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Comparative analyses of potential wind—wave impact on bottom sediments in the Vistula and Curonian lagoons

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A comparison of potential conditions for wind-wave generated impact on bottom sediments in the Vistula and Curonian (Kuršių Marios) lagoons were quarried out by analysis of simulated wind-wave fields. The potential wind-wave impact was parameterised by the one quarter wave length criterion, and was discussed in terms of both impact recurrence and intensity on the basis of statistical approach. Results showed that potential wave impact on bottom sediments is comparatively higher in the Curonian Lagoon than in the Vistula Lagoon, which is, however, more shallow. The reason is the combination of three factors: wind conditions, bathymetry, and lagoon morphometry. It is further supposed that the deep water areas located in the southern part of the Curonian Lagoon are maintained by wind-wave induced resuspension, which prevents final deposition of suspended material transported into the lagoon by the Neman River.

☐ Wind—waves, modelling, suspended sediments, resuspension, lagoons, the Baltic Sea.

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INTRODUCTION

Fine-grained sediments and associated organic matter are not permanently deposited in high-energy shallow water environments. Frequent current (Sanford et al. 1991) or wind-wave generated resuspension (Weir & McManus 1987) entrain this material into the water column where it is subjected to advection towards the final depositional area (Floderus & Håkansson 1989; Christiansen et al. 1997). Research on erosion, transport, and deposition is vital as, for example, pollutant dynamics are closely related to the transport mechanics of these sediments and thus their spatial distribution. Several studies show that wind-wave generated resuspension plays a fundamental role in the dynamics of fine bottom material and suspended particulate matter in a variety of shallow coastal (Sanford 1994; Schoelhammer 1995; Lund-Hansen & Eriksen 1996, Lund-Hansen et al. 1997; Lund-Hansen et al. 1999) and fresh water (Kenney 1985; Luettich et al. 1990) environments. This emphasises that resuspension is an important variable regarding mass balance studies and transport of suspended particulate matter in aquatic environments.

Wind-wave generated bottom motion and the associated sediment resuspension have further been shown to increase nutrient concentrations in the water column (Simon 1989; Hellström 1991), and Floderus (1988) documented that the nitrogen export from shallow water zones depended on the frequency of resuspension events. However, despite the importance of resuspension processes there have only been a few attempts (Floderus & Pihl 1990) to describe the spatial variation and frequency distribution of resuspension events regarding specific and well-bounded areas. Resuspension processes are caused by the physical interaction between water and sediments, which depends on two principal properties: water dynamics and sediment characteristics (grain-size, organic matter, and water content etc.). Differences in grain-sizes as well as sediment characteristics, establish completely different conditions for resuspension whereas water dynamics can be considered as constant. For example, the existence of a thin oxide skin-layer covering the sediment surface reduces effective shear stress (Aibulatov 1990; Aibulatov & Artukhin 1993). Therefore, the influence and effects of the water dynamics is the main factor of resuspension that should be studied at first. Even though that long-term suspended sediment dynamics is well studied in the Curonian (Kuršių Marios) and Vistula lagoons (Repechka et al. 1980, Gudelis & Pustelnikovas 1983, Galkus 1988, Pustelnikovas 1998, Chubarenko et al.1998), data on field measurements of resuspension in these lagoons are limited. The single field experiment was held only in the Vistula Lagoon (Blazhchishin & Chechko 1997), which showed a high range (28-141) g m^{-2} day^{-1}) of short-term sedimentation rates induced by storm resuspension. The role of resuspension in relation to other terms in the sediment balance (the load from rivers or aeolian transport) has not yet been studied in any of the lagoons.

The purposes of the present paper are: (i) to study the conditions of potential wind-wave influence on the bottom sediments in two Baltic lagoons (Curonian and Vistula lagoons) in terms of statistical characteristics and spatial variation of theses characteristics, and (ii) to compare these conditions for both lagoons regarding differences in lagoon bathymetry and morphometry.

