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Estimating the risk for erosion of surface sediments in the Mecklenburg Bight (south-western Baltic Sea)

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Abstract The aim of this study is to define areas with the potential for erosion of natural surface sediments in the Mecklenburg Bight. For this purpose a risk-based probabilistic concept of erosion is applied and maps with the erosion risk are constructed. For 47% of the study area an erosion risk at storm events of more than 10% was identified with hydrodynamic data in a temporal resolution of one hour and a model time of one year. It is shown that this high resolution of data is required, because the erosion process is ruled by storm events, which last for a few hours only. The highest risk of erosion during these storm events (up to 87%) appears in the near coastal areas, whereas areas with a water depth of more than 23 m have an erosion risk of less than 10%. It is demonstrated that a calculation of erosion risks is the best approach to evaluate the potential for erosion, because the classic, deterministic threshold concept leads to an underestimation of the size of areas for erosion.

Keywords *Baltic Sea, erosion risk, surface sediments, sediment dynamics, storm events.*

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INTRODUCTION

Sediment dynamic processes in coastal seas – such as the Baltic Sea – have an increasing importance, because of a growing use of these marine environments. For practical purposes (e.g. dumping sites or off-shore constructions, such as wind power plants) estimations of the potential for erosion of submarine sediments are required. This paper presents an approach to estimate the erosion risk for natural marine surface sediments in the Mecklenburg Bight (south-western Baltic Sea, Germany, Fig. 1). For practical applications, these estimations may serve as natural background values for the evaluation of anthropogenic impacts.

Research on sediment dynamics has a long tradition, beginning with the classic studies of Hjulström (1935), Shields (1936) and Sundborg (1956). In spite of numerous efforts, a lot of questions still remain open, mainly regarding natural and cohesive sediments (e.g. Lau & Droppo 2000; Black et al. 2002). A fundamental property for the description of the erosion behaviour is the critical shear stress velocity $u*_{cr}$, which identifies the point of incipient motion of the sediment particles. Though criticism on the concept of a threshold value exists (e.g. Lavelle & Mofjeld 1987), this approach is still a wide-spread tool for the description of erosion characteristics (e.g. Paphitis et al. 2001; Poulos 2001; Jago et al. 2002; Porter-Smith et al. 2004). But empirically derived threshold curves, which correlate critical shear stress velocities with sediment parameters (e.g. mean grain size), have severe limitations (Miller et al. 1977) and should be treated with caution (Paphitis 2001). Consequently erosion experiments should be executed to derive more reliable values for the studied sediments (e.g. Soulsby 1997; Whitehouse et al. 2000). A large scatter of data often prevents an unambiguous confirmation of correlations between sediment properties and critical shear stress velocities. This supports the idea of a stochastic nature of the incipient erosion that was first mentioned by Einstein (1936) and later by Grass (1970), Lavelle & Mofjeld (1987) and Zanke (1990). According to this idea it is not possible to define a flow stage at which particles are suddenly placed in motion in a massive amount. Instead sediment erosion takes places gradually over a wide range of shear stress velocities as the flow velocity is increasing (Grass 1970). Lavelle & Mofjeld (1987) emphasize that a movement of particles can even occur at current velocities below the threshold value and there would be no true threshold as a motion-no motion transition. Based on these considerations Lopez & Garcia (2001) have presented a risk-based probabilistic approach. They take in account both, the variations of the critical shear stress velocity and the turbulence of the hydrodynamic conditions, to calculate the risk of sediment erosion. Their formula will be applied in this study for sediments of the Mecklenburg Bight for the first time. For this purpose information about the sediments at the sea floor and the hydrodynamic conditions are required. These data are collected by measuring sediment properties, executing erosion experiments and gathering results from hydrodynamic models of the Baltic Sea. To compare the stochastic view on erosion with the classic, deterministic threshold concept, mapped erosion risks are compared with calculations of differences between threshold values and flow- and wave-induced shear stress velocities. Furthermore the erosion risk is calculated with data from two different hydrodynamic models, to evaluate the effects of different temporal and spatial resolutions.

DATA SETS

Sediment Data

In the study area (Fig. 1) surface sediment samples (upper 3 cm) were collected with a box corer in a grid of one nautical mile during cruises with RV "A. v. Humboldt" and RV "Professor Albrecht Penck". Several sediment parameters were measured: mean grain size, sorting, silt and clay content, water content, content of total organic carbon (TOC). To determine the grain size distribution a laser-optical particle size-analyser (Galai CIS-50) was applied for muddy sediments and a combined wet and dry sieving procedure was used for sandy sediments. The silt and clay content was separated by manual wet sieving and the fraction > 63 µm was subsequently analysed by a dry sieving machine (Retsch AS 200 control). The water content was calculated from the difference between the weights of wet and freeze-dried samples. The content of total organic carbon (TOC) was measured with an automated C/S-analyser (Eltra Metallic 100).

