum recorded dune retreat at the Danish North Sea coast was 60 meters at Thyborøn and a retreat of 46 meters was recorded at Vedersø in 1981; this indicates the scale of potential erosion along the Danish North Sea coast.

2.2.2 Flooding

The hinterland at Skodbjerge consists of Sønder Holmsland Tange, Ringkøbing Fjord and the surrounding towns which are all low-lying. The 20 year and 100 year storm return periods are 2.57 meter and 2.74 meter above daily normal at Hvide Sande, respectively. In Figure 11 the national digital elevation model has been used to do a simple bucket fill analysis showing the area at risk in case of dune breach and subsequent flooding with a water level reaching as high as 3 meters above normal.

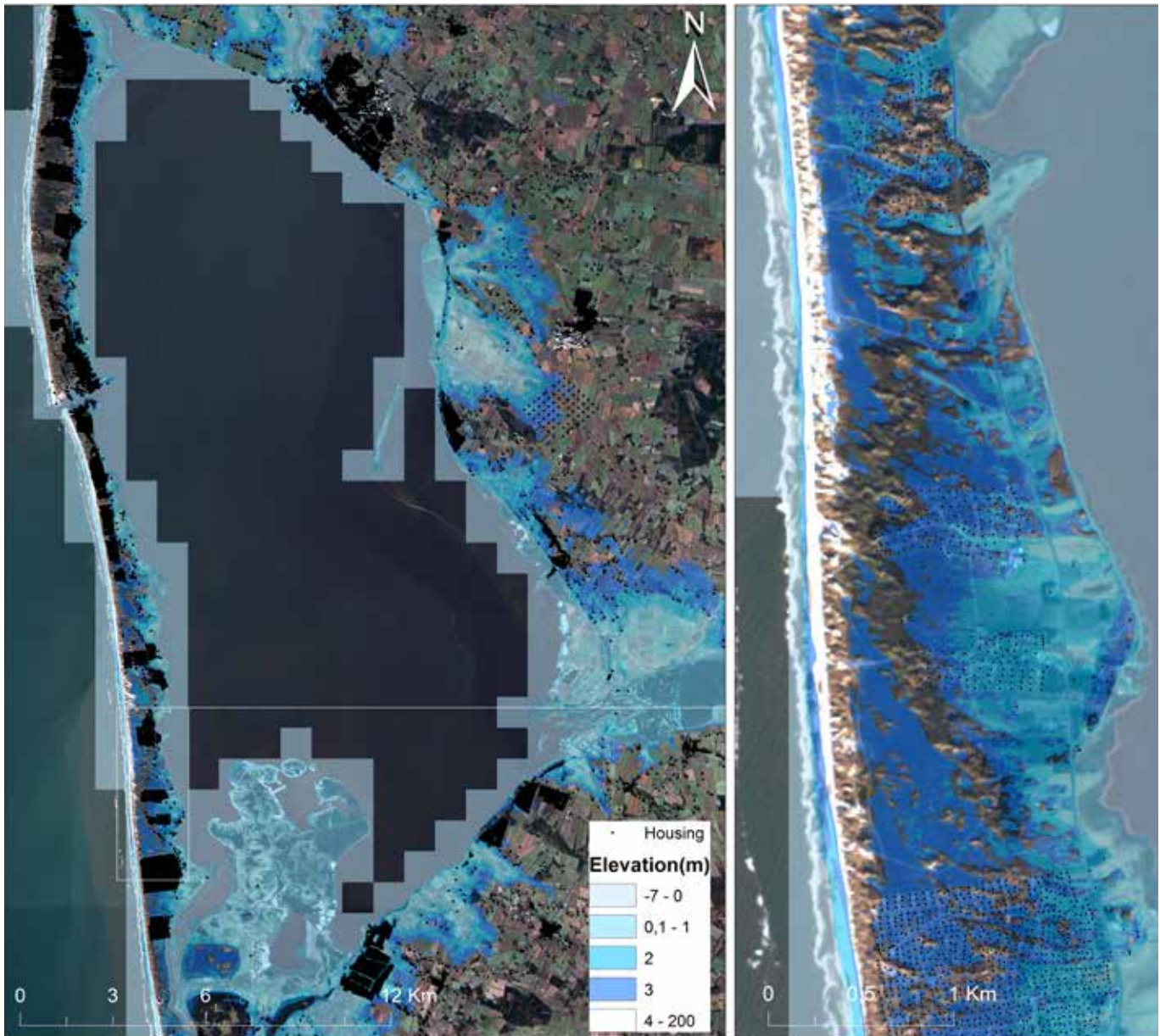


Figure 11: The maps show a flood risk analysis based on the national elevation model including housing. Left: Section of Ringkøbing Fjord. Right: Illustration of the local flood challenges, especially in relation to the vacation homes in the dune valleys (© Digital Elevation Model, 2014, SDFE).

