A Changing World : Expected Effects of Climatic Change on a Barrier Island - Case Study Sylt Island/German Bight

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ABSTRACT

This paper describes a multidisciplinary German project dealing with the expected reaction of natural and social conditions on the island of Sylt (North Frisian Islands, German North Sea). Climate change, i. e. increasing of the mean sea level (MSL) and storm activity, will influence the coastal development of sandy islands like Sylt. To estimate the influence of climate change a numerical model was used to predict the development of the coastline of Sylt island. Data of coastal retreat are available from 1876 to 1997 and were measured each 500 m longshore (~70 profiles). Wave data are available from 1986 to 1997. The model was calibrated and verified with these data. The coastal retreat was calculated to the year 2050 under the following scenarios (International Panel on Climate Change, IPCC): MSL +25cm; tidal range +25cm; wave height +10%; wave direction ± 10°.

Accordingly, little changes in the Sylt coastline configuration over the next 50y are expected when the modern strategy (i. e. nourishments) of western shore protection is maintained. In contrast, if modern protection strategies are not maintained, significant changes of the Sylt coastline configuration (both west and east coast) may occur due to partly dramatic erosional shore retreat in case of an assumed 10% increase of wave height and a 10° change of all westerly wind directions toward the north. Only moderate changes in coastline configuration and weak erosional shore retreat can be expected when the wind direction is turned 10° to the south and the wave height did not increase.

INTRODUCTION

Over the past two decades, public and scientific discussions intensively stressed the consequences of anthropogenically induced global climatic changes for coastal zones affected by human activities. In case of global warming, near-coastal industrial zones and human settlements are endangered due to assumed sea level rise and increased numbers of storm surges (e.g. von Storch et al., 1998). From man's point of view it is most significant if changing climate has negative impacts on people living in areas concerned by the consequences of climate change. In order to optimise adaptation strategies regarding climate change and, furthermore, to develop and improve Integrated Coastal Management (ICM) tools, we need an inventory of regional environmental conditions as well as socio-economic and psychological aspects of affected societies.

The island of Sylt (Fig. 1) is one of the most prominent and famous sites in western Europe affected by coastal retreat. Sylt is situated at the west coast of Schleswig-Holstein/Germany and is directly influenced by wave attack. Sylt is build up of Plio-Pleistocene outcrops in the middle of the island between Kampen and the south of Westerland (fig. 6). The north sea reached these outcrops 7000 years ago at a level round about 10 m below recent sea level. The mean coastal retreat during the last 7000 years can be estimated by 1.5 m/a. Long spits developed from the outcrops to the north to List and to the south to Hörnum-Odde. In the protection of these spits a waddensea and a moory landscape developed. During the catastrophic storm surges in the middle age Sylt become a real island. The first more or less realistic map is from 1650 (Fig. 2). The coastline from 1240 is more or less schematic.

Fig. 1: Overview

The morphodynamic system of the west coast of Sylt island is characterised by a longshore bar and trough and ridge and runnel. Rip currents occur between 700 and 1400 m. The distance between the longshore bar and beach is 200 to 400 m.

Tidal currents are dominant (<-10 m depth) seaward of the longshore bar with a resulting sediment transport to the north (AHRENDT 1994). A complicated sediment exchange takes place between longshore bar and beach with a resulting sediment loss to the north, northerly of Westerland and to the south, southerly of Westerland (Fig. 3).