Fig. 2 presents a map with the resulting distribution of the natural surface sediment types in the study area. The selected study area contains all typical sediments of the Mecklenburg Bight. The regionalisation of these types follows the concept of "regionalized classification" (Harff & Davis 1990; Davis et al. 1996). For this purpose the measured sediment parameters were classified into six sediment types by using a combined hierarchical cluster and discriminant analysis, as it was described by Bobertz & Harff (2004). Sandy sediments (mainly fine and medium sands) occur in the near coastal region and in the eastern part of the study area with an increasing mean grain size towards the coastline. The bottom of the basin area in the western part of the study area is covered by a silt-sized mud (so-called Schlick). Table 1 shows the range of values of the parameters for the different natural sediment types.

Two erosion devices were used to derive experimental critical shear stress velocities: an erosion chamber called microcosm, and a straight flume. A description of the microcosm can be found in Gust & Müller (1997) and Tolhurst et al. (2000). The flume is described by Springer (1999), Springer et al. (1999) and Friedrichs (2003). The microcosm is a cylindrical chamber (diameter 20 cm) covered by a removable lid with a stirring disc and a water input and output. Water is pumped through an external water cycle through a central axis and back into the overlying water of the core. By controlling the rotational speed of the disc and the pumping rate, the device generates a spatially homogeneous shear stress velocity at the bottom. The second device, the flume, has a length of 3 m and a height of 0.4 m. The flow is generated by a propeller located in a return pipe and connected to an adjustable electric motor. An opening in the flume's bottom enables the insertion of small sediment cores (diameter 10 cm). The flow velocity is measured by an acoustic Doppler-

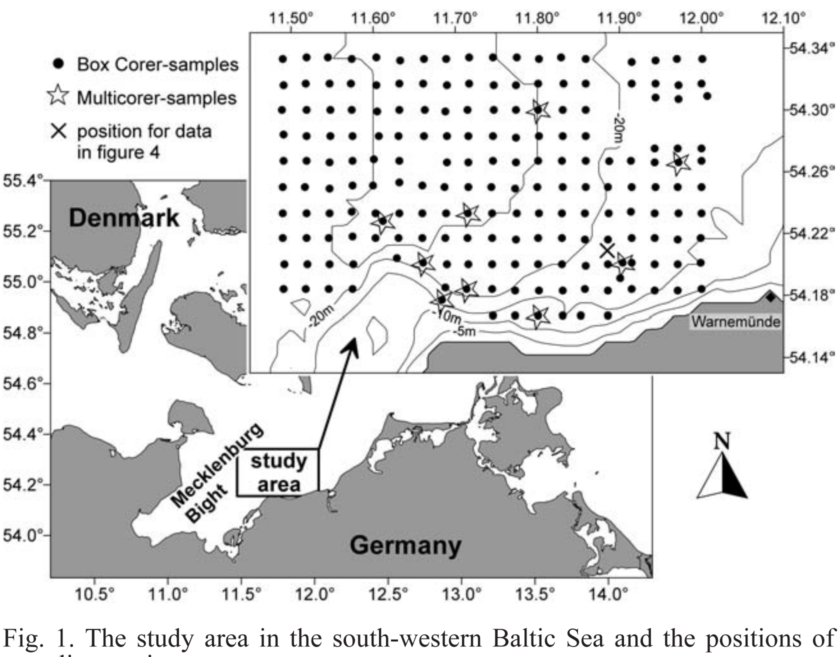

Fig. 1. The study area in the south-western Baltic Sea and the positions of sampling stations.

velocimeter at the position of the sediment sample. The microcosm was calibrated for shear stress velocities by the manufacturer of this device, whereas the flume in the used configuration gives results in current velocity measured in 3 cm height above bottom. Comparative experiments (Bohling 2003) have shown that results from both devices are comparable when translated by a conversion equation. For all experiments the sediment surface is visually observed while shear stress velocity (or current velocity respectively) is gradually increased. The shear stress velocity is increased in steps of 0.1 cm/s with an exposure time of 10 to 20 min. At the point of beginning movement of particles – the incipient erosion – the shear stress velocity is recorded. This threshold is said to be reached when a constant transport on the entire sediment surface is observed. This shear stress velocity is defined as the critical shear stress velocity for bed load transport. To get undisturbed surface samples, the experiments were conducted on Multicorer-samples. But the experience during sampling has shown that it is impossible to derive truly undisturbed samples. Consequently, the experimental results refer to naturally composed sediments with a flattened surface. The samples were taken from selected stations in the study area (Fig. 1) and cover all different sediment types. The experimentally derived critical shear stress velocities are listed in Table 1. The shear stress velocities generated with the used erosion devices are not sufficient to cause an incipient motion of the sediment type 1 (mud). Therefore, the threshold value for this sediment type is estimated from the Hjulström-plot (Hjulström 1935) and transformed into shear stress velocity according to an approach proposed by Soulsby (1983, see also Bohling 2003).

