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Impacts of sea level changes on coastal regions – a local study for SEAREG

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Abstract

SEAREG analyses socio-economic and environmental effects of climate and sea level changes in the Baltic Sea Region (BSR). The result of the project will be a decision support frame which is addressed to planning authorities. Within the project, the Swedish Meteorological and Hydrological Institute (SMHI) develops scenarios of future climate and sea level for the year 2100 which will then be connected with regional data. These are morphological data for calculating the coastal dynamics and an elevation model to search for flood-prone areas.

Coastal dynamics was estimated for the next 100 years, considering the island of Usedom as an example. The changes of the historical shoreline of Usedom were determined by maps and aerial photographs from the year 1825 up to now. The results show an abrasion of 216 metres at Streckelsberg and an accumulation up to 185 metres at Ahlbeck in the last 175 years. Future coast lines were calculated with the model of Wagner (1999). Data of the different SMHI climate scenarios were used for this calculation.

A high resolution elevation model of the Island of Usedom was generated to estimate flood-prone areas depending on different sea level rise scenarios. The potential flood-prone areas was intersected with economical and ecological data sets. Two types of results were produced for the planning authorities, firstly maps and tables showing the affected economical and ecological areas and, secondly, a classification map of the affected areas to establish a priority list of actions.

1 Introduction

The discussion about the future evolution of the sea level and its consequences is getting more important. While previous models were concentrated on global sea level changes, the project SEAREG is focusing the local relationships of the Baltic Sea Region. The main goal of the project is to develop the Decision Support Frame (DSF) for planning authorities (see article Staudt et al. in this booklet). The Swedish Meteorological and Hydrological Institute (SMHI) calculated future climate and heights of sea level up to the year 2100 on the basis of two different models. Both models are used for different scenarios. The possible physico-geographic and socio-economic consequences of these scenarios were estimated and discussed for the Usedom Island. The aim of the first part was to find a practical method to calculate the future development of the outer coast. In the second part a geographic information system (GIS) shall be implemented in a DSF. However, these methods shall be transferable to other coastal regions.

2 Investigation area

The Island of Usedom is the easternmost part of the West Pomeranian coast. The area of interest extends from the Peenemünder Haken up to the Polish border with approximately 406 km² and a coastal length of 231.5 km (41.5 km sea coast, 190 km lagoon coast). The island consists of Pleistocene sediments and Holocene deposits (fig. 1). During the Littorina transgression the sea level rose rapidly from -20m at around 7800 BP to –2 m at 5800 BP (Lampe 2003). Afterwards it became more stable, rose with only minor oscillations to about –0.5 m at about 1000 BP. In this period abrasion material was deposited in bay-like depressions, building barriers, on which dunes were built up. During the following sea level rise peat has accumulated on sheltered lowlands behind the dune belt. Drainage of fenlands started in the 19th century which initiated peat degradation. The surface of the fenland is now at or below the sea level due to strong decomposition. The area is mainly used for tourism, farming and forestry. While tillage predominates on the moraine areas, the peatland is used as grassland and feedlot.