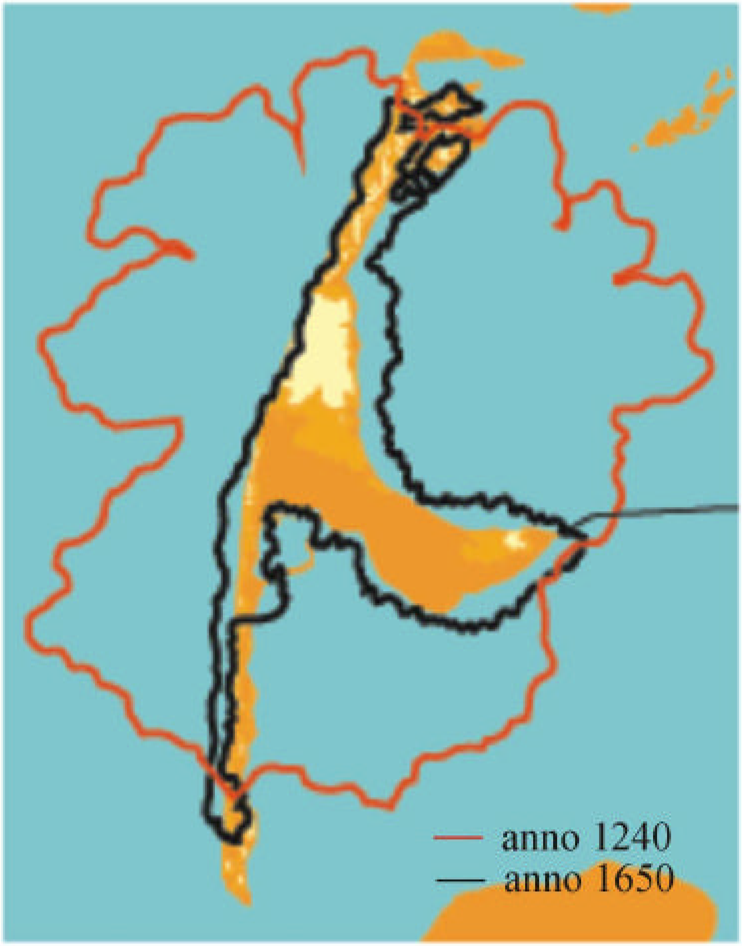

Fig. 2: Sylt anno1240, 1650

The first georeferenced map is from the year 1870. The coastal retreat from 1870 to 1952 and from 1952 to 1984 is shown in Figure 4. An increase in coastal retreat occurred from 1952 to 1984.
However, the general coastline configuration could be maintained since the middle of the 80ies by nourishments. The sediment loss is round about 1 200 000 m^3/a. 800 000 m^3/a are lost between the 10 m depth contour and the beach and 400 000 m^3/a are lost by dune erosion. 800 000 m^3/a are lost to the north and 400 000 m^3/a are lost to the south, calculated by depth of closure and map analysis (Tab. 3).

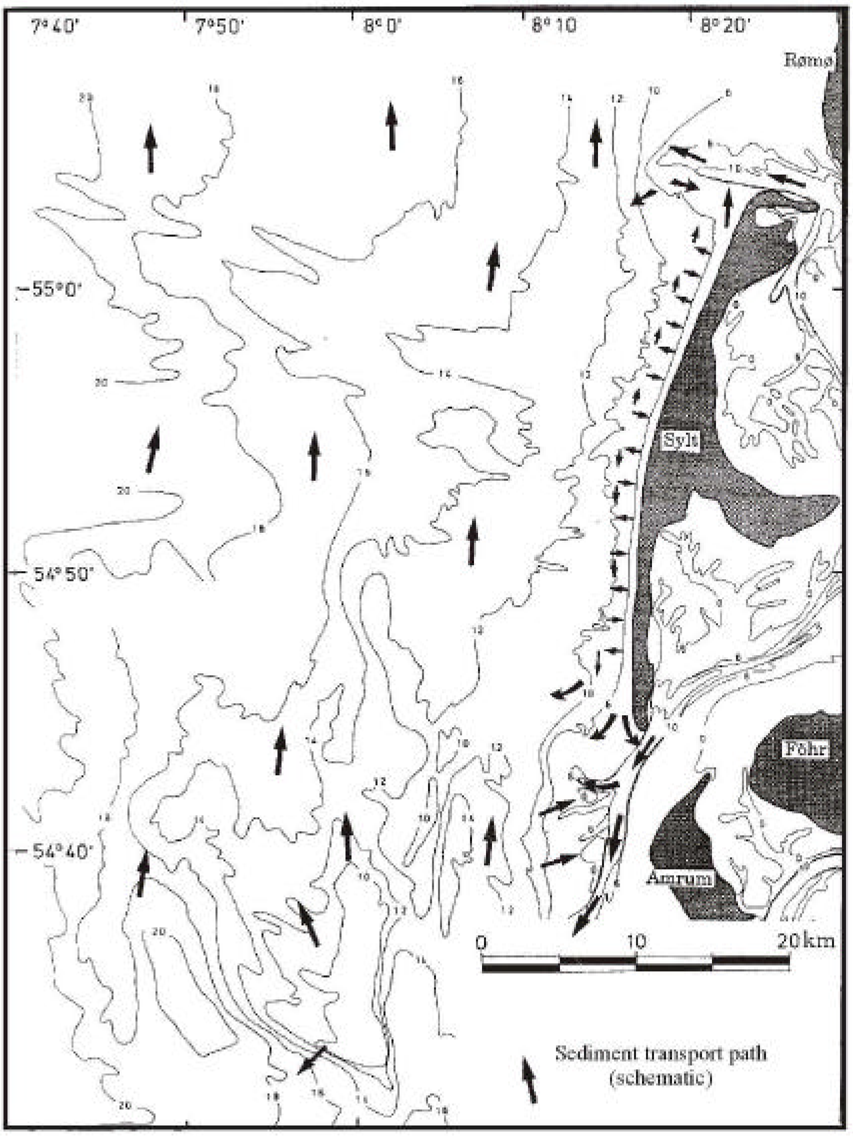

Fig 3: Sediment transport around Sylt (schematic)