STUDY AREAS

The bathymetric structure of the Curonian (Kuršių Marios) and Vistula lagoons (Fig. 1) forms ideal conditions for the occurrence of wind-wave resuspension. The Curonian Lagoon is a shallow flat depression having a significant bottom slope only near the coast. The average depth of the lagoon is 3.8 metres and the greatest depths (up to 5.8 m) are found in the southern part of the lagoon (Hydrometeorological State 1985). Water depths above 6 metres are located in the Klaipėda channel that forms the entrance to the lagoon. The Vistula Lagoon has an average depth of 2.7 metres and is characterised by relatively large areas of shallow water, although the maximum depth of 5.2 m is comparable to that of the Curonian Lagoon. Total annually average river discharge values for the Vistula and Curonian lagoons are 120 and 750 m^3 sec^{-1}, respectively (Hydrometeorological State 1985). The biggest river in the Vistula Lagoon catchment is Pregolja River, which quota is 42% of total discharge. In the Curonian Lagoon the Neman River contributes with 92% of the total fresh water yield.

Fig 1. The location of the Curonian and Vistula lagoons in the south-eastern part of the Baltic Sea.

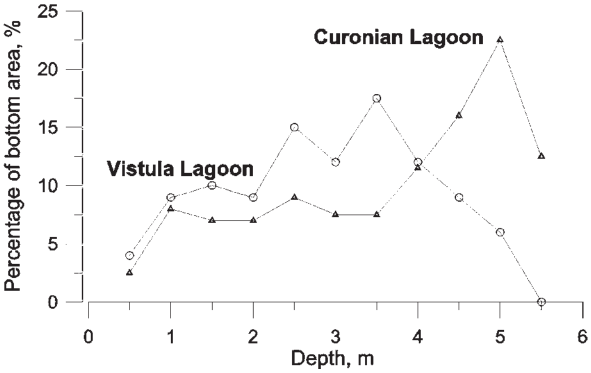

Fig 2. The distribution functions of water-covered area (percent) against a lagoon depth for the Vistula and the Curonian lagoons.

The principal differences in the morphometric structure between the two lagoons, regardless of their spatial sizes, can be illustrated by Fig. 2, which shows the distribution of lagoon surface area against depths. It can be seen that the Vistula Lagoon is shallower in comparison to the Curonian Lagoon in terms of fraction of lagoon surface area covered by lesser water depths.

Average values of concentrations of suspended particulate matter in the Vistula Lagoon vary between 25 and 66 mg l^{-1} (Chubarenko et al. 1998) whereas they vary between 10 and 85 mg l^{-1} in the Curonian Lagoon (Repechka et al. 1980, Pustelnikovas 1998). According to estimations by V. Chechko (Table 1) (personal communication), the content of sand in the upper 10 cm of the lagoons sediments, as well as the content of coarse material in the suspended sediments are higher in the Curonian Lagoon as compared to the Vistula Lagoon. The content of sand in the sediments of the Curonian and Vistula lagoons averages 54% and 30%, respectively, and the content of grain-sizes larger than 0.01 mm in the suspended sediment is 81% in the Curonian Lagoon and 76% in the Vistula.

The recurrence of wind with a speed greater than 10 m s^{-1} is high for the Vistula Lagoon (Table 2) for all wind speeds for the year on average, regardless of wind direction (Hydrometeorological State 1985).

Wind-waves are generated by local winds that are limited by the shallowness of the lagoons and fetch. Waves originating in the Baltic Sea can not penetrate into any of the lagoons. The wind-waves are the main

Table 1. The percentage of areas of the Curonian and the Vistula lagoons occupied by different types of sediments (estimations by V. Chechko, personal communication).

Type of sediments *(Bezrukov & Lisitzyn 1960)*	The Curonian Lagoon	The Vistula Lagoon
Sands with grain size of 1 – 0.1 m^{-3}	54%	30%
Coarse aleurite with grain size of 0.1 – 0.05 m^{-3}	25%	22%
Fine aleuritic mud with grain size of 0.05 – 0.01 m^{-3}	18%	45%
Pelite with grain size less than 0.01 m^{-3}	3%	3%
Total area, m^6	1584	838

Table 2. Comparison of the recurrence of the wind velocities for the Curonian and Vistula lagoons for the year on average (regardless wind directions).

