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Climate change and coastal adaptation strategies: the Schleswig-Holstein perspective

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Abstract Schleswig-Holstein, the northernmost federal state of Germany faces two seas: the North Sea to the west and the Baltic Sea to the east. In all, it has a coastline of 1,190 km and about 3,700 km^2 of flood-prone coastal lowlands. In these lowlands, that represent almost 25% of total surface area, 345,000 people live and economic assets worth of 47 billion Euros are concentrated. In recognition of the high assets at stake and of future climate change, the Schleswig-Holstein Government adopted in 2001 a master plan: *Integrated Coastal Defence Management in Schleswig-Holstein.* It contains the strategy and the financial concept for coastal defence in the coming decades. After a general overview of the coastal zones, this paper describes the coastal defence strategy in Schleswig-Holstein. Special consideration will be given to the climate change adaptation components in the master plan. The paper ends with an outlook towards the implementation of the EU Flood Directive.

Keywords *Climate change, sea level rise, storm surges, coastal adaptation strategy, EU Flood Directive, Schleswig-Holstein.*

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INTRODUCTION

Schleswig-Holstein, the northernmost federal state (Bundesland) of Germany with about 2.8 million inhabitants, faces two seas: the North Sea to the west and the Baltic Sea to the east. In all, it has a coastline of 1,190 km and about 3,700 km^2 of flood-prone coastal lowlands (Fig. 1). In these lowlands, that represent almost 25% of total surface area, 345,000 people live and economic assets worth of 47 billion Euros are concentrated (Table 1). Further, the yearly economic productivity in these lowlands amounts to about 8.5 billion Euros and most tourist facilities are concentrated here.

In recognition of the high assets at stake and of future climate change the Schleswig-Holstein State Government adopted, in the year 2001, a new master plan: "Integrated Coastal Defence Management in Schleswig-Holstein" (MLR 2001). It contains the strategy and the financial concept for coastal defence (coastal flood defence and protection against coastal erosion) in the coming decades. For the first time in Germany, a master plan for one public sector was established applying the principles of ICZM, including the consideration of climate change and its consequences.

After a general overview of the coastal zones, this paper describes the coastal defence strategy in Schleswig-Holstein. Special consideration will be given to the climate change adaptation components in the master plan. The paper ends with an outlook towards the implementation of the EU Flood Directive.

Table 1. Relevant coastal defence parameter for Schleswig-Holstein (* only those facilities are considered that have a capacity of more than 8 beds).

Area	North Sea coast	Baltic Sea coast	Schleswig-Holstein
Coastline (km)	553	637	1,190
Sea dikes (km)	408	119	527
Flood-prone area (km^2)	3,404	318	3,722
- inhabitants	252,618	91,606	344,224
- economic assets (million €)	31,627	15,439	47,067
- gross value added (million €)	4,367	4,065	8,432
- working places	85,089	87,091	172,180
- tourist bed capacity *	31,986	19,533	51,519

Fig. 1. Map of Schleswig-Holstein showing the coastal lowlands and sea dikes.

Overview of the coasts

The North Sea coast of Schleswig-Holstein is characterised by reclaimed coastal marshes and the Wadden Sea. This tidal landscape results from a development that started about 8,000 years ago with the marine flooding of the coastal plain during the Holocene transgression (Hofstede 2005). From this time on, tide, wave and storm induced water movements could induce sediment redistribution and restructure the coast. After the decline of the strong early-Holocene sea level rise for about 6,000 years, extensive coastal marshes developed. In the district of Nordfriesland, among 1100 and 1650 AD, these coastal marshes were transformed into a tidal landscape during catastrophic storm surges. At the same time people started to reclaim salt marshes by building sea dikes. Today, the coastline measures about 553 km (mainland: 297 km, islands: 256 km). The about 2,500 km^2 large Wadden Sea is situated in front of the mainland. It consists of extensive tidal flats, tidal gullies and inlets, sandy barriers and two estuaries. The Wadden Sea of Schleswig-Holstein is one of the few remaining ecosystems in Germany where natural dynamics still prevail. In recognition of this fact, the State of Schleswig-Holstein in 1985 declared about 2,850 km^2 of the area to national park.