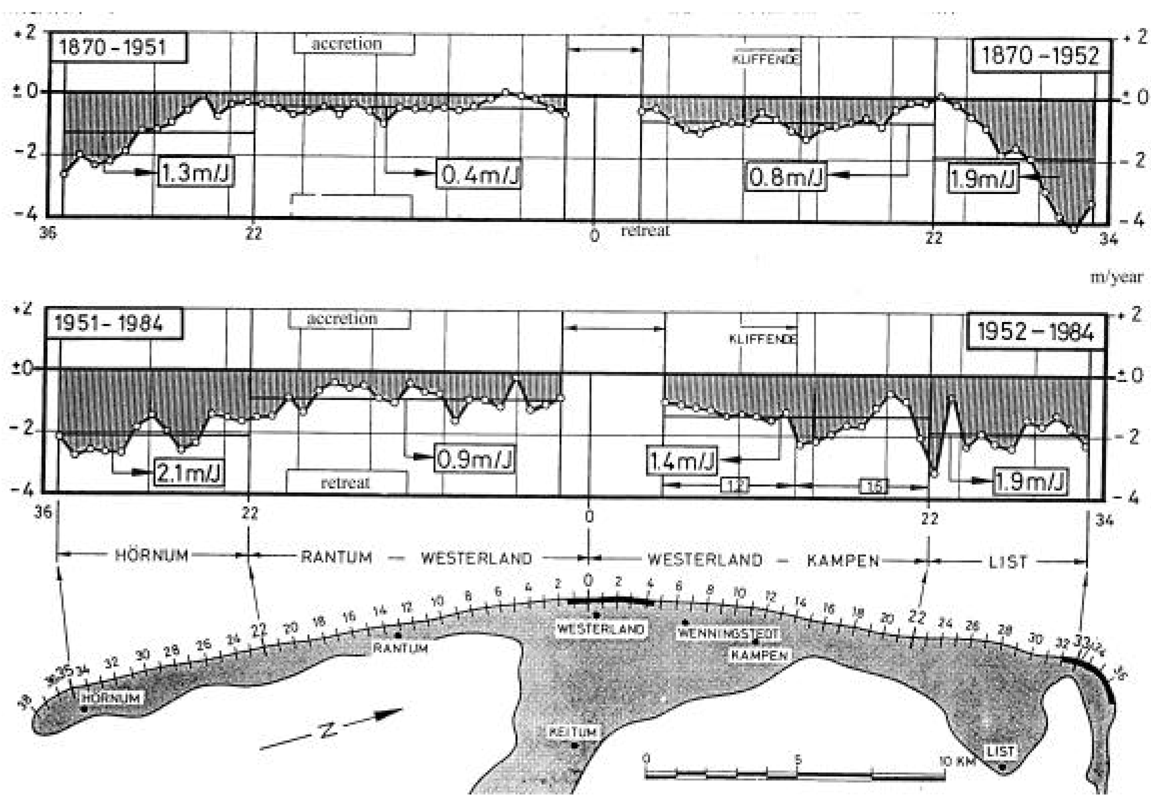

Fig. 4: Coastal retreat from 1872 to 1984 (after ALR 1985)

The wave climate is measured continuously since 1986 at the 10 m depth contour and is shown in table 1. Westerly wind between 247.5° and 315° are dominant. The maximum measured wave height was round about 9 m.

The vulnerable island has a multi-functional socio-economic character (e.g. tourism) and is covered by a mixture of natural and cultural territories. Besides high level standards in living and recreation facilities, Sylt provides unique aspects of a biotope and offers perfect opportunities for the development and establishment of coastal protection techniques.

According to the IPCC (International Panel of Climatic Change) model predictions, the mean global sea level rise of 0.49 m until 2100 (considering local variations) can also strongly affect the island of Sylt and the adjacent region. Today, only little is known about regional climate change and potential consequences on environmental and socio-economic conditions. In order to improve our understanding on the correlation between man and natural environment, and to develop ICM as an integrative tool to be applied to natural and civilised coastal systems on regional and local scales, the case study Sylt was designed from seven different disciplines: geology, coastal and water engineering, ecology, geography, economy, psychology, and sociology.
Few of the most important integrative questions are:
- How do Sylt inhabitants and tourists as well as regional and local authorities evaluate potential climate change and subsequent island damage?
- How can different strategies of coastal protection be evaluated from an ecological, economical and social point of view?

- Which morphological and socio-economic future scenarios over the next 50y are most realistic for Sylt?

Wavestatistics, 4018 days, 01.10.86 - 30.09.97

Hm0 [m]/Degree

	0,0	22,5	45,0	67,5	90,0	112,5	135,0	157,5	180,0	202,5	225,0	247,5	270,0	292,5	315,0	337,5	
0,25																	
0,50	1,650	1,305	1,019	0,587	0,342	0,302	0,295	0,250	0,516	0,843	1,209	1,533	2,658	4,233	6,568	1,724	25,035
0,75	0,476	0,133	0,154	0,089	0,114	0,093	0,179	0,325	0,456	0,599	1,079	3,739	2,616	4,285	7,739	1,296	23,372
1,00	0,107	0,002	0,011		0,002	0,005	0,011	0,011	0,094	0,252	1,198	2,958	0,554	4,002	3,524	1,313	14,045
1,25	0,064	0,000			0,001		0,003	0,008	0,035	0,185	0,991	1,865	0,730	3,356	2,197	0,719	10,154
1,50	0,064	0,002							0,002	0,081	0,639	1,251	0,760	2,414	1,556	0,412	7,181
1,75	0,021								0,001	0,042	0,473	0,937	0,764	1,829	1,150	0,232	5,450
2,00	0,002								0,001	0,040	0,324	0,672	0,678	1,514	0,870	0,105	4,206
2,25									0,001	0,032	0,194	0,534	0,544	1,179	0,599	0,047	3,131
2,50										0,009	0,093	0,430	0,442	0,801	0,440	0,030	2,246
2,75											0,085	0,239	0,422	0,593	0,311	0,003	1,653
3,00											0,053	0,201	0,349	0,419	0,208	0,003	1,232
3,25											0,024	0,170	0,271	0,264	0,078	0,003	0,809
3,50											0,009	0,106	0,196	0,253	0,062		0,627
3,75											0,002	0,062	0,123	0,180	0,029		0,397
4,00											0,001	0,028	0,076	0,091	0,009		0,205
4,25												0,011	0,045	0,058	0,001		0,115
4,50												0,012	0,029	0,042			0,083
4,75												0,002	0,012	0,020			0,034
5,00												0,003	0,008	0,006			0,017
5,25												0,001	0,004				0,005
	2,385	1,443	1,183	0,676	0,459	0,400	0,488	0,594	1,108	2,082	6,374	14,754	11,283	25,540	25,34	5,888	100,0