Wind velocity scale, m s^{-1}	10 – 13	14 -- 17	18 – 20	21 – 24	25 – 28	29 -- 34
Recurrence (%)						
The Curonian Lagoon	8.06	2.21	0.57	0.07	0.02	0
The Vistula Lagoon	13.6	5.5	1.73	0.1	0.03	0.015

forcing factor, which induce near bottom currents. The advective component of near bottom current induced by gradient flow amounts to 0.1–0.15 m s^{-1} (Dubravin et al. 1977). For comparison, the critical shear velocity is in the range of 0.05-0.5 m s^{-1} for particles with a mean diameter of 0.01-1 mm (according to different methods of estimation reviewed in Alexievskiy & Mykhinov 1991).

METHODS

Among different parameterisation of water dynamics, i.e. near-bottom shear stress, the direct parameterisation versus wind-wave parameters was chosen following (Sly 1978) and (Floderus 1988) as the most convenient method for generalised spatial and comparative analysis. The following procedure was assumed to describe the wind-waves influence on bottom sediments in the lagoons. First, the zones of potential influence were determined in the lagoons for series of fixed wind velocities and directions. Then, the integrated charts of these zones for a period of one year were created considering the annual wind statistics, and these charts were the basis for the comparative analysis. The main point is how to determine the zones of potential influence? Even when wind conditions are fixed, there is a whole spectrum of wind-waves at the given point of lagoon area. On the other hand, the sediment in any given point is a mixture of compounds with different grain-size compositions. And so, theoretically, rare and episodic resuspension events of very fine-grained material at the given point could take place for very weak winds. However, only developed resuspension should be considered when wave impact becomes significant to resuspension, and therefore the crude criterion of "one quarter" was applied according to Sly (1978) and Floderus (1988). The depth at a given point should be less then one quarter of significant wavelength. To quantify this, the criterion that the wave potential penetration depth should equal one quarter of the significant wavelength was used in the present study. We applied this criterion for both lagoons for comparative reasons. Although this criterion is rather rough and do not consider specific physical mechanisms of resuspension as, for example, wave-induced pore-water pressure variations (Spierenberg 1988), etc., it is, nevertheless, suitable for qualitative and comparative considerations on wind-wave impact. There are empirical, semi-empirical, and spectral methods available for the calculation of wave parameters in shallow water areas (Bishop & Donelan 1989). However, a dominant feature of both the Curonian and Vistula lagoons is that both deep- and shallow-water regimes of wind-waves occur in the lagoons. For this reason, the method given in the Shore Protection Manual (1984), which includes both deep-water and shallow-water approaches, was chosen for the calculation of significant wavelength for any given wind, which implicitly corresponds to significant wave height and period. However, the following questions need to be assessed for a description of the wind-wave impact: (i) what part of the bottom areas are influenced by wind-waves for different wind conditions, (ii) how often is a specific point under wave impact, and (iii) what is the intensity of the wave impact at the point?

To address these questions numerically, two auxiliary functions were applied for every grid point in both lagoons. The first function (*OVL*) equals the difference between the real depth (*H*) and the potential wave penetration depth (*HP*) in absolute (1) and relative (2) forms for a given wind w_a:

$$\mathrm{OVL}\ (x, y, w_a) = \mathrm{HP}(x, y, w_a) - \mathrm{H}(x, y), \qquad (1)$$

$$\mathrm{OVL}_{\mathrm{REL}}\ (x, y, w_a) = \mathrm{OVL}\ (x, y, w_a) / \mathrm{H}(x, y), \qquad (2)$$

where $H(x, y)$ is the depth at the point (x, y), $HP(x, y, w_a)$ is the potential wave penetration depth at that point under the given wind conditions, and (x, y) are the coordinates of the point considered. Potential penetration depth equals one quarter of the significant wavelength (for a given wind w_a) according to the one quarter criterion. The relative parameter (2) describes to what extent the wave penetration depth overlaps the real depth at a given point. It is obvious that intensity of wave impact on sediments will be directly and nonlinear proportional to this parameter. Therefore, by comparing this parameter for both lagoons, we actually compare the wave impact intensity in the lagoons.