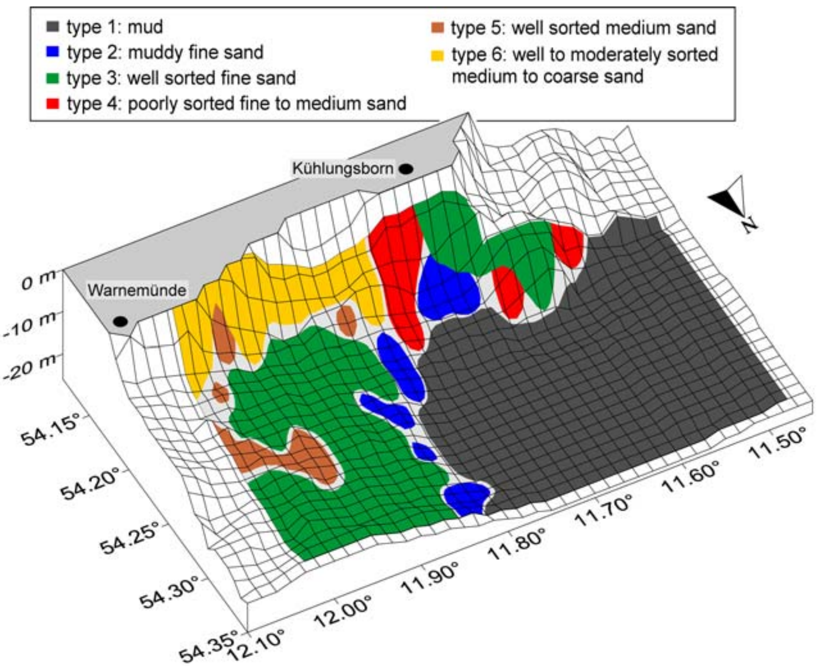

Fig. 2. The types of natural surface sediments in the study area; bathymetric data by Seifert & Kayser (1995).

Natural sediments occasionally carry a so-called fluffy layer on their uppermost surface. The aggregations and flocs of this fluffy layer are easily eroded prior to the underlying sediment itself. Only the underlying sediment is referred to as "surface sediment" in this study. The fluffy layer was not considered in the classification either. The erosion behaviour of the fluffy layer in the Mecklenburg Bight is discussed by Ziervogel & Bohling (2003).

Hydrodynamic Data

Two models were available to deliver hydrodynamic data for the study area:

1. A model by Rietz et al. (2000) with a spatial resolution of one nautical mile. The combined current- and wave energy derived from six hour snap shots of the model year 1996/97 were supplied for this work.
2. A model by Kuhrts et al. (2004, see also Kuhrts et al. 2002 and Kuhrts et al. 2003), which delivers shear stress velocities with a spatial resolution of three nautical miles. This model refers to the model year 1993. Daily and hourly mean values were calculated and provided to the author.

The model by Rietz et al. (2000) is based on the "Modular Ocean Model" MOM-2 (Pacanowski 1996). Its circulation model and an additional wave module are forced by an atmospheric module with weather data based at reanalysed data from the model HIRLAM (Gustafsson 1993). The resulting data were available as "theoretical velocities", which were calculated from the modelled combined current- and wave energy (Bobertz & Harff 2004). To convert these velocities into shear stress velocities the so-called von-Karman-Prandtl-equation, also known as "Law of the Wall", was applied (e.g. Soulsby 1983; Wright 1989). This requires the assumption of a logarithmic velocity profile in a boundary layer above the sea floor. For the conversion the height of the lowermost model box above the bottom and the roughness length of the sea floor had to be considered. The roughness length was approximated via the mean grain size of the sediment type (e.g. Soulsby 1997; Dade et al. 2001). The height of the lowermost model box above the bottom varies in the study area between one and two meters.

The model by Kuhrts et al. (2004) is based on the "Modular Ocean Model" MOM-3 (Pacanowski & Griffies 2000) and adds to this, inter alia, a bottom boundary layer module. This boundary layer module enables the user to get values of shear stress velocity directly from the model calculations. The boundary layer module considers both the influence of currents and waves and achieves this by incorporating a wave boundary layer into the logarithmic velocity profile (Grant & Madsen 1979; Nielsen 1983).