Tab. 1: Wavestatistic from 01.10.1986 to 30.09.1997 in %

The author will focus out here mostly the future coastal development. For more details of the other disciplines see http://soel.geographie.uni-kiel.de/sylt/

METHODS

Individual sub-project tasks are:

geography:

The geographic sub-project is responsible to cover the scientific coordination of all contributing individual sub-projects. The particular challenge consists in the integration and combination of research output from (i) geo-scientific and technological sub-projects as well as from (ii) social sciences and economy/ecology efforts. Additionally, in close co-operation with the external "Sylt-GIS"-project, the work focuses on adapting integrative scientific concepts. Main target is to develop a conceptual framework (environmental-quality-concept) for the evaluation of our joint results. Furthermore, the results and the integrated, GIS-supported, evaluations are provided to German authorities in order to enable and support political and/or administrative decisions towards an improved "Intergated Coastal Zone Management" (ICM) on the island of Sylt and along the German North Sea coast in general.

ecology:

One main focus of this sub-project is to reconstruct the historical development and changes of Sylt's coastal marine ecosystems and to evaluate their changing impacts on island inhabitants and tourists. Modern inventories of marine ecosystem populations and areal species distribution as well as an overview on biological productivity and exchange processes will help to develop predictive ecosystem scenarios. Predictions on the direction and velocity of expected ecological changes will rely on forecasts of functional interactions within the regional ecosystem (e.g. sediment balances, hydrodynamics, techniques of coastal protection etc). Moreover, politically sensitive topics like the use of local marine resources and nature conservation will be stressed.

water and coastal engineering:

Changing wind fields lead to variations in wave fields. Since the wave field is the decisive component for coastal erosion, investigations on wind-wave correlation around Sylt are necessary. Once knowing the changing wave impact on coastal sections particularly exposed to shore erosion, relevant protection strategies and techniques can be developed.

sociology:

Ascertainment, composition and comparative confrontation as well as evaluation of potential directions of social developments of Sylt are the principal objectives of this sub-project. From the sociological point of view the question rises, in which sense Sylt might be of interest or importance for public life. In this concern different complexes will be stressed: Sylt as a status symbol, as a living resort, as a high standard recreation area, as a biotope, as an example of effective coastal protection, and Sylt as a native and protection-worth environment. Particular questions are:

- What is the modern attraction of Sylt based on, and under which conditions the attraction can no longer be preserved?
- Are we talking about Sylt as a North Frisian island, or does the modern Sylt represent the "status quo" of a profit-concept evolved during historical and cultural development of the island?
- What happens if society interests decline individual life-style (inhabitants, tourists) or dominate German financial politics (particularly in terms of coastal zone protection) due to consequences of climate change?

psychology:

The works of this sub-project focus on human actors' abilities to reflect their impacts on - and own exposure to - environmental systems. Particularly, errors and biases in environment-related perception and evaluation and - as a consequence - communication on environmental risks are of interest. Errors and biases are assumed not to be arbitrary, but systematically related to positions and roles of individual actors in social systems. Since certain actors dominate decisions and influence environment-related activities on the island of Sylt (e.g. coastal zone management, land use, energy consumption), they have direct impact on the dynamics of local and regional social systems.

economy:

The purpose of this sub-project is to evaluate the financial consequences of climate change on the socio-economic and natural systems of Sylt using a benefit-cost-analysis. Based on the sedimentological model scenarios, the economic damage due to erosional coastline retreat will be appraised. For both the "protected" case (simulated coastal retreat *with* shore protection) and the "non-protected" case (simulated coastal retreat *without* shore protection), the investments in coastal works (nourishments etc.) after erosion-induced damages have to be identified and estimated. Main financial consequences to be considered are property loss (housing, land, business, infrastructure) as well as loss of public recreation areas and unique environmental sites.

MODEL SCENARIOS AND METHODS

Numerical simulations on alongshore sediment transport and subsequent coastline development were carried out using the LITPACK model supplied by the Danish Hydraulic Institute (e.g. ENGELUND and FREDSOE, 1976). Physical model parameters considered are (i) wave direction and height, (ii) current conditions, (iii) grain size distribution of local deposits, and (iv) the declination of coast-normal and -parallel topographic profiles. Due to a significant lack of data and observations on local climatic changes, quasi-realistic meteorological and oceanographic parameters were derived from IPCC simulations in order to trigger the LITPACK modellings (Table 2).