In contrast to the flat west coast, the sandy Baltic Sea coastline was formed during the last ice age by glaciers. They left a strongly undulating relief with morainic hills and glacier valleys. In the course of the Holocene sea level rise these valleys became inundated and a coastal landscape, characterised by elongated bays (Förden) and headlands, developed. As a result of the Holocene sea level rise and the hydrodynamic processes, the long-term morphologic development is characterised by a general retreat of the headlands. The material that was eroded from the headlands was partly transported into the bays (longshore drift). Here, it accumulated in spits which in some cases almost completely cut off the bay from the Baltic Sea. In all, the coastline measures 637 km, 162 km of which belong to the semi-enclosed Schlei Förde and another 87 km to the island Fehmarn. About 146 km of the coastline is occupied by sandy cliffs.

Coastal defence has a long tradition in Schleswig-Holstein. More than 2,000 years ago people started to build dwelling mounds in the coastal marshes along the west coast in order to protect themselves and their houses against storm surges. About 1,000 years ago the first ring dikes were erected to protect farm land from flooding by salt water. By the end of the 14th century the entire North Sea coast was, more or less, protected by a continuous dike-line. Due to the constricted possibilities these early dikes were rather low and steep and breaching of dikes frequently occurred. Along the Baltic Sea coast no such coastal defence tradition exists. Here, the first sea dike was built in 1581. Being under dimensioned, it was destroyed soon afterwards during storm surges. In the year 1872, a catastrophic storm flood occurred that caused severe damages and the loss of 271 lives. With a water level of locally up to 3.3 m above mean sea level this event was almost 1 m higher than all previous and following surges (Fig. 2). In consequence, the Prussian government announced new regulations on dike dimensions and on the organisation of coastal defence.

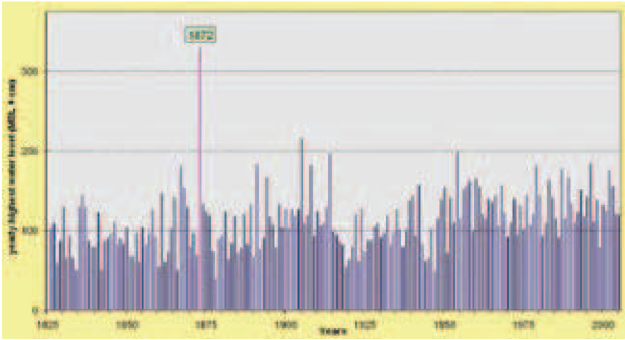

Fig. 2. Yearly highest water levels since 1825 in Lübeck-Travemünde.

Triggered by the catastrophic storm surges of 1953 in the Netherlands and 1962 in the German Wadden Sea, a first master plan "Dike-strengthening, dike-shortening and coastal de-fence in Schleswig-Holstein", was adopted by State Government in the year 1963. It has been updated in the years 1977 and 1986. The validity of this master plan was restricted to the year 2000. In 2001, a new master plan: "Coastal Defence – integrated coastal defence management in Schleswig-Holstein" was adopted by State Government. The main contents are described below.

THE SCHLESWIG–HOLSTEIN COASTAL DEFENCE STRATEGY

The master plan contains the strategy and the financial concept for coastal defence in the coming decades. It is not a legally binding document, but a (strong) self-commitment of the State Government. In the preface the minister, responsible for the implementation of public coastal defence in Schleswig-Holstein, lists a number of political principles to underline this commitment:

• Political consensus exists (in Schleswig-Holstein) that coastal defence, i.e., the safeguarding of human lives, outweighs all other interests, including those of nature conservation.

• In politics and administration, coastal defence will, now and in the future, maintain its own and basic importance.

• As a consequence of its basic importance for the safeguarding of people, coastal defence cannot be executed on a purely benefit-cost basis. However, with respect to restricted public finances, priorities need to be set on the basis of risk assumptions.

• The goals and tasks of coastal defence must be considered in other political fields (e.g., tourism, nature conservation, spatial planning) as well. This requires a continuous campaign for these goals and tasks.