The following data sets, derived from the described models, were used for this study. Maximum values refer to one grid point, i.e. the maximum values at two different positions in the study area may have occurred at two different times of the model year:

- mean values of the year 1996/97 according to Rietz et al. (2000)
- maximum values of the year 1996/97 according to Rietz et al. (2000)
- maximum daily mean values of the year 1993 according to Kuhrts et al. (2004)
- maximum hourly mean values of the year 1993 according to Kuhrts et al. (2004)

CALCULATION OF EROSION RISK

All data sets, both sedimentologic and hydrodynamic data, were interpolated on the same grid. For this purpose the programme "Surfer" and the method "Point-Kriging" were used. For the resulting interpolated data sets a spatial resolution of four grid points per nautical mile was chosen. Subsequently at every grid point in the study area the parameters can be related to each other and the following calculations can be made and isoline maps (Figs. 3 and 5) can be created.

According to Grass (1970) the instability of a sediment surface is the result of the interplay of two statistically distributed random variables:

1. The stability of every single grain of the sediment depends on the stochastically distributed factors form, weight and positioning in relation to other grains. This leads to the variability of the critical shear stress velocity of single grains.
2. All natural hydrodynamic conditions are turbulent (Open University 1989). Turbulence leads to statistically varying flow- and wave-induced shear stress velocities that instantaneously act on the sediment surface.

The approximate methodology to calculate a risk for erosion by Lopez & Garcia (2001) considers the distribution of the sediments critical shear stress velocity and the distribution of the shear stress velocity that is generated by flow and waves. Lopez & Garcia (2001) assume the distributions to be Gaussian normal