A second function (*RES*) describes the recurrence of wave impact at a given point under given wind conditions. Its value depends on the sign of $OVL\ (x, y, w_a)$ at the given point:

$RES\ (x, y, w_a) = 0$, *if* $OVL\ (x, y, w_a) < 0$
(no wind wave impact)
$RES\ (x, y, w_a) = 1$, *if* $OVL\ (x, y, w_a) > 0$
(wind wave impact occurs at given point) *(3)*

To obtain a value of the impact recurrence for a given point (x,y) during a given time interval, we need to integrate the function $RES\ (x, y, w_a)$ along this time interval and than normalise the result. Another way is the following. If the function RES (x, y, w_a^0) equals 1 for a given wind condition (w_a^0), which is characterised by a fixed probability of recurrence (n_0) during the year, then wave impact occur at the point considered with the probability of recurrence of (n_0). Note that these functions only describe the potential wind wave impact at a given point. Calculations were made for all nodal points of a finite elements curvilinear grid: (40 x 40) for the Curonian Lagoon and (101 x 19) for the Vistula Lagoon. These grids were constructed by using a calculation procedure that makes it possible to create the curvilinear adaptive regular grid for any basin with a complex boundary configuration (Ivanenko 1993). The characteristics at any internal point inside the 4-node grid element were calculated using a linear form function. The values of the functions for the whole elements were calculated as the arithmetical mean among its node values. According to this mathematical approach the continuous functions *RES(x,y), OVL(x,y), and OVLREL(x,y)* transform into a discrete form: *RES(i,j), OVL(i,j), OVLREL(i,j),* where $i=1,N$, $j=1,M$ are the indices of the cell in a finite element grid of $(N \times M)$ dimension.

To compare the conditions of wind-wave impact in both lagoons independently of differences in their shape, size and wind statistics, the distribution functions for some indicator parameters (wave fetch, height, penetration depth and depth) along the lagoon area were used as a main tool in the comparison. The relative values of these indicators, in terms of the ratio of the current value to maximum value of this parameter in a lagoon area, were considered. Regions where wave orbital movements are potentially able to resuspend bottom material, were determined for 72 situations for both lagoons, *i.e.* for 9 wind velocity intervals (0 - 3, 3 - 7, 7 - 11, 11 - 15, 15 - 19, 19 - 22, 22 - 26, 26 - 31, above 31 m s^{-1}), and for 8 wind directions (N, NE, E, SE, S, SW, W, and NW). The integrated spatial distribution of areas of potential resuspension in the lagoons for a one year period, were obtained in terms of the maps of wave impact recurrence and intensity (Figs. 3-6) according to equations (4) and (5). Each of these maps (Figs. 3-6) was constructed using the annual statistical probability for each of the 72 wind situations. First integral function introduced in the present study represents the statistical probability (or recurrence) of the wind wave impact at each computational point (i,j) during the year:

$$RESAVR(i,j) = \mathrm{S}\ n_{kl} * RES_{kl}\,(i,j) \qquad (4)$$

where $k=1, 9$ is the index of wind speed interval, $l=1,8$ is the index of wind direction, and n_{kl} is the probability of the (k,l) wind situation for the analysed one year period. This function considers both the wind and

Table 3. Comparison of measured and estimated average wave heights (m) for different directions, fetch (km), and wind speeds (m s^{-1}) in the central part of the Vistula Lagoon.