Scenario	Wave-		Change in water level
	height	direction	
A	10% increase of wave height in westerly directions	-	0,00m - 0,50m
B	-	10° to North	0,00m - 0,50m
C	-	10° to South	0,00m - 0,50m
D	10% increase of wave height in westerly direction	10° to North	0,00m - 0,50m
E	10% increase of wave height in westerly direction	10° to South	0,00m - 0,50m

Tab. 2: Description of the scenarios

Moreover, the simulations are supported by findings about past changes of the coastal morphology due to geological, geomorphological, meteorological, hydrological and socio-economical processes. The model results will be used as data base for project partners with social and economic perspectives (human activities, settlement, damage costs etc.).

The sediment drift was calculated by a model which consists of two calculation parts: a longshore current calculation and a sediment transport calculation (STP). The cross shore distribution of longshore current, wave height and set up for an arbitary coastal profile, is found by solving the long- and cross-shore momentum balance equations. The longshore current model includes a description for regular and irregular waves, the influences of tidal current, wind stress and non-uniform bottom friction as well as wave refraction, shoaling and breaking. The associated sediment transport is based on the local wave, current and sediment conditions. The model is an intra-wave-period model which describes the time-varying distribution of both suspended load and bed load within the wave period in combined wave and current motion, including the effect of wave breaking when relevant.
The modul STP is described by:

$$q = \frac{u^2}{(s-1)gd} \Rightarrow q_B = \frac{1}{T}\int_0^T f(q)dt$$

θ Shields Parameter
u boundary layer velocity
s relative density of bed material
g acceleration of gravity
d grain size
q_B bed load transport

The suspension load is described by the sediment concentration C:

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial z}\left[e_s \frac{\partial C}{\partial z}\right] + w\frac{\partial C}{\partial z}$$

C sediment concentration
z vertical component (zero at bed)
ε_s eddy viscosity
w fall velocity
ε_s is equal the turbulent eddy-viscosity of the currents. The concentration near bed is given by C_B

by z = 2d. C_B is determined after BAGNOLD (1954) as funktion of θ. The suspension load q_s is calculated as product of sediment concentration and velocity U as mean value of the wave periode

T: $q_s = \frac{1}{T}\int_0^T \int_{2d}^D CU dy dt$

T wave period
U current velocity
D water depth

LITDRIFT describes the longshore current and the sediment transport. The sediment transport is calculated by STP based on local wave, current and sediment conditions (DEIGAARD et al. 1988, FREDSOE 1984):

$$\tau_b - \frac{d}{dy}[\rho E D \frac{du}{dy}] = -\frac{ds_{xy}}{dy} + \tau_w + \tau_{cur}$$

τ_b bed shear stress by surf current
τ_w shear stress by wind
τ_{cur} shear stress by current
ρ density of sea water
E impulse coefficient
D water depth
s_{xy} coastal parallel radiation stress

As result LITDRIFT is able to give a deterministic description of the cross-shore distribution of longshore sediment transport for an arbitrary, non-uniform, bathymetric and sediment profile, as well as a detailed description of the sediment budget.

The model LITLINE calculates the long-shore coastline position based on input of wave climate as a time series. The model is based on a one line theory, in which the cross shore profile is assumed to remain unchanged during erosion/accretion. The coastal morphology is solely described by the coastline position (cross-shore direction) and the coastal profile at a given long-shore position. The programme calculates and tabulates transport rates as a function of water level, the surface slope due to regional currents, grain size, the wave period, height and angle compared to the coastline normal:

$$\frac{\partial y_c(x)}{\partial t} = -\frac{1}{h_{act}(x)}\frac{\partial Q(x)}{\partial x} + \frac{Q_{sou}(x)}{h_{act}(x)\Delta x}$$

$y_c(x)$ distance from the baseline to the coastline
t time
Q(x) long-shore transport of sediment expressed in volumes
x long shore position
Δx long-shore discretization step
$Q_{sou}(x)$ source/sink term expressed in volumes/Δx
$h_{act}(x)$ height of active cross-shore profile

$h_{act}(x)$ and $Q_{sou}(x)$ are calculated based on user specifications, while the long-shore transport rate Q(x) is determined from tables relating the transport rate to hydrodynamic conditions at breaking. For more details see DEIGAARD et al. (1988) and FOSTER & SKOU (1992).

RESULTS

The actual sediment loss was calculated to 1 200 000 m³/a. This is the same as estimated by map analysis. When the wave climate is changed 10° to north, the sediment loss is nearly the same but the direction is visa versa. This will result in an increasing coastal retreat northerly of Westerland. When the wave climate is changed 10° to south, the sediment transport is also nearly the same but without a net transport to the south. This will result in a coastl retreat southerly of Westerland. An increase in the wave height of 10% will also result in an increase in the sediment transport from 1 200 000 m³/a to 1 950 000 m³/a. A rise in sea level from 25 cm or 50 cm does not result in a significant increase in sediment transport but shifted the main sediment transport region shoreward.