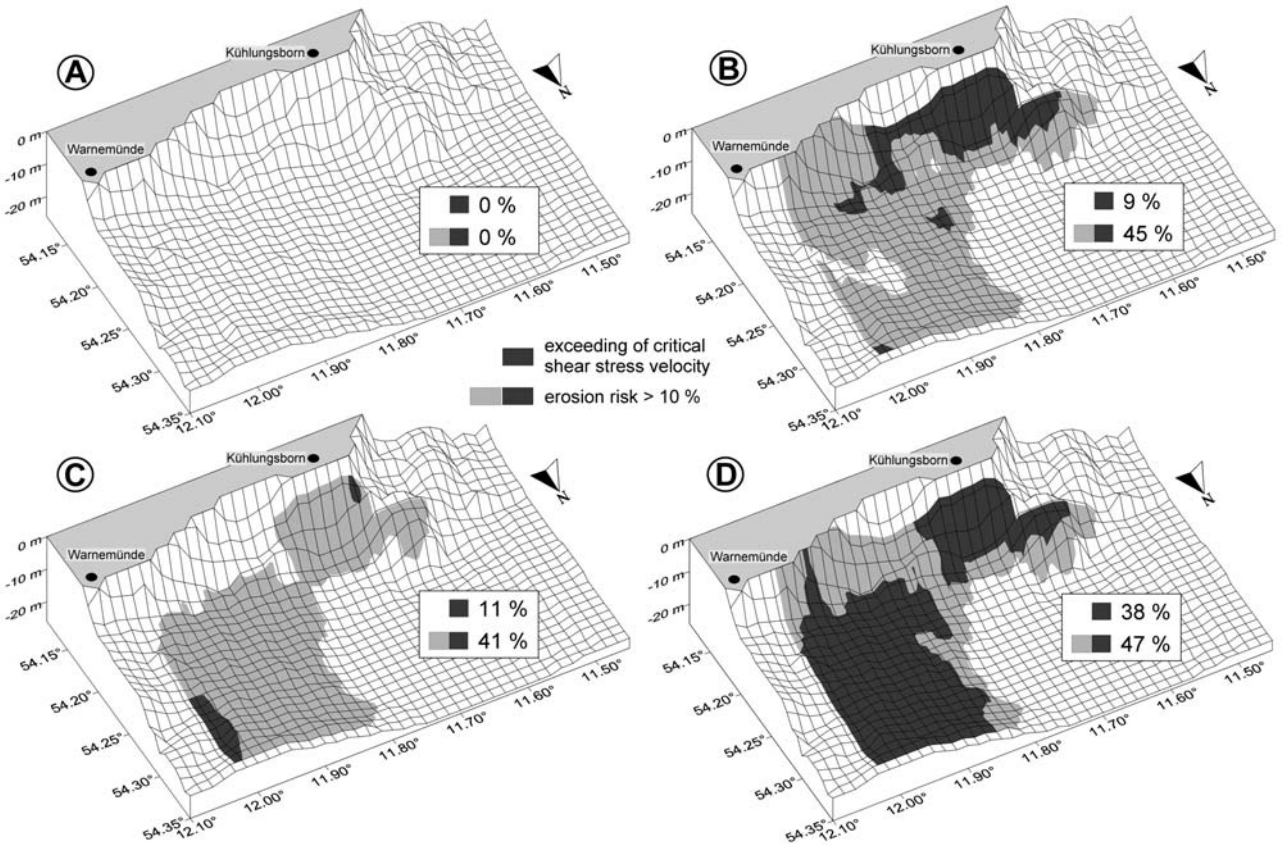

Fig. 3. Areas where the mean critical shear stress velocity for the natural surface sediment is exceeded in comparison to areas with erosion risks of more than 10%. Figures of percentages in the maps refer to the whole study area. An erosion risk > 10% appears on areas marked in grey including black areas. A = mean shear stress velocities of the year 1996/97 (Rietz et al. 2000), B = maximum shear stress velocities of the year 1996/97 (Rietz et al. 2000), C = maximum daily mean shear stress velocities of the year 1993 (Kuhrts et al. 2004), D = maximum hourly mean shear stress velocities of the year 1993 (Kuhrts et al. 2004).

distributions and estimate them by means of a polynomial approximation. Mean values and standard deviations of critical shear stress velocities and flow- and wave-induced shear stress velocities are inserted into the following formulas:

$$R = 0.5X^{-4} \quad \text{if } Y \geq 0$$

$$R = 1 - 0.5X^{-4} \quad \text{if } Y < 0$$

where

$$X = 1 + 0.196854|Y| + 0.115194|Y|^2 + 0.000344|Y|^3 + 0.019527|Y|^4$$

where $$Y = \frac{\overline{u*_{cr}} - \overline{u*_f}}{\sqrt{\sigma_{cr}^2 + \sigma_f^2}}$$

where R = risk for erosion, $\overline{u*_{cr}}$ = mean critical shear stress velocity (Tab. 1) [cm/s], $\overline{u*_f}$ = mean flow- and wave-induced shear stress velocity (model data) [cm/s], σ_{cr} = standard deviation of critical shear stress velocity (Tab. 1) [cm/s], and σ_f = standard deviation of flow- and wave-induced shear stress velocity ($\sigma_f = 0.4u*_f$) [cm/s].

For calculations of erosion risks in the Mecklenburg Bight the experimentally derived critical shear stress velocities for the different sediment types from Table 1 and their standard deviations were used. It is assumed, that they represent the distribution of all possible threshold values for sediments without bedforms. To estimate the variability of the instantaneous flow- and wave-induced shear stress velocity an approach by Grass (1970) is applied ($\sigma_f = 0.4u*_f$), which was also used by Lopez & Garcia (2001). By applying modelled data for special conditions (maximum values), also the calculated erosion risk represents the risk at these special conditions. It has to be noted that this calculation of erosion risk applies to non-cohesive sediments, due to missing values for the standard deviation of critical shear stress velocities for cohesive, muddy sediments. A similar general theory for the erosion of cohesive sediments is not yet available. Thus the calculations for sediment type 1 (cohesive mud) have to be treated with caution.

EROSION RISK IN THE MECKLENBURG BIGHT

Fig. 3 shows areas with an erosion risk of at least 10% for the four different hydrodynamic data sets. To compare erosion risks with the classic, deterministic approach, additionally the difference between mean critical shear stress velocity and modelled flow- and wave-induced shear stress velocity was calculated. According to the classic concept with an erosion threshold as a motion-no motion transition, areas in which the critical shear stress velocity is exceeded are areas of erosion. The mean shear stress velocities according to Rietz et al. (2000) fall below the critical value in the whole study area. The maximum values according to Rietz et al. (2000) are exceeding the critical values on 9% of the study area. The maximum daily mean shear stress velocities of the model by Kuhrts et al. (2004) exceed the critical values on 11% of the area, whereas the maximum hourly mean shear stress velocities are high enough to exceed the erosion threshold on 38% of the area. A comparison with the area with an erosion risk of more than 10% shows that

Table 1. Sediment parameters of the natural surface sediments in the Mecklenburg Bight. The mean grain size was calculated with moment statistics and the sorting was calculated according to Folk & Ward (1957). Values in brackets are mean values. $u*_{cr}$ = critical shear stress velocity, s_{cr} = standard deviation of critical shear stress velocity, + = the threshold value for mud was estimated from the Hjulström-plot (Hjulström 1935) and transformed into critical shear stress velocity.