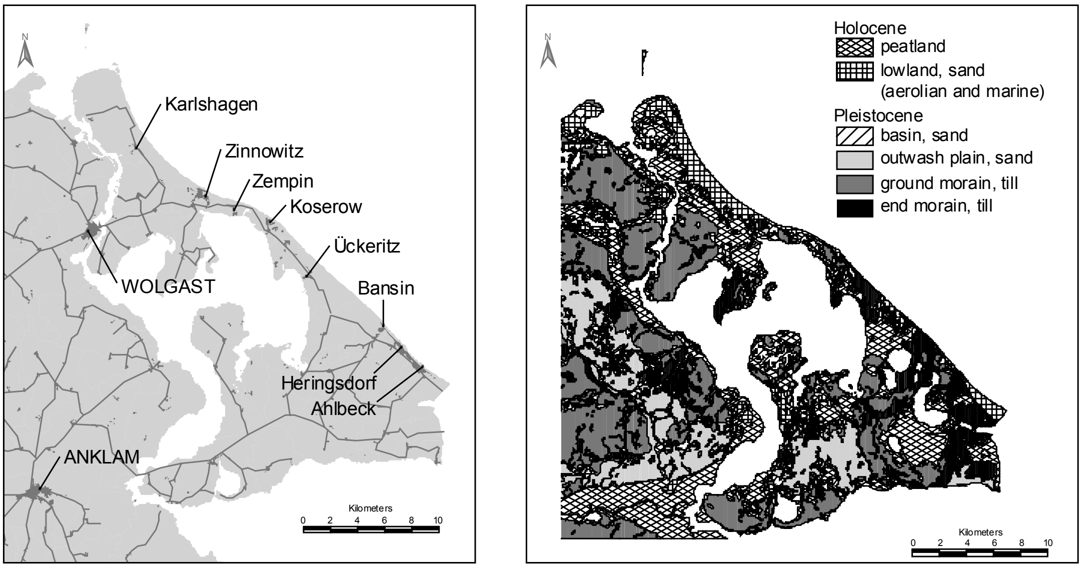

Figure 1: General and geological maps of the Usedom Island.

3 Evolution of the sea coast

The sea coast of Usedom is characterised by processes of accumulation and abrasion. In spite of abrasion and exposure to storm floods nine settlements are located close to the sea and require coastal protection for many decades. The government of Mecklenburg-Vorpommern invested 202.6 million € in coastal protection from 1991 to 2002 (STAUN 2004). Therefore, future development of the coast is of great interest. To get information about the magnitude of accumulation/abrasion historical maps and aerial photographs were evaluated from the past 200 years. In a second step abrasion and accumulation rates were calculated for the next 100 years combining methods of Wagner (1999) and Stephan & Schönfeldt (1999). The practical application for planners is discussed in paragraph 3.3.

3.1 Coastal evolution during the past 200 years

Methods

Romond (1993) investigated the coastal change since 1695, using historical maps. We revaluated this material using Arc View, which lead mainly to higher accuracy of the data. However, the revaluation started with the map from 1829, because the Swedish maps of 1695 are inaccurate in many details.

The following maps and aerial photographs were used:

Preußisches Urmeßtischblatt	1829
Meßtischblatt	1885
Hansa Aerial Photograph	1937
Aerial photograph	1998

Some problems such as the low number of bench marks needed for georeferencing of historical maps, distortions due to the scanning process, faults on historical maps and arguable delineation of shorelines on aerial photographs could not be solved completely and restrict the attainable accuracy.

The maps and images were scanned and combined to a coherent picture using Photoshop software. These pictures were then georeferenced in Arc View 3.2 with extension Image Warp, using the Topographical Map 1:10.000 (Transverse-Mercator projection with Bessel ellipsoid) as base map. Afterwards shorelines, cliff edges, cliff and dune bases were digitised. The distances between the lines were measured every 250 m.

Results

Changes of coastlines

Despite the described problems, the results might give a quite realistic picture of the evolution during the last 200 years. Figure 2 shows the historical shorelines. Therefore, the Usedom sea coast can be divided into 3 morphodynamical sections: northwest Usedom from the Peenemünder Haken to Zempin, central Usedom from Zempin to Heringsdorf and southeast Usedom up to the Swina barrier.