	North	South	Total
Sedimentloss today	850 000	-350 000	1 200 000
Wave climate 10° north, scenario B	195 000	-705 000	1 050 000
Wave climate 10° south, scenario C	1 430 000	45 000	1 475 000
+ 10% Hs, scenario A	1 480 000	-470 000	1 950 000
+ 10% Hs and 10° north, scenario D	370 000	-1 000 000	1 370 000
+10% Hs and 10° south, scenario E	2 450 000	80 000	2 530 000

Tab. 3: Sediment losses in m³/a, negative values are losses to the south

The coastal retreat is measured since 1870 at profiles all 500 m in distance along the coastline. A 120 years long time series from 1872 to 1992 was used for calibrating the LITLINE model. Figure 5 shows as example for calibration the measured and calculated coastal retreat northerly of Westerland. This calibration was also be done in same quality for the south part of Sylt.

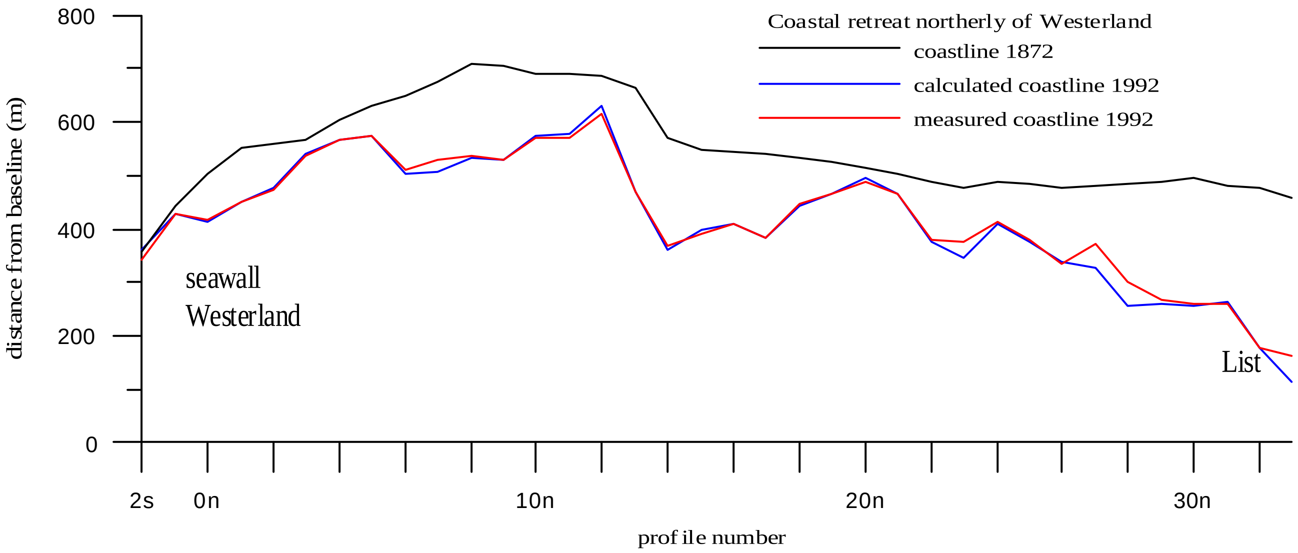

Fig. 5: Calibration of the model for the part northerly of Westerland

The scenario-supported model efforts concerning the modern and future sediment budget on the western coast of Sylt identify the regions of List, Kampen, Wenningstedt, Hörnum and Rantum as the presumably most concerned areas. Figure 6 shows the minimum coastal retreat and Figure 7 shows the maximum coastal retreat in the year 2050 (without coastal protection). Investigations on the impact of sea level rise on sediment transport capacities do not generally show significant changes in resulting sediment transport. However, significant changes within individual profiles are evident. An increase of local sediment transport by a factor of 1 to 1.5 (with increasing wave height) within the next 50y seems to be possible. Based on available techniques in coastal protection the forecasted long-term morphological development of Sylt seems to be controllable.