Sediment type	Mean grain size (µm)	Sorting (Folk & Ward)	Silt and clay-content (wt.-%)	Water-content (wt.-%)	TOC-content (wt.-%)	$u*_{cr}$ (cm/s)	σ_{cr} (cm/s)
Type 1: mud	8-36 (14)	1.04-1.81 (1.34)	54-100 (95)	43-67 (58)	1.6-5.7 (4.0)	3.75 +	-
Type 2: muddy fine sand	44-92 (71)	0.32-0.64 (0.46)	19-38 (25)	28-38 (33)	0.5-1.3 (1.0)	0.9-2.6 (1.7)	0.68 = 40%
Type 3: well sorted fine sand	90-180 (135)	0.26-0.75 (0.40)	0.2-14 (5)	16-34 (22)	0.1-0.9 (0.3)	0.8-1.6 (1.2)	0.26 = 22%
Type 4: poorly sorted fine to medium sand	96-230 (170)	0.81-1.46 (1.11)	1.4-23 (10)	15-32 (22)	0.1-1.1 (0.5)	1.2-1.9 (1.5)	0.30 = 20%
Type 5: well sorted medium sand	192-249 (207)	0.49-0.65 (0.57)	0.1-0.5 (0.2)	16-18 (17)	0.1-0.2 (0.1)	1.4-2.0 (1.5)	0.30 = 20%
Type 6: well to moderately sorted medium to coarse sand	341-653 (452)	0.49-0.94 (0.76)	0.0-0.9 (0.4)	11-14 (13)	0.0-0.2 (0.1)	1.4-2.1 (1.9)	0.40 = 21%

Table 2. The size of the areas affected by different levels of erosion risk in different hydrodynamic models (percentages of study area).

Hydrodynamic data	Area where risk > 10%	Area where risk > 50%	Area where risk > 80%
Mean values of the year 1996/97 (Rietz et al. 2000)	0%	0%	0%
Maximum values of the year 1996/97 (Rietz et al. 2000)	45%	9%	2%
Maximum daily mean values of the year 1993 (Kuhrts et al. 2004)	41%	11%	0%
Maximum hourly mean values of the year 1993 (Kuhrts et al. 2004)	47%	38%	23%

the classic, deterministic approach clearly underestimates the potential for erosion (Fig. 3). The size of the area with an excess of the critical shear stress velocity agrees with the size of the areas with an erosion risk of more than 50% (Tab. 2). This indicates that the erosion threshold corresponds to an erosion risk of 50% and illustrates that even below the erosion threshold the erosion of the sediment can not be excluded and that exceeding of the threshold value does not lead to an erosion risk of 100%.

Enormous discrepancies between the different hydrodynamic data sets appear. On the one hand discrepancies can be explained by differences in the weather conditions of the two model years 1996/97 and 1993 and by different spatial resolutions, but on the other hand the different temporal resolutions (mean of a year, snap-shots every six hours, mean of one day and mean of one hour) are very likely to affect the coverage of maximum shear stress velocities and thus the calculation of erosion risk more significantly. This explanation is supported by Fig. 4, which shows the erosion risk for one exemplary position (Fig. 1). The risk was calculated for January 1993, the stormiest period of this model year, with hydrodynamic data from Kuhrts et al. (2004), because this model offers the highest temporal resolution of one hour. The sea floor at the station is covered by fine sand (type 3), the most frequent sandy sediment type in the study area. The critical shear stress velocity of fine sand was exceeded for summarised 32 hours only during the considered period of 1434 hours. The erosion risk shows peaks, which appear during events with high shear stress velocities. Only at these maximum shear stress velocities an erosion risk of 2% is exceeded. Exclusively these maximum events, which last for a few hours only and can be explained as storm events, rule the erosion process of the surface sediments. The same observations can be made at other positions in the study area. Consequently it is required to use hydrodynamic data with a temporal resolution of one hour (or higher) to cover these peak-like events. Otherwise, an underestimation of the potential for erosion is possible. This conclusion is supported by Table 2, where the size of the areas affected by different levels of erosion risk in different hydrodynamic models is given. With the highest temporal resolution (model data by Kuhrts et al. 2004) the largest area can be affected by erosion. As Fig. 4 shows, about ten peaks of erosion risk appear within the considered winter month. This applies also on other positions in the study area (not shown here). Thus for Figs. 3 and 5 an erosion risk of more than 10% can be illustrated as "when all storm events during a winter month have the intensity of the maximum event of the model year, then at least one event has the capability to erode the natural surface sediment". Consequently an erosion risk of 10% may be an appropriate and meaningful figure to describe the potential for erosion.

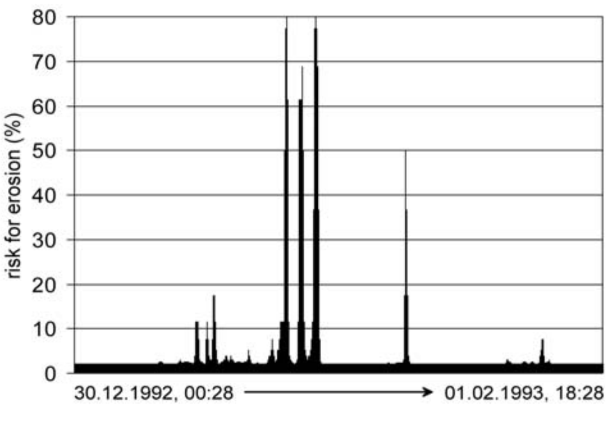

Fig. 4. The erosion risk for fine sand at one position (Fig. 1) during one month of the model year 1993 (Kuhrts et al. 2004) with a temporal resolution of one hour.