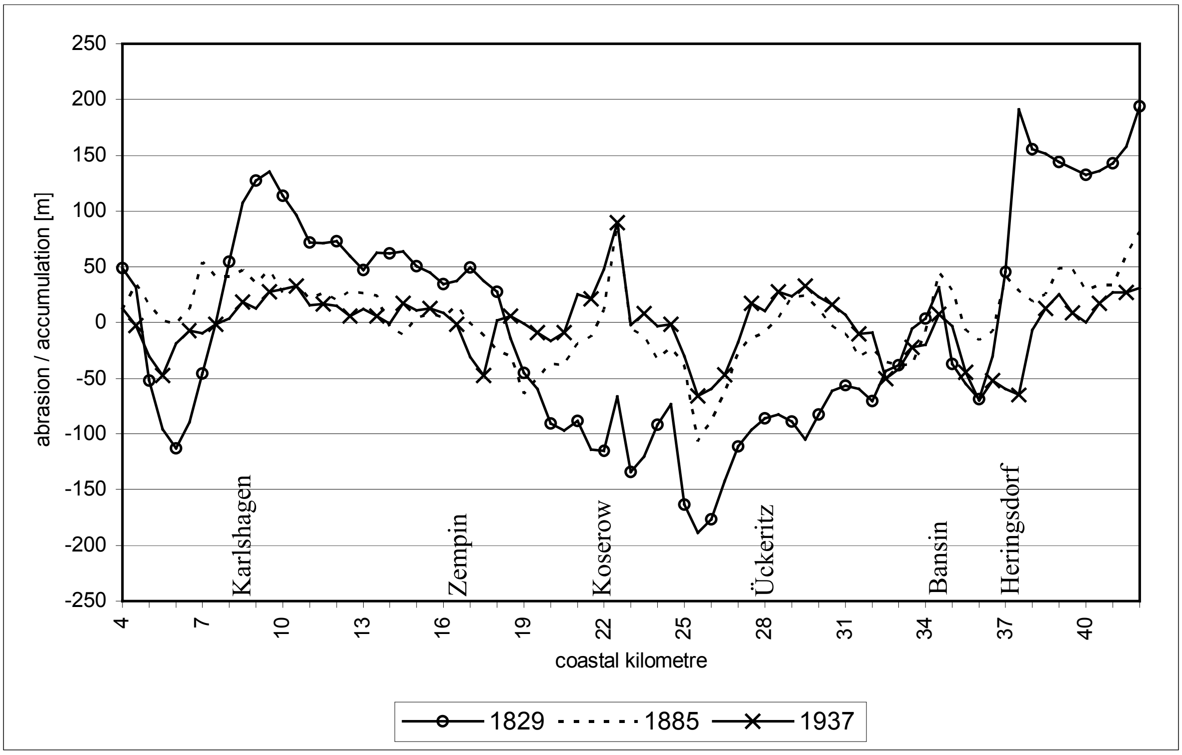

Figure 2: Shoreline changes since 1829, 1885 and 1937 (the x-axis represents the shoreline of 1998).

The sections can be described as follows:

Northwest Usedom (up to the coastal kilometre (ckm) 17.50) is characterised by accumulation, which increases from southeast to northwest. The average accumulation rate between 1829 and 1998 is 0.23 m/yr. The highest one occurred in the period from 1829 to 1885 amounting to 1.87 m/yr (ckm 8.75). However, an area of abrasion can be observed at Kienheide (ckm 6.00) with a length of approximately 3 kilometres. The transition to central Usedom is located in the section between Zempin and Lütten Ort and marks the change from accumulation to abrasion.

Central Usedom (17.50 – 36.00 ckm): This coastal section is characterised by cliffs with a maximum height of 56 metres at the Streckelsberg near Koserow. The average abrasion rate is 0.47 m/yr with a maximum of 1.14 m/yr at Kölpinsee. South-eastwards of Kölpinsee an accumulation area is attached up to Bansin. Again abrasion predominates between Bansin and Heringsdorf.

Southeast Usedom (from ckm 36.00 on): The average accumulation rate is 0.86 m/yr with the tendency to rise in eastern direction. In the period 1829 - 1885 the highest increase can be found.

Dynamical interactions

The comparison of the abrasion and accumulation rates between the three periods shows temporal variations of coastal behaviour (fig. 3). Several reasons are responsible for these differences:

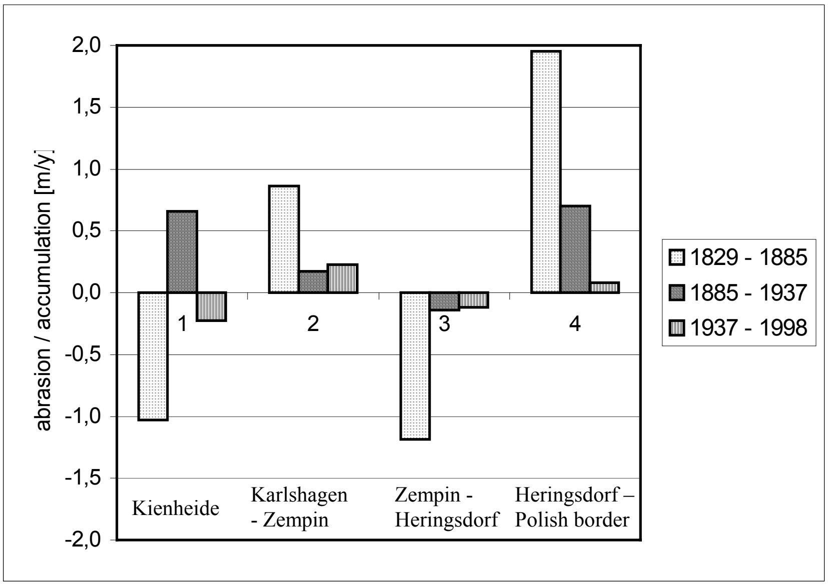

Figure 3: Shoreline changes of the areas northwestern Usedom (Kienheide and Karlshagen to Zempin), central Usedom (Zempin to Heringsdorf), southeastern Usedom (east of Heringsdorf) in the periods 1829 to 1885 (1), 1885 to 1937 (2) and 1937 to1998 (3).

Coastal protection

Especially coastal protections off the Streckelsberg cliff near Koserow have affected all other coastal areas of Usedom and the recent coastline does not show natural dynamics. In 1865 a fascine fence was constructed off the Streckelsberg and in 1895 the first wall was built at the toe of the cliff. The accumulation rates of northwestern and southeastern Usedom were much bigger in the period between 1829 and 1885 (period 1) than in the periods between 1885 and 1937 (period 2) and between 1937 and 1998 (period 3). The accumulation peaks at the Streckelsberg during the 2nd and 3rd periods were caused due to the construction of detached wave breakers and sand nourishments (1996) (fig. 2, ckm 22,00). Another example is Lütten Ort, a place near the village Zempin. In the last 300 years there have been 8 breakthroughs caused by storm floods, which were all closed artificially (Schumacher 2003).

Wave direction

The amount of sediment transported depends on wave power and direction. Both are coupled with wind directions and fetch. Stephan & Schönfeldt (1999) compared wind data of the term 1885-1939 to those of the term 1940-1984. The authors concluded that in the term 1940-1984 the wind from east and south increased and the wind from west and north decreased, which could cause alterations in sediment transport directions and quantity. Therefore for every 250 m along the Usedom coast the angle of the shoreline normal related to North was determined (fig. 4). The curve shows, that the angle has the highest value in the northwestern part of the island. The area Kienheide is located there from ckm 4 to ckm 7.25, where a change from accumulation (1885-1937) into abrasion (1937-1998) took place (fig. 3). Probably this phenomenon can be explained by the wind alteration observed by Stephan & Schönfeldt (1999).

Isobathes

The inclination of surf zones is another factor influencing the wave energy. To evaluate this factor the distance between the shoreline and the 10 m isobath was determined and depicted in fig. 4. The 10 m-line forms a "funnel" in the area off Kienheide. Also, the 10 m isobath off Kölpinsee is closer to the coast than in the west or east of this section. This steeper shoreface, caused probably by the spatial distribution of sediments of different resistivity, allows that higher wave energy can affect these sections.