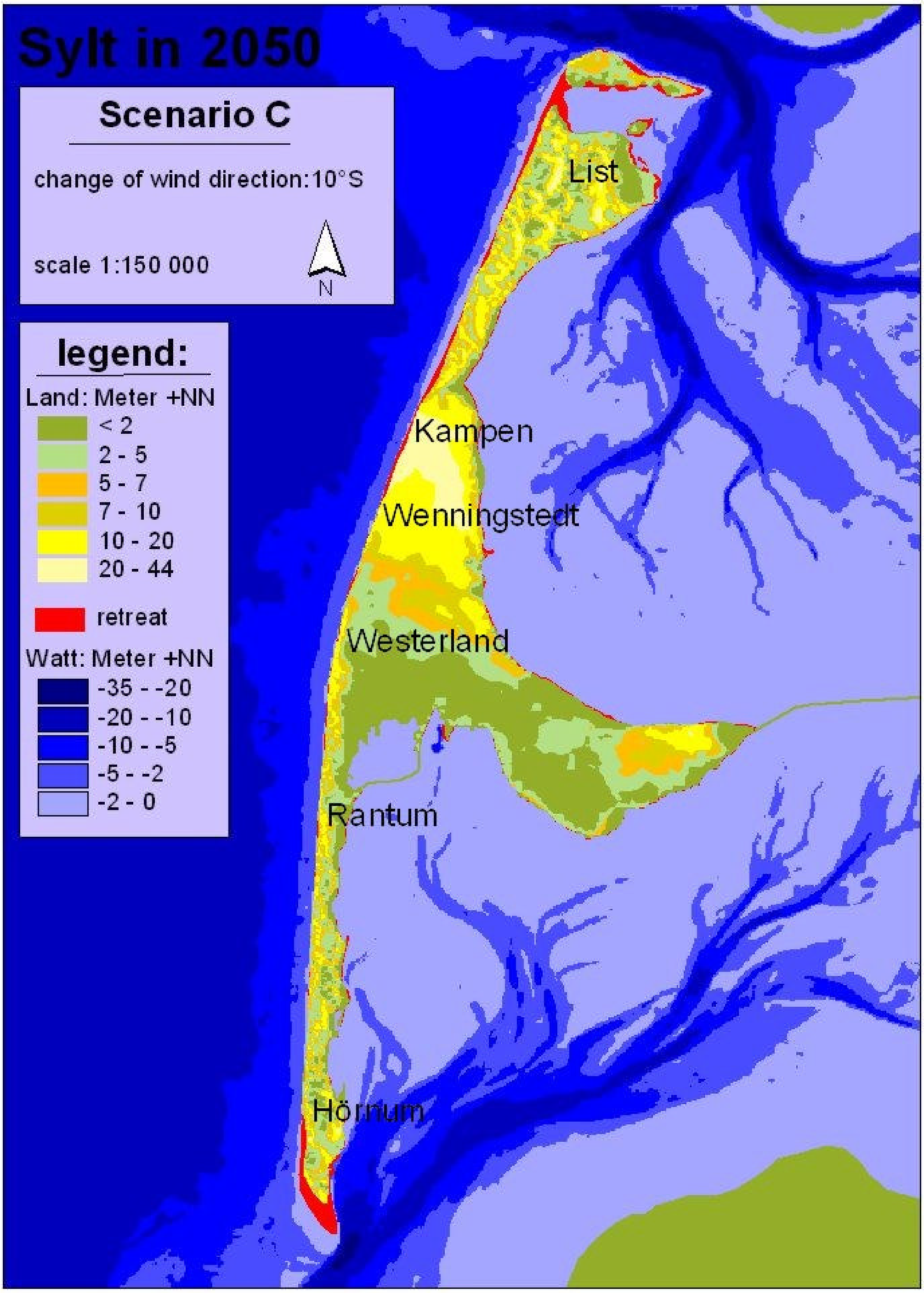

Fig. 6: Coastal retreat in the year 2050, changing the wave direction 10° to south