Wind direction	SW	E	NE	W	SW	E	NE	W
Fetch (km)	52	15	13	5	52	15	13	5
Wind speed (m s^{-1})	5	5	5	5	10	10	10	10
Measured wave height (m)	0.5	0.4	0.4	0.4	1.0	0.9	0.9	0.6
Estimated wave height (m)	0.5	0.3	0.3	0.3	1.0	0.8	0.7	0.5

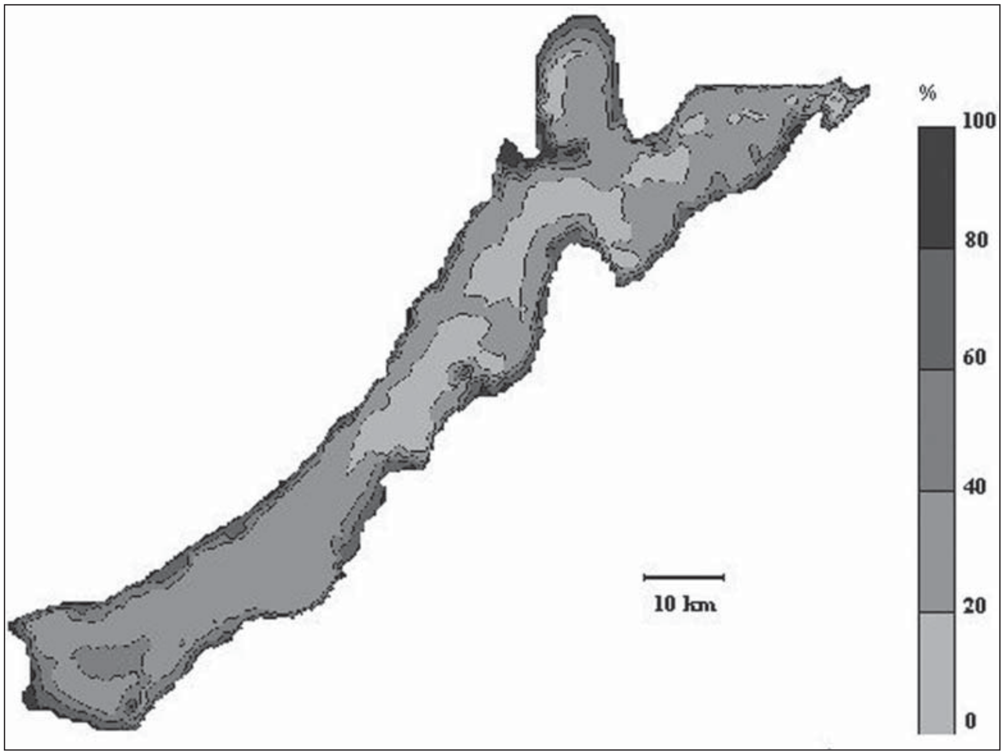

Fig 3. The recurrence (percent) of wave impact on the bottom of the Vistula Lagoon for a one year period in relative units corresponding to the maximum value in the basin.