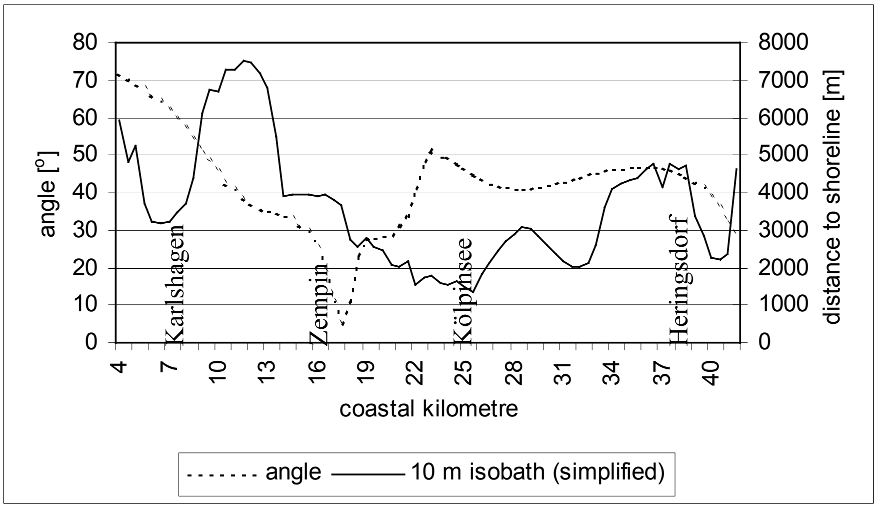

Figure 4: Angle of shoreline normal related to North and distance of the 10 m isobath to the shoreline.

3.2 Calculation of accumulation and abrasion rates by means of coastal evolution models

The coastal form is influenced by the action of wind energy, waves and currents as well as by the sea-level rise and anthropogenic impacts. Several methods exist to calculate dynamic processes of coasts, e.g. those of Stephan & Schönfeldt (1999) or the program GENESIS. The aim was to find a practical method to predict a one hundred year evolution of the sea coast of Usedom. It should be a method which can be applied flexibly to the data available. The methods mentioned above have proved to be unsuitable for this. E.g., the methods are very complex because many initial parameters are needed. However, a method from Wagner (1999) was used for the calculation of the theoretical sediment transport of sandy sediments.

Methods

The following data were available for the calculations: Wind time series with speed and direction of the 4 SMHI-scenarios for the period 2070 to 2100 as well as for the two control runs between 1960 and 1990; data of the wave model SGBAL from Germany's National Meteorological Service (Deutscher Wetter Dienst - DWD) for the time period between 1995 and 1999 (DWD 1995) with wind speed, wind direction, wave height, wave direction and peak periods (no data were available for a longer time period). Measured wind data from the station Arkona (Rügen Island) were used for comparison. The SMHI calculated 3 scenarios of sea level changes for the next 100 years (1cm, 41 cm and 82 cm rise). A sea level scenario with 24 cm was also used, which was published by Stigge (2003). Topographical maps 1:10.000 were used as georeferenced grid data.

Classified wind speeds and directions (12 classes each) were used for the consecutive calculations. The four SMHI scenario data sets were subtracted from the data of the control runs to identify changes in the scenario wind distributions. These changes were added to the DWD-1995 data set to obtain forecast data for the year 2100, leading to four different data sets (DWD-2100 a-d).

In the next step the theoretical sediment transport along the sea coast was calculated using a method described by Wagner (1999). Due to the NE-exposure of Usedom´s coast only 6 wind categories from

150o to 300o were used in the following calculations. From the calculated sediment volume [m³a-1] the annual shoreline shift was estimated according to Stephan & Schönfeldt (1999) and extrapolated for a 25-year period and 250 m sections, from which a new shoreline could be constructed. Shoreline changes were calculated with DWD-1995 data set for the next two 25-year periods. For the two periods 2050-2075 and 2075-2100 the 4 DWD-2100 scenarios were used. The shoreline shift caused by sea level change was calculated separately and added to the previous results (Stephan & Schönfeldt 1999).

Results

The DWD-2100d scenario is believed to be most probable whereas the DWD-2100a scenario has the lowest probability (see article Staudt et al. in this booklet). In the following only these two scenarios were considered. Figure 5 shows the calculated wind distribution. The impact on Usedom is higher in DWD-2100a because this scenario predicts a higher probability of easterly winds. That means, that coasts with an exposure to the West will experience a higher impact in the DWD-2100d scenario, e.g. the coasts of Fischland, Darss and Hiddensee Island. Similar results were found in the distributions of wind speed in the two scenarios.