The detailed maps in Fig. 5 present the erosion risk for natural surface sediments during maximum flow- and wave-induced shear stress velocities only, because with mean values of one year a low risk of less than 10% is present in the whole study area, as Fig. 3A has shown. With maximum values an erosion risk exceeding 10% is reached in the near coastal area and in the eastern part of the study area. The highest erosion risks appear near Kühlungsborn. The near coastal area next to Warnemünde is affected by lower erosion risks, what can be explained by the presence of sediment type 6, which has a higher erosion resistance (Table 1). Analogously the presence of sediment type 5 is the cause for an insularly reduced risk in the eastern part of the study area. These examples show the significance of the sediment distribution for the patterns of erosion risk distribution.

With maximum shear stress velocities according to Rietz et al. (2000) an erosion risk of more than 10%

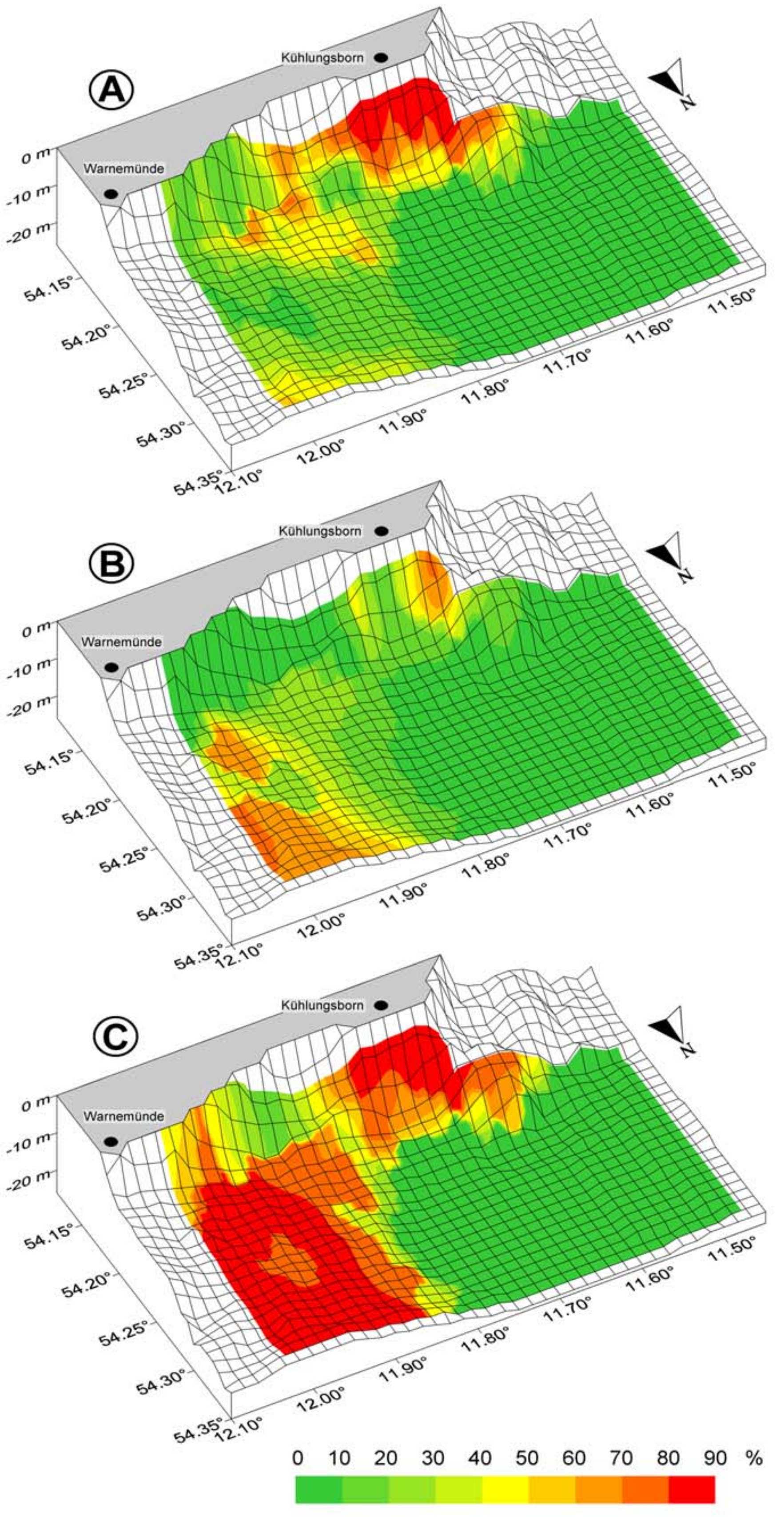

Fig. 5. The erosion risk for natural surface sediments in the study area determined for three different hydrodynamic data sets. A = maximum shear stress velocities of the year 1996/97 (Rietz et al. 2000), B = maximum daily mean shear stress velocities of the year 1993 (Kuhrts et al. 2004), C = maximum hourly mean shear stress velocities of the year 1993 (Kuhrts et al. 2004).