• Applying these political principles, the coastal defence administration in Schleswig-Holstein developed a vision and 10 development goals. The vision is defined as follows: "*Protected from flooding by storm surges and from land loss by the erosive forces of the sea, the people of Schleswig-Holstein live, work and relax in the coastal lowlands, today and in the future*." On a next level, 10 development goals were defined. These goals should reflect the vision, but consider external limitations (e.g., financial, technical, societal) and other interests in the coastal zone (e.g., nature protection) as well. Hence, they present compromises. The development goals might be called the starting point for ICZM in coastal defence. Some relevant development goals are:

• The protection of people and their houses by sea dikes and other defence structures is of highest priority.

• The protection of land and valuables by sea dikes and other defence structures is an important condition for the vitalisation of the rural areas. It possesses a high priority.

• Hydro- and morphological developments and possible climate changes as well as their consequences are monitored and evaluated carefully. Scenarios are defined that allow prompt reactions.

• Impacts on nature and the landscape due to the execution of coastal defence measures are minimised. The development and implementation of other justified claims for the coastal zone are enabled.

Sea dikes constitute the main flood defence in Schleswig-Holstein. In all, 570 km of State and Regional dikes protect the lowlands from flooding. Already with the establishment of the first master plan in the year 1963, a safety standard, including a design water level and a design wave run up, was introduced for the State sea dikes (Fig. 3). The design water level should meet three basic requirements:

1. it should have a (statistical) return period of once in a century,
2. it should not be lower than the highest water level observed in the past (incl. sea level rise since than), and
3. it should not be lower than the sum of highest spring tide water level and highest observed surge.

For the North Sea coast, the statistical value delivered the highest water level, for the Baltic Sea coast it was the storm surge of 1872 (Fig. 2). In consequence, these values represent the respective design water levels (Fig. 3), on top of which a wave run up was calculated applying empirical data as well as modelling results.

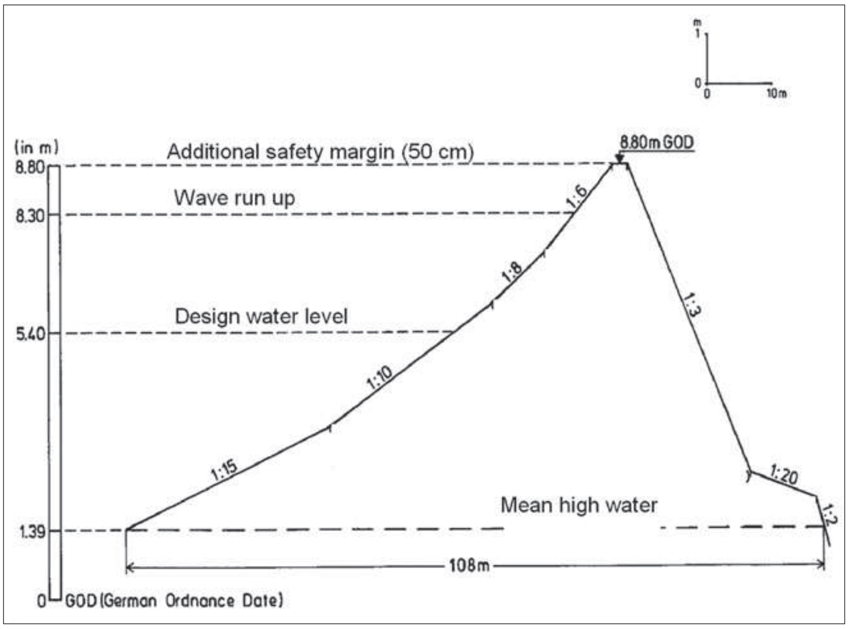

Fig. 3. Design parameter for a State sea dike along the west coast of Schleswig-Holstein.