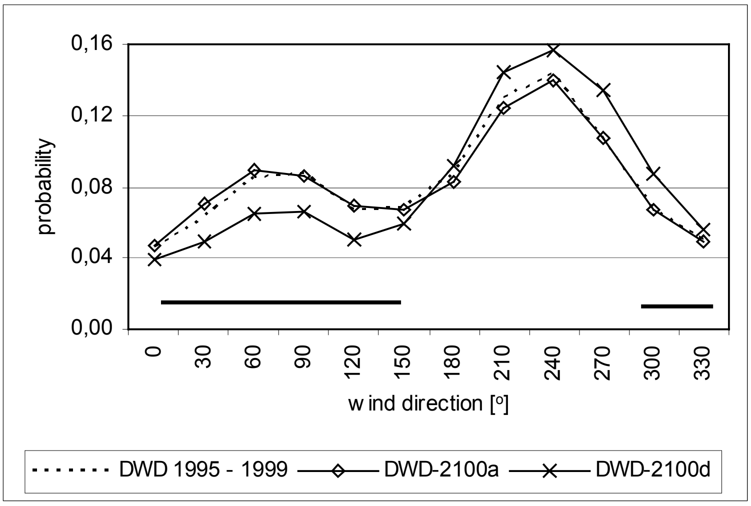

Figure 5: Comparison of the probability of wind distributions. The bars show the wind directions, relevant for Usedom´s sea coast.

For the less probable, but less favourable scenario DWD-2100a the coastline changes were calculated for three different sea-level rise predictions (fig. 6). The shoreline of the scenario with 0.01 m rise show no significant changes compared with the scenario with no rise. In case of a 0.82 m rise three areas would experience approximately 50 m additional abrasion. They are located around Zempin/Lütten Ort, Ückeritz and Bansin.

The results show that the trend in the coastal evolution observed in the historical record will continue in the next 100 years. Only for the area around Kölpinsee a contrary trend was found. Due to the exposition of the coastline to the prevailing wind direction accumulation was predicted, instead of the abrasion observed.