As shown in Figure 11 (left part) flooding at Skodbjerge is a threat to the vacation homes, the main road and finally Ringkøbing Fjord and the surrounding towns. Extensive efforts to enhance the dunes and thus minimize the risk of flooding have been made at Skodbjerge. However, there are still challenges and flooding occurs locally, especially affecting vacation homes located in dune valleys, see Figure 11 (right part).

2.3 Coastal Protection at Skodbjerge

At Skodbjerge both shoreface and beach nourishment have taken place, as illustrated by Figure 12. These were performed in the years 1992, 1994, 1999, 2010 and 2011. In 1989, 1990, 1993, 1996-2001 scraping of the beach took place to better distribute the sediment that is deposited in the berm during calm weather. However, The Danish Coastal Authority no longer performs beach scraping, as this method has several disadvantages such as heavy machinery on the beach and interference with the natural distribution of sediment along the Danish North Sea coast.

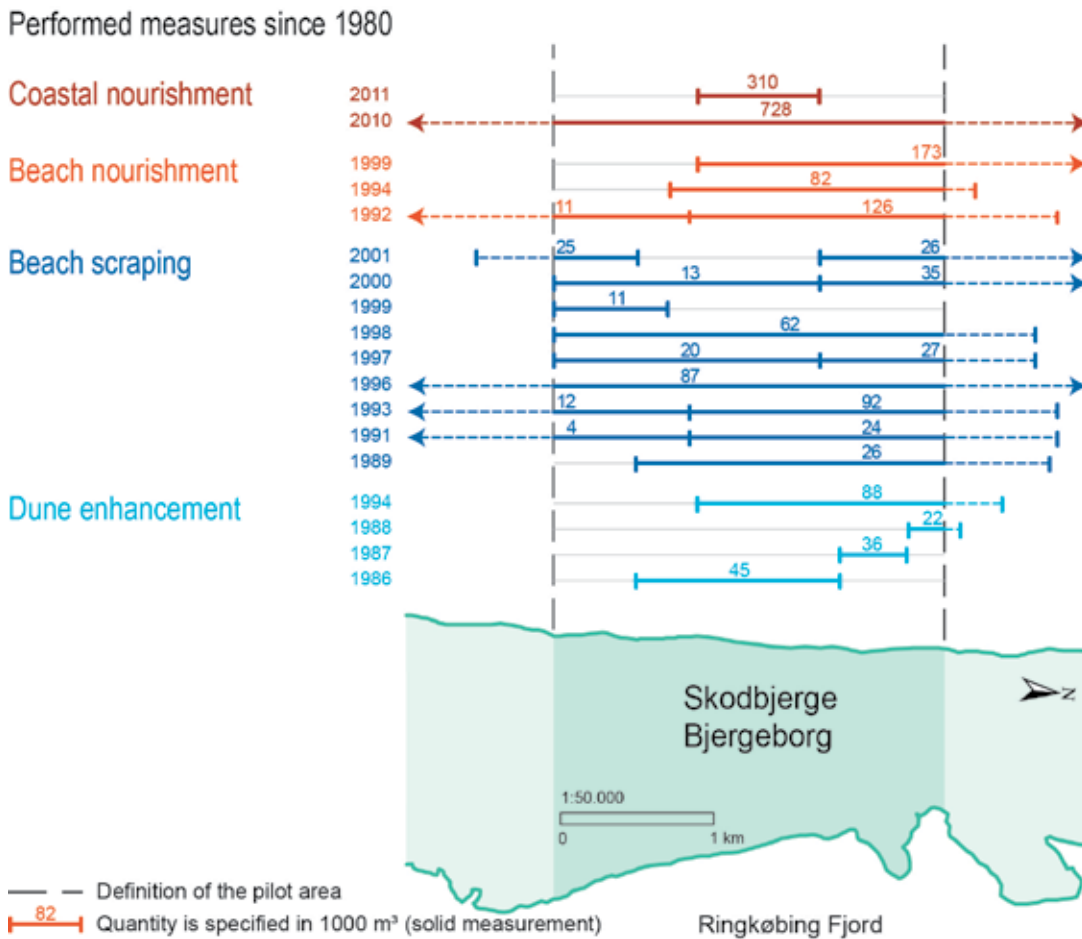


Figure 12: Coastal protection measurements implemented at Skodbjerge from 1980 until today.