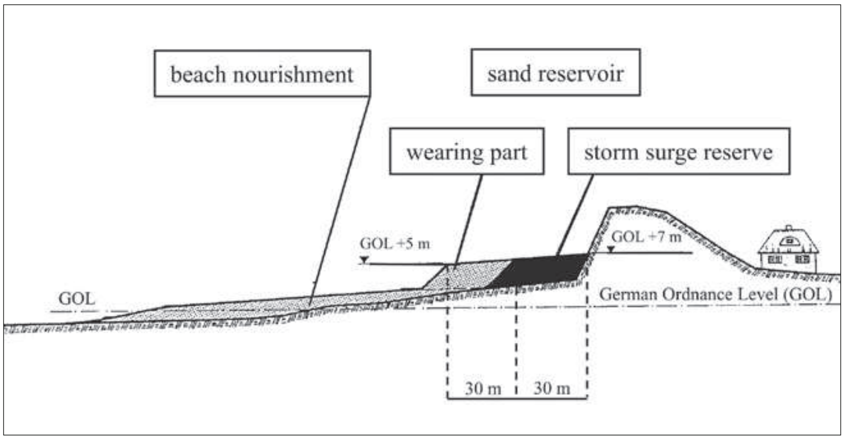

Fig. 4. Schematic presentation of beach nourishment on the island of Sylt.

Sand nourishment at the islands Sylt and Föhr constitute another main aspect of the coastal defence strategy in Schleswig-Holstein (Fig. 4). Since 1963, about 40 million m^3 of sand has been nourished on the beaches of these two islands (Sylt 37, Föhr 3 million m^3). With this sand, the coastal erosion at these two islands could be halted. Comprehensive investigations clearly demonstrate that this technique, the results of which are sometimes questioned, is most effective for technical as well as economic and environmental aspects (BMFT 1994). An alternative technique to optimize the cost-effectiveness of the sand replenishments was tested on a large scale in 2006 in front of Sylt. Instead of pumping the sand on the beach (the traditional technique) about 800,000 m^3 of sand was dumped directly from the ship on the outer reef slope. Hence, the costs of pumping the sand to the beach (including installation of pipes) were saved. In result, for the same price, about 150,000 m^3 of sand more could be replenished as with the traditional technique. Preliminary results from geodetic monitoring suggest that the foreshore as well as the beach behind the nourishment have been stabilized successfully. Hydrodynamic forces redistributed the dumped sand to the optimal (natural) locations. Investigations are, however, still going on.

With the new master plan, an innovative planning concept: "Integrated Coastal Defence Management (ICDM)", based on the principles of ICZM, was introduced (Hofstede 2004; Fig. 5). ICDM stands for a dynamic and continuous planning concept by which sustainable decisions for the protection of people and their assets against the natural forces of the sea are taken. Safety against storm floods and land loss is the aim; ICDM is the instrument to achieve this goal. It presents an enhancement of the traditional methods, in that:

- it considers coastal defence as a spatial planning process (instead of holding the line / sea dike),
- it duly and early integrates others demands for the coastal zone into the development goals for coastal defence (see above),
- it increasingly involves the public into the planning process for coastal defence, and
- it increasingly considers climate change (as well as the uncertainties in its predictions).

As an example of a participatory instrument, the Integrated Coastal Defence Board (BIK) is presented here in more detail. In 1999, the BIK was initiated by the responsible minister. The board consists of 27 members that represent public and private interest groups (stakeholders) in the coastal zone on a state, regional and local level. Members come from the coastal defence administration (7 members), the environmental administration and NGOs (6), dike and water boards (7) and from municipal, city and county administrations (7). Two meetings per year are held under the chairmanship of the minister. It has an advisory status. The main objective of the board is an active involvement of the private and public stakeholders in the planning of policies and strategies in coastal defence. Technical aspects are discussed under duly consideration of other claims for the coastal zones. A flow of information in two directions is aimed at. The coastal defence authorities inform the population about new developments (e.g., master plan, regulations, financing, etc.). The representatives of local people may inform the coastal defence authorities about concerns that exist in the local population. Possible conflicts may be anticipated or compromises be found by the early integration of other interests.