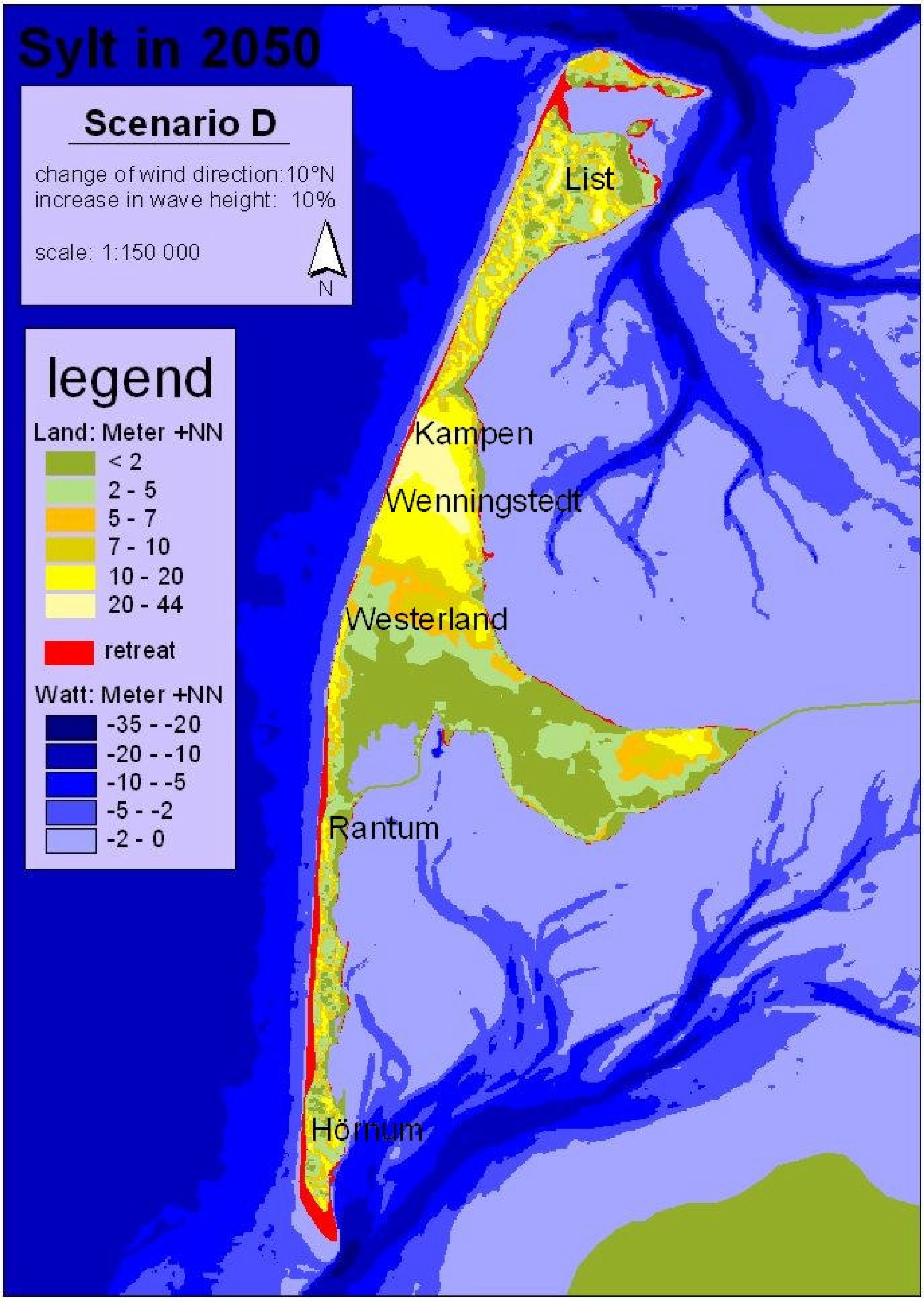

Fig. 7: Coastal retreat in the year 2050, changing the wave direction 10° to north with an increasing wave height of 10%

Effects of changing climate on the local marine ecosystem are generally less serious: comparing quantitative investigations on dominant species in the western Sylt wadden sea and along the already 2-4°C warmer north Atlantic coast show that no fundamental changes in respect to species distribution and lateral population sequences have to be expected around the island. From this aspect, no negative local developments for Sylt as a recreation area will occur. Ecological consequences of nourishments show that a fast re-colonization by local fauna could be observed in the areas investigated. Considering fauna-communities (meiofauna, macrofauna and mobile epifauna) as indicators for the ecological evaluation of beach sections, nourishments can be regarded as ecologically acceptable. In contrast, hydrodynamic conditions on the eastern part of the island have to be evaluated as more critical from the ecological point of view. Outgoing from intensified local erosion it can be assumed that the eastern shore will be increasingly shaped by technical constructions. This does not only prevent a natural biotope development, but also results in a 'negative' change of the landscape.

The investigations of damage potential at particularly endangered sites of Sylt's west coast demonstrate that the consecutive costs of climate change are rather limited. The consecutive costs consist on the one hand in expenses for additional coastal protection on the western side of the island, on the other hand they arise from biotope loss in the wadden sea subsequent to enforced protection of the eastern coast. From the economical perspective, no reason is given for changing the modern coastal protection strategy. No substantial changes of this statement will be expected in the forecasted period (until 2050). Increased costs for additional future nourishments will be covered by the economical use of protected private and public assets (infrastructure, private properties etc.). Considering the rich local sand resources, the costs for additional nourishments seem rather low compared to the routine seasonal protection measures.

An analysis of payment-readiness for the protection of the wadden sea against consequences of climate change shows the existance of a significant public demand for the good "protection of the natural environment". However, sociological investigations reveal that potentially concerned persons attribute little significance to the consequences of possible climate change for Sylt. Topics like tourism, construction activity and general environmental protection are more important for Sylt keypersons than particular problems of coastal protection and changes of the island's shape. On contrary, shedding particular light during the interviews on potential climate change, Sylt keypersons regard measures of coastal protection as most important. Conclusively, the public discussion on coastal protection of Sylt in first approximation seems to be rather independent from the perception and evaluation of potential climate changes.

The general opinion of Sylt inhabitants suggests not only intensively to care about coastal protection of the island, but also promote the development of future tourism and to improve job perspectives particularly for young persons. However, only little substantial structural improvements were proposed by the Sylt publicity. Potential conflicts may arise from the ambivalent public position concerning tourism. On the one hand, the marketing sector pronounces positive environmental factors like surf, dunes and 40 km sand beach to promote the public image of Sylt and, thereby, to enhance the touristic using of the island or, at least, maintaining the modern level. On the other hand, the modern capacity of tourism or even an increase in touristic activities are regarded as a reduction of life quality and, thus, may endanger the internal functions of the social community.

CONCLUSION

The project efforts show that it is necessary to investigate a changing environment like Sylt from multidisciplinary perspectives. According to our numerical simulations, climate change may strongly promote Sylt's future shore retreat subsequent to enhanced storm and wave activity, if modern strategies of shore protection are not maintained. In this case, a partly dramatically changing and retreating coastline would have substantial impacts on human activities, life quality and economic potential on the island. However, outgoing from modern techniques in coastal protection and assuming only moderately increasing costs for sand nourishments, most of the sub-projects agree that the environmental and socio-economic consequences of a potential climate change will be not be serious and, thus, controllable for Sylt. Outlooking it can be stated that recurrent coastal protection is an inalienable tool to reduce future changes in the Sylt coastline configuration, and to maintain the island as a unique biotope and as a site of high quality living. Furthermore, intensified future application of ICM (Integrated Coastal Zone Management) on the connections between human activities and natural processes in the North German Wadden Sea will help to learn more about a fast changing environment and may reduce environmental damage costs.

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