A series of dune enhancements were performed in 1986-1990, which is illustrated by the shaded area on the dunes in Figure 12. However, the exact amount of sand, deposited as an enhancement behind the existing dunes is unknown. The long series of dune reinforcements made in 1990 aimed to reduce the risk of flooding of the hinterland in case of a breach of the narrow dune zone.

2.4 The Effect of Coastal Protection at Skodbjerg

The effects of the coastal protection measures implemented as part of the Joint Agreement are evaluated at the end of each agreement period. Figure 13 shows the calculated annual coastal retreat without nourishment, the maximum accepted retreat as governed by the Joint Agreement and finally the actual annual retreat in the period from 2009-2016. At Skodbjerg the coast actually advanced about 0.5 meters per year from 2009-2016. During this period two nourishments were performed.

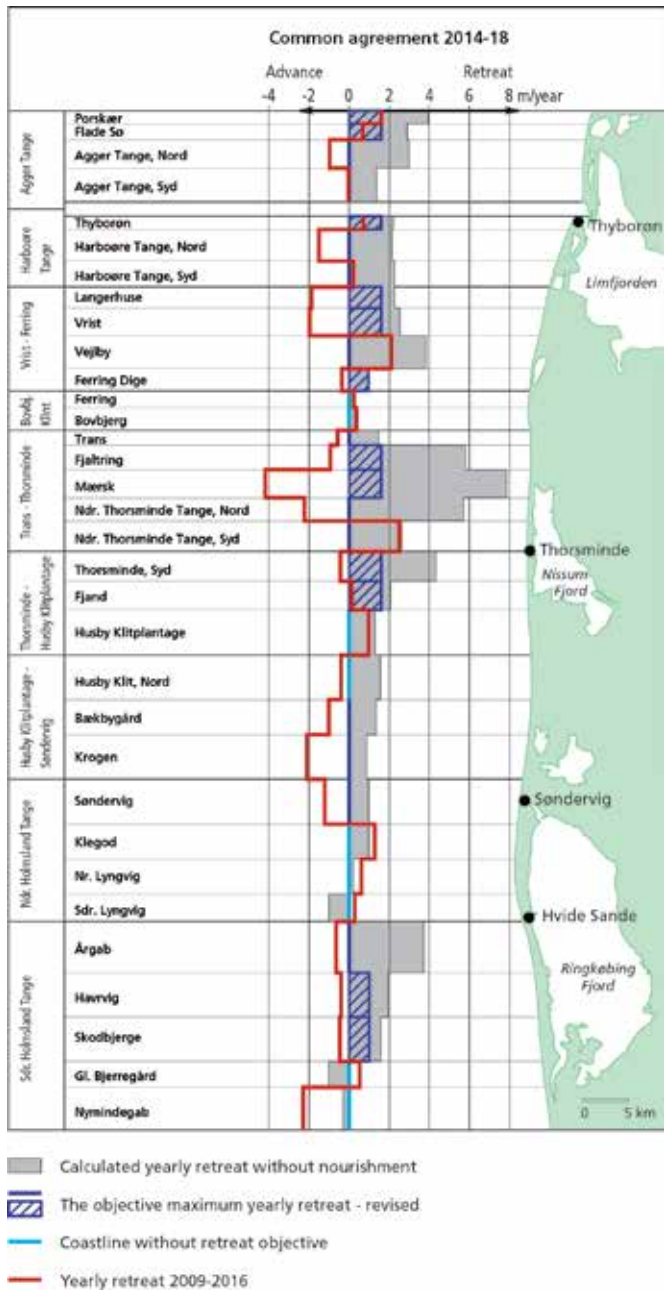


Figure 13: Map showing the effect of the coastal protection carried out under the Joint Agreement.