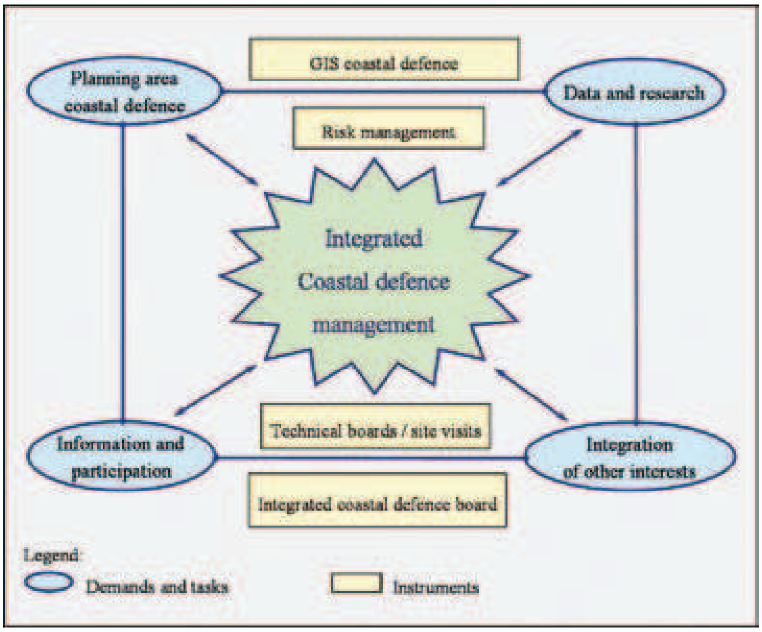

Fig. 5. Structure of the integrated coastal defence management concept in Schleswig-Holstein.

ADAPTING TO CLIMATE CHANGE

Coastal adaptation strategies for climate change aim at minimizing the hazards of flooding and land loss through coastal erosion. In this respect, future changes in sea level and storm surge intensity are most relevant. They determine the hazards and, therewith, the need for adaptation.

In 2007, the Intergovernmental Panel on Climate Change published its fourth assessment report (IPCC 2007), including scenarios on global sea level rise. Accordingly, by the end of this century global sea level may be 18 to 59 cm higher (pending on the models used and on our future behaviour) than in the reference year 1990. However, a number of uncertainties still exist (apart from model uncertainties and our future behaviour). Firstly, newer research outcomes suggest that the Greenland ice cap may melt faster and sooner as expected. IPCC (2007) gives a maximal value of up to 20 cm extra sea level rise for this factor. Secondly, regional deviations from the global mean values, e.g. due to changing ocean currents, are highly probably. For the North Sea and the Baltic Sea, neither the absolute amount nor the algebraic sign are known. Thirdly, the rise in sea level will not proceed linearly, but increasingly with time. At present, acceleration in sea level rise (compared to the last century) cannot be observed in German gauge stations (Hofstede 2007a). Finally, tectonic and glacio-isostatic land movements in the

North Sea and the Baltic Sea region alter the global mean values.

With respect to future changes in storm surges, IPCC (2007) states: "Extra-tropical storm tracks are projected to move poleward, with consequent changes in wind, precipitation, and temperature patterns, continuing the broad pattern of observed trends over the last half-century." This rather vague statement does not give any information on future changes in storm surge water levels in the North Sea or the Baltic Sea. The GKSS research station in Germany delivered four scenarios on storm surge water levels in the North Sea (Woth *et al*. 2006). Applying two models and two SRES-scenarios from IPCC, they calculated a maximal increase in storm surge water levels of about 40 cm along the German North Sea coast by the end of this century compared to the end of the last century. Already today, maximal surge values of more than 400 cm are observed in this region. Further, at some localities, the storm surge water levels increased by about 50 cm over the last century (Fig 6). Hence, the influence of anthropogenic climate change on storm surge water levels seems to be relatively low along the North Sea coast of Germany. For the Baltic Sea, no information on future storm surge water levels is available. At present, the GKSS research station is preparing an analogical study for the Baltic Sea.