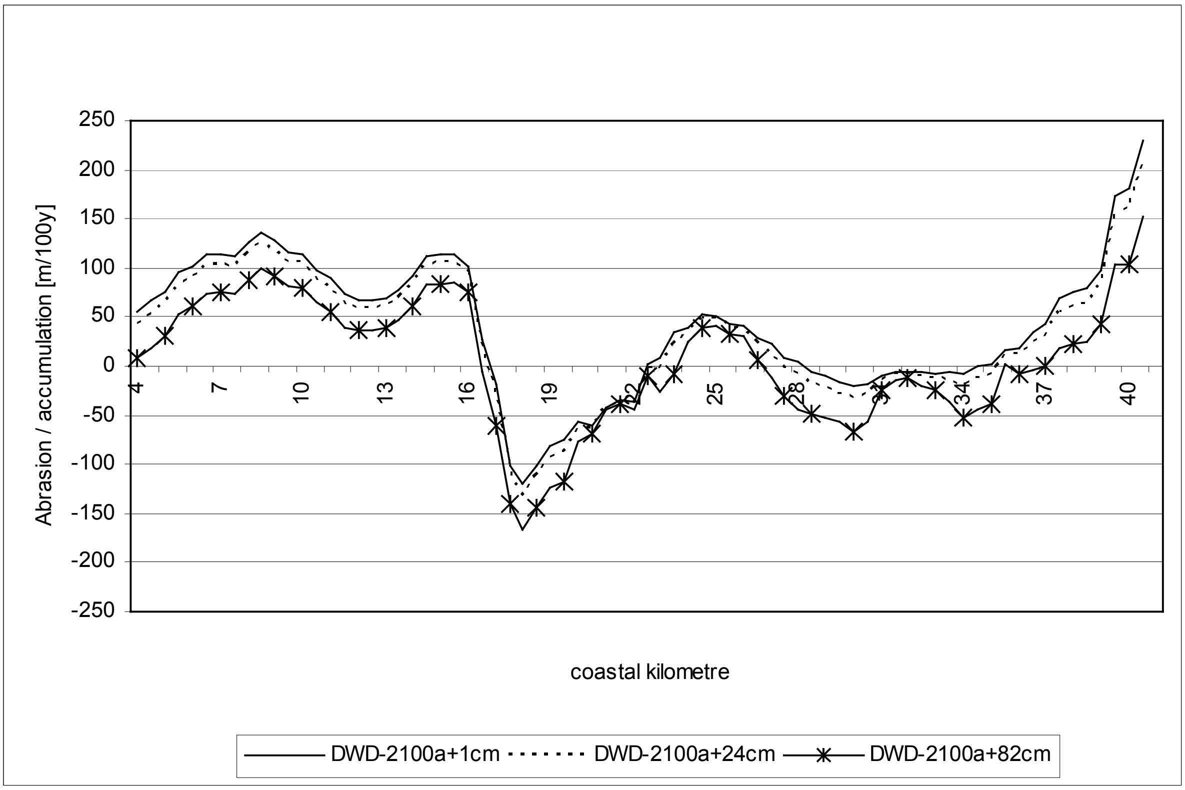

Figure 6: Impacts of different sea level rise scenarios calculated by the climate scenario DWD-2100a.

3.3 Application for planners

The application of the results could be carried out in two ways:

1. The historical evolution can be integrated as a theme into a GIS. Used in a GIS application as programmed by Röber (see below) the planner would be enabled to evaluate the evolutionary trend of a coastal area to be developed.
2. The methods to calculate future shoreline evolution should be integrated into a computer programme, which allows easy adaptation to other coastlines and climate scenarios. The results could then be presented as GIS themes and may be used in subsequent GIS applications.

4 Implementation of a geo information system in the Decision Support Frame

The aim of Part II of the local study Vorpommern is a GIS supported vulnerability assessment of endangered areas. This analysis shall enhance the reproducibility of decisions by planners and other actors for their own authority and district.

4.1 Data base

At the first step recent data, which are available for planners, have been analysed. There are two focuses: the first is a high resolution elevation model and the second is a high quality regional thematic data set.

For the region Vorpommern (or parts of it) several elevation models are available, for example:

GTOPO 30 - from the United States Geological Survey (USGS),

DGM 50 - from the state agency of country survey,

Greifswalder Bodden model - from the University of Greifswald,

Island Usedom - from the State Agency of Nature and Environment.

None of these models has the required geometrical resolution and map projection. Therefore a new model was produced on the basis of the Topographic Map 1: 10 000.

The thematic data sets are very heterogeneous in their geometric accuracy and in their information content. E. g. the data set “BNTK” (biotope type and land use map) is very accurate and available for the whole federal state Mecklenburg-Vorpommern. The dataset “ATKIS-DLM” (digital landscape model, cartographic vector data) is also available, but there are many overlaying polygons which may cause problems during the calculation of area sums etc. The data sets from the Agency for regional planning Vorpommern cover their own planning region. Two data sets of them have been tested, the set of the regional spatial plan and the one of the automatic planning cadastre.

4.2 GIS as a tool for DSF

The analysis of all these data sets leads to the second step: an open tool for processing several data sets from different actors. The processing result is a map which displays a vulnerability assessment on the basis of used data.

“Open tool” means, that the user can choose the method, the data, the area of interest, the resolution and the predicted sea level change.

The implementation from a GIS in a DSF will be realised with Avenue in Arc View 3.2.

The choice of different input themes is necessary to open the tool for actors from different authorities and countries. The data analysis has shown that each country and each office has its own data structure and so it is not possible to determine a fixed data structure on the input side.

The choice of resolution (a raster of squares) and area of interest (states, counties, parishes or land use plans) enables the user to produce different levels of analysis results.

The choice of sea level change (in 5 cm steps) means that the user can adapt his results to the current prognosis of climate changes and sea level changes or he can analyse all areas below a defined elevation level.

There are three methods of classification – an absolute, a relative and a verbal one. The tool reads the objects from the input theme and the user fills in or loads a table of assessment. The values of the table are cash value per hectare for absolute classification, factors for the relative and a fuzzy scale (very low, low, middle, high, very high) for the verbal classification. It is necessary to differ between dominate or highest value per square at the verbal classification.

The tool will standardise the single theme results for analysing many themes for one result map before they will be merged together.