occurs on 45% of the study area and the maximum risk is 85%. The maximum daily mean shear stress velocities of the model by Kuhrts et al. (2004) lead to an erosion risk of more than 10% on 41% of the area and cause a maximum erosion risk of 74%, whereas the maximum hourly mean shear stress velocities cause a risk of more than 10% on 47% of the area and lead to a maximum erosion risk of 87%. The sediments in the area with a water depth of more than 23 m have an erosion risk below 10%. This area is covered by cohesive mud (sediment type 1) and thus the calculation according to Lopez & Garcia (2001) is not the fully appropriate method. Nevertheless, the high critical shear stress velocity of this sediment type (Table 1) leads to the conclusion, that this low erosion risk may be the first realistic estimation. Besides the sediment characteristics, the fact that the shear stress velocity in the study area is dominated by the wave contribution (Kuhrts et al. 2004) can be an explanation for the low erosion risk. In this case the depth limit for an influence of waves on the sediment would be 23 m.

Table 3 shows the percentage of an area covered by one sediment type, which exceeds specific erosion risks, when the maximum hourly mean shear stress velocities according to Kuhrts et al. (2004) are used. All of the area covered by sediment type 3 (fine sand) has an erosion risk > 50% and on 69% of the area the erosion risk is even higher than 80%. Compared to the other sediment types these are the highest values and thus the fine sand can be judged as the most mobile sediment type in the study area. Almost 100% of the area covered by sediment types 2, 5 and 6 have an erosion risk > 10%, but the area with an erosion risk > 80% is 0% (type 2 and 6) or 32% (type 5). These

Table 3. The size of the areas affected by different levels of erosion risk at maximum hourly mean shear stress velocities according to Kuhrts et al. (2004) (percentages of the area covered by one sediment type).

Sediment type	Area where risk > 10%	Area where risk > 50%	Area where risk > 80%
Type 1: mud	0%	0%	0%
Type 2: muddy fine sand	97%	21%	0%
Type 3: well sorted fine sand	100%	100%	69%
Type 4: poorly sorted fine to medium sand	56%	36%	10%
Type 5: well sorted medium sand	96%	96%	32%
Type 6: well to moderately sorted medium to coarse sand	100%	26%	0%

figures show that strong differences in the potential for erosion can occur between the sediment types. A possible result of erosion is the formation of bedforms, such as ripples, on the sediment surface (e.g. Soulsby 1997; Mazumder 2000). An incipient motion of sediment particles is the prerequisite for bedform genesis. This corresponds to observations of the sea floor in the study area, which show the most mobile sediment type 3 (fine sand) to be the one with the most frequent appearance of ripples.

CONCLUSIONS

This study has revealed three main requirements for a realistic estimation of the potential for erosion of submarine sediments in the south-western Baltic Sea:

- A detailed knowledge of the sediments and their distribution is essential, because the different sediment types can have a noticeable influence on the distribution of erosion risks.
- Hydrodynamic data with a high temporal resolution (at least one hour) are required in order to cover storm events, which last for a few hours only and rule the erosion process of surface sediments.
- A risk-based probabilistic concept of erosion (e.g. Lopez & Garcia 2001) has to be preferred, because the classic, deterministic threshold concept leads to an underestimation of the potential for erosion.

The distribution of the erosion risk for natural surface sediments in the Mecklenburg Bight is presented in this study. The highest risk of erosion during storm events (up to 87%) appears in the near coastal areas, whereas areas with a water depth of more than 23 m have an erosion risk of less than 10%. For 47% of the study area an erosion risk at storm events of more than 10% was identified. Maps on the erosion risk can deliver helpful information for practical applications, such as dumping of dredged material. Positions with a low risk for remobilisation of natural sediment types can be identified. Maps of the erosion risk of one specific dumped material can be created with the procedure presented in this study, when a distribution of this specific sediment type in the whole study area is assumed. These kinds of maps can be the basis for recommendations to minimise one aspect of anthropogenic impacts on the environment. Additionally the results of this study can serve as a base for further investigations on the effect of bedforms or the influence of biology on sediment dynamic processes.

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