3 Source-Pathway-Receptor

The coastal system at Skodbjerg can be described with a Source-Pathway-Receptor (SPR) model.

In the Skodbjerg system the sources are wind, waves, tide, marine surge and current. The pathway is the coastal profile from the shoreface over the beach right to the dunes. While the receptors are the infrastructure, vacation homes, Ringkøbing Fjord, the towns bordering on Ringkøbing Fjord and the protected nature around Ringkøbing Fjord.

The consequence of the source action is erosion and retreat of the pathway (shoreface, beach and dunes) which can cause flooding at the receptor or erosion of the receptor. To prevent the sources from causing retreat and flooding, the pathway is strengthened with modification elements such as nourishment, different kinds of hard coastal protection and planting of vegetation in the dunes. The Building with Nature project focuses on modification of the pathway using nature based solutions.

Figure 14 shows the source-pathway-receptor model in a schematic form.

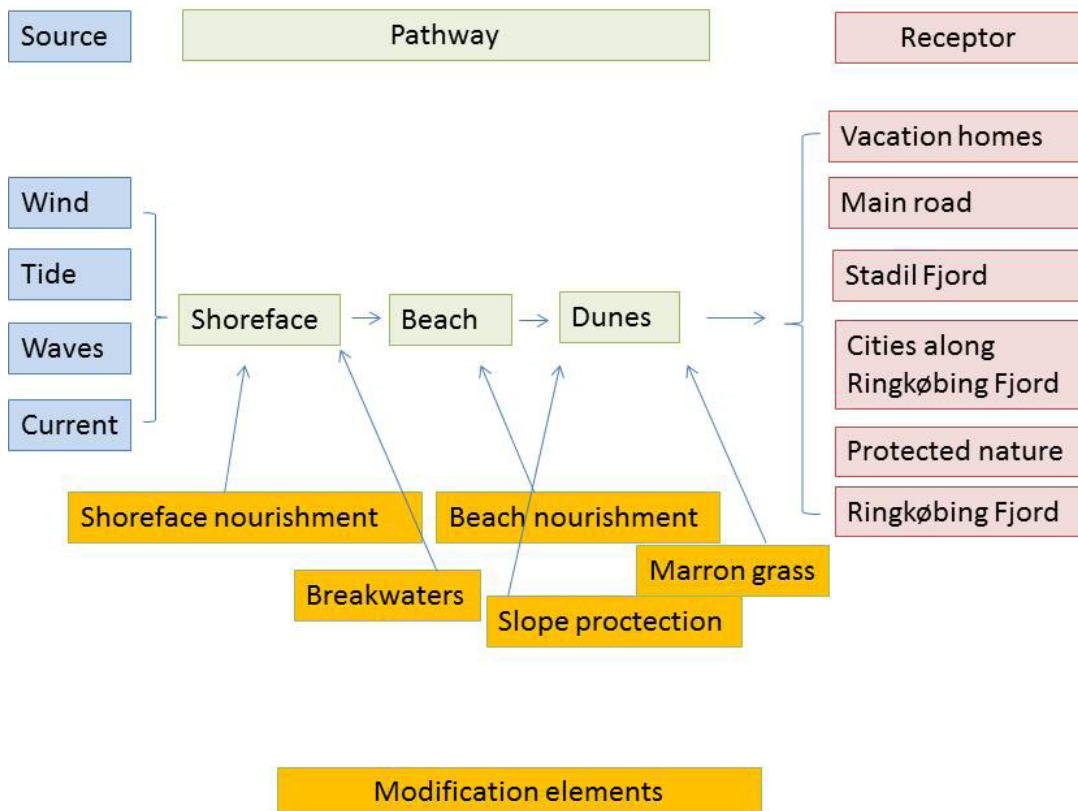


Figure 14: The source-pathway-receptor model.

Through the Building with Nature project different aspects of the modification elements in the pathway will be analyzed at Skodbjerg.

The development of a shoreface nourishment will be analyzed in the software program MorphAn. Additionally, it will be attempted to set up a 2D model to illustrate acute erosion. Aeolian sand transport from the beach into the dunes is a third field that will be looked into in the Skodbjerg laboratory. Last but not least the storm data in the area will be used to make a classification of storms.



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