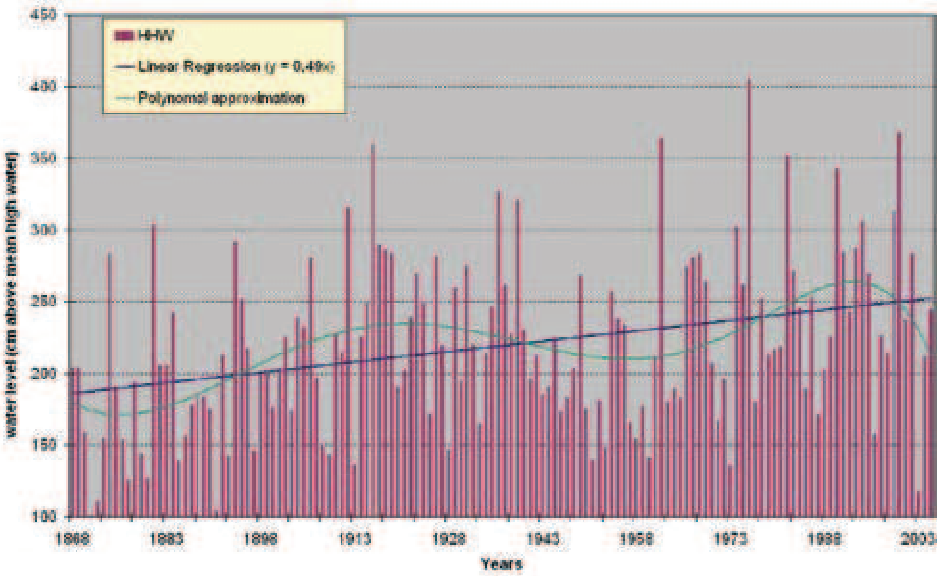

Fig. 6. Development of yearly highest water levels at gauge station Husum along the North Sea coast of Schleswig-Holstein since 1968.

With this large amount of uncertainties and unknown factors, it may seem inappropriate to develop adaptation strategies at all. However, from the available and validated information it becomes clear that, at least in the mid-term, the impacts on the coastal zone will significantly increase. The problem is the exact timing and the magnitude. With this in mind, a coastal adaptation strategy should be flexible, i.e., including no-regret measures that can easily be adjusted to new circumstances if necessary. Sand nourishments (Fig. 4) are one example of a no-regret measure. This measure is environmentally friendly (no exotic or hard components) and the amount may easily be adjusted from year to year.

In order to detect changes in hydro- and morphological tendencies as soon as they appear, monitoring is an essential part of a coastal adaptation strategy. This requirement is articulated in development goal 8 of the master plan (see above). As an example, long-term geodetic surveying of the dune-beach-foreshore-system at the Isle of Sylt revealed a mean yearly coastal erosion of about 1.2 million m^3. This erosion is combated through yearly nourishments in the same order of magnitude (Fig. 4). As performance review and in order to establish the needed nourishment volume (which varies from year to year), each year, the entire beach and dune system (38 km) is surveyed twice (spring and autumn) by airborne laserscanning. Extra laserscan surveys may be conducted after heavy storm surges. To monitor the long-term development, every five years the entire foreshore up to 1 km seaward of the coastline is surveyed hydrographically. These morphological surveys are completed by hydrological monitoring at two water level stations and one integrated gauge station (sea levels, wind, waves, currents and temperature) in deeper water. It is clear that such a comprehensive monitoring system is, only, necessary at focal points where, already today, strong coastal erosion occurs. In other areas, five year geodetic surveys completed by long-term gauge stations may be sufficient.

As stated above, sea dikes constitute the main flood defence in Schleswig-Holstein. A comprehensive safety check of the State sea dikes revealed that 110 km need to be strengthened in order to meet the safety standards. In the master plan, it is stipulated that, in the planning of the strengthening campaigns, an extra safety margin of 50 cm along the North Sea coast and 30 cm along the Baltic Sea coast must be included in the dike dimensions (Fig. 3) to account for future climate changes. These values were determined on the basis of the IPCC scenarios of 2001, the life time of sea dikes and so called "no-regret considerations". If sea level rise turns out to be (much) higher as expected, a life time of at least 50 years is anticipated. If sea level rise turns out to be lower, not too much (public) money was invested and, with proper maintenance, the