Figure 7 shows four steps of processing: a) the input theme (BNTK from NW Island Usedom), b) a set of communities, c) sea-level rise by 70 cm and d) a classification of endangered areas with a resolution of 250 m.

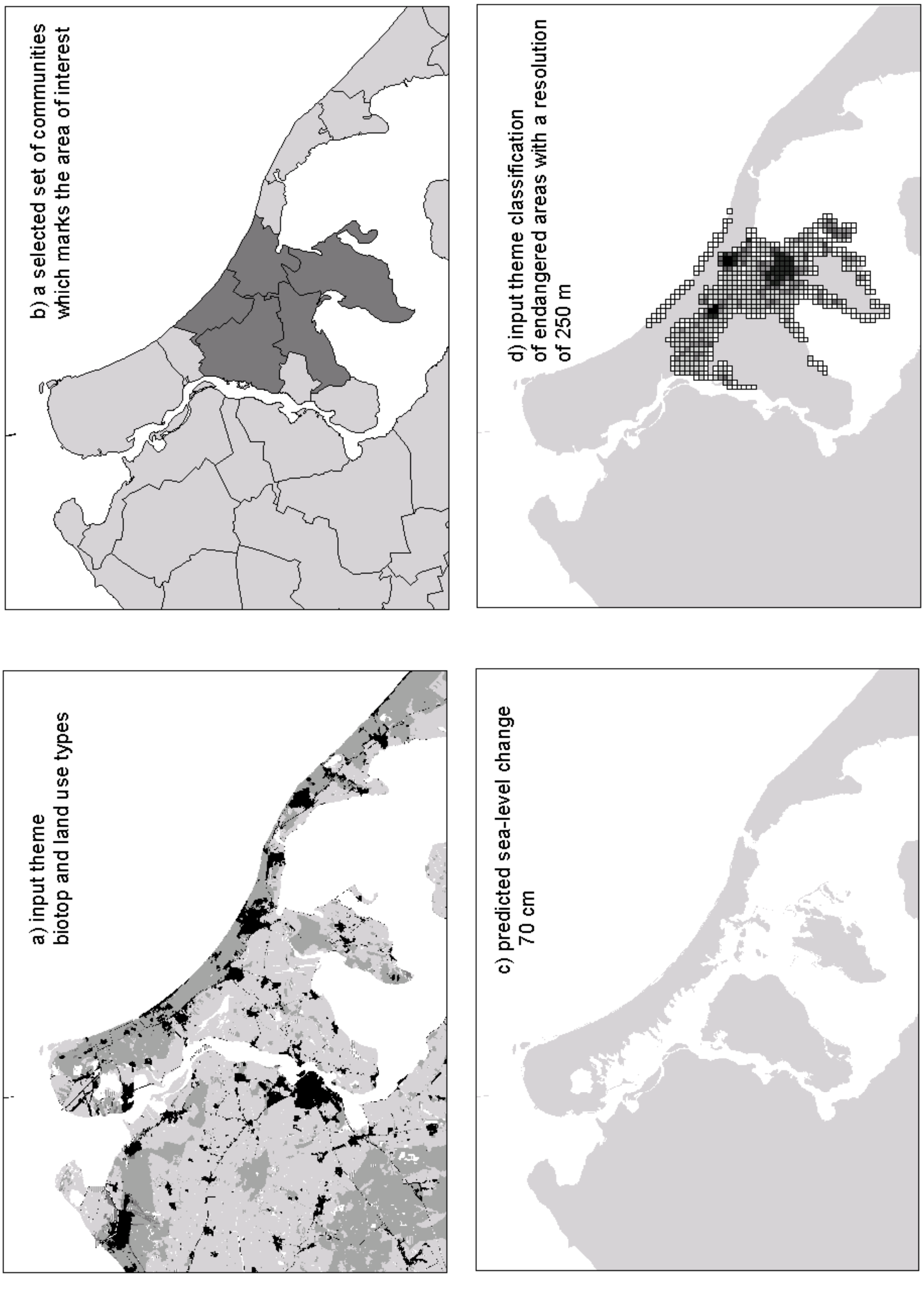

Figure 7: Steps of processing in the DSF tool.

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