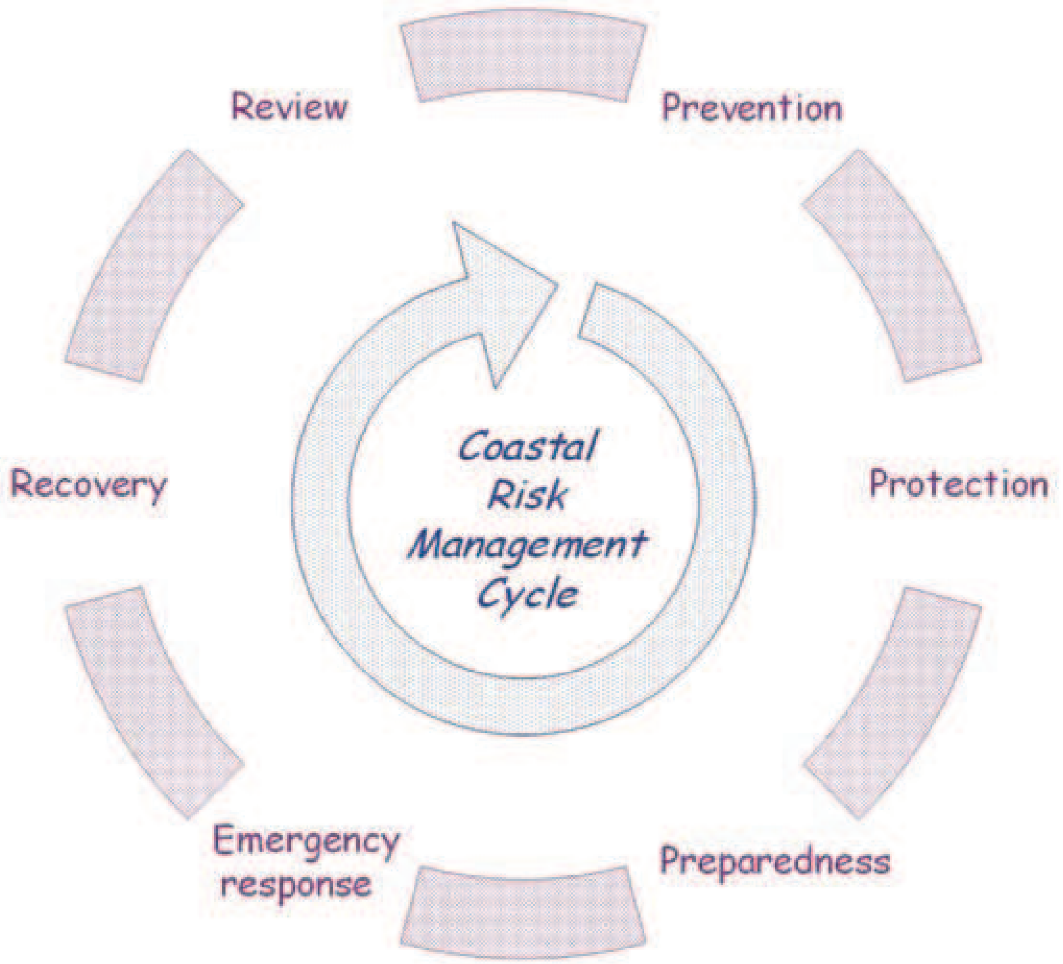

Fig. 7. Coastal risk management cycle.

life time may expand correspondingly. Further, every ten years, a safety check of the State sea dikes on the basis of newest information about future changes in sea level and storminess is conducted. This allows for a time-near adjustment of the strengthening campaigns if necessary.

CONCLUSIONS

The impacts of climate change on the coastal zones will be serious and should not be underestimated. The coasts and the defence schemes will, at least in the mid-term, be exposed to increased hydrodynamic stresses. For Schleswig-Holstein, on the basis of the elaborations above, no adjustments to the present strategies seem necessary. In a mid- to long-term perspective, more (technical and financial) efforts will be needed to maintain present safety standards, especially with regard to protection against coastal erosion. This directly depends on the rate of sea level rise and storm surge intensities. With increased rates and intensities, erosion increases as well. Hence, in the coming decades, stronger coastal erosion must be accounted for, also along stretches that are stable or accreting today.

With respect to this challenge, duly considerations about sustainable adaptation strategies become evident. Besides technical solutions, these elaborations should also include spatial planning and public awareness campaigns as non-structural alternatives. Non-structural options do not reduce the hazards or, rather, the probabilities of flooding and erosion. They aim at diminishing the consequences (damages), thereby reducing the overall risks in the sense of a holistic coastal flood risk management (Hofstede 2007b; Fig 7). This corresponds closely to the intentions of the new EU-Flood Directive. Accordingly, until 2015, all EU member states have to establish flood risk management plans for flood hazard zones, considering all aspects of flood risk management and climate change.

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