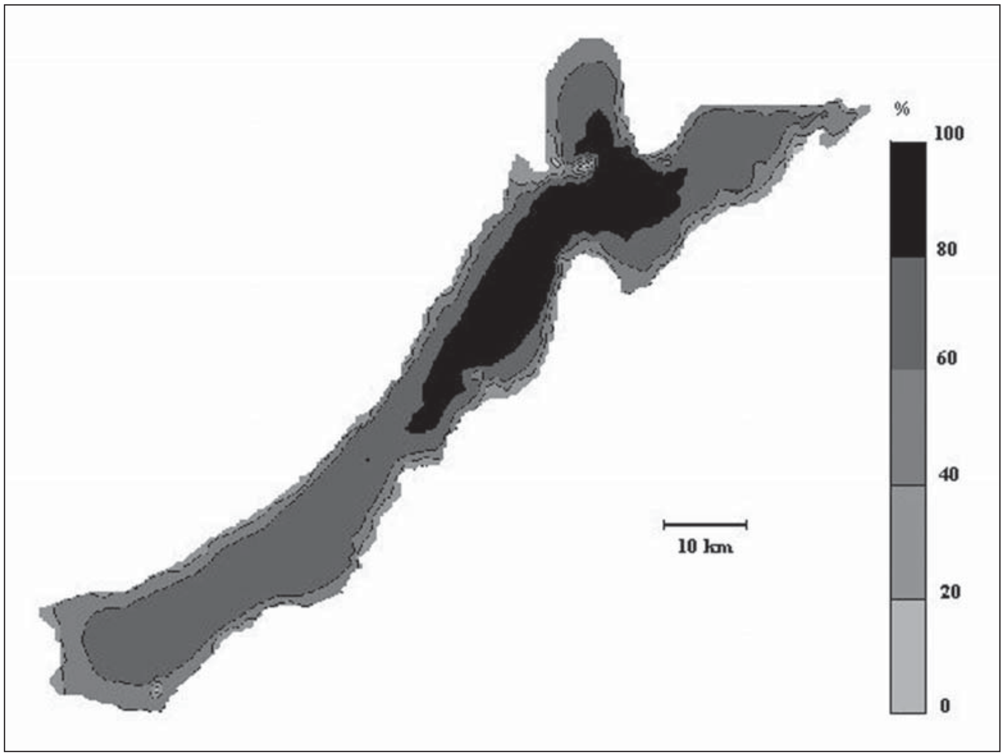

Fig 4. The average intensity (percent) of wave impact on the bottom of the Vistula Lagoon for a one year period in relative units corresponding to the maximum value in the basin.

lagoon depth information and represents the spatial variation of the recurrence for the potential resuspension in the study area.

The second integral function reflects the spatial variation of the wave impact intensity for the analysed one year period:

$$OVLAVR\ (i, j) = S\ n_{kl} * OVL_{kl}\ (i,j) \qquad (5)$$

The wind statistics applied in the present study (Hydrometeorological State 1985) were measured by the State Meteorological Service at stations situated on the seaside of the Vistula and Curonian lagoons for the period between 1961 and 1975.

RESULTS AND DISCUSSION

Measured wave parameter data that were used in a comparison of measured and simulated wave parameters are only available for the Vistula Lagoon. These were collected by wave stake visual measurements in the central Vistula Lagoon (3.2 m depth) with the time interval of 1 hour in 1964 (Hydrometeorological State 1985). However, the comparison between simulated and measured wave height for different wind directions, speeds, and fetch shows that the error by simulation does not exceed 14% (Table 3). Although that this comparison only comprises measured and simulated wave heights the low error in the simulation strongly indicate that simulation results are reliable.

The absolute values of the two integral functions (4, 5) have no direct physical meaning, therefore the relative units corresponding to the maximum value in the basin were used (Figs. 3-6). With the help of these functions, it is easy to point out the areas where wave action occurs more often and with the highest intensity. For example, from Fig. 3 (function *RESAVR* for the Vistula Lagoon*)* it can be seen that the regions with 60-100% of the maximum potential resuspension recurrence are located in an approximately 2 km wide strip along the shoreline of the lagoon. Regions with low recurrence (0 - 20% of maximum) coincide with deepwater regions and wave shadow areas.

Furthermore, from Fig. 4 it can be seen that the area with the highest wave impact intensity in the Vistula Lagoon is located in the central (deepest) part of the lagoon and coincides with the area of low potential resuspension recurrence (Fig. 3). By contrast, the near shore zone is characterised by a low intensity of impact.

For the Curonian Lagoon (Fig. 5), most of the area in the southern part is characterised by potential resuspension recurrence of 20-40% of the maximum. The lowest recurrence is characteristic for the southwest corner, because of the wave shadow in this part of the lagoon for the majority of winds. The isolated sub-area with 40-60% of maximum recurrence in the middle of the southern part of the lagoon is related to a significant development of waves due to the large fetch for most wind directions.

The general tendency regarding the spatial distribution of wave impact intensity in the Vistula Lagoon is also observed in the Curonian Lagoon (Fig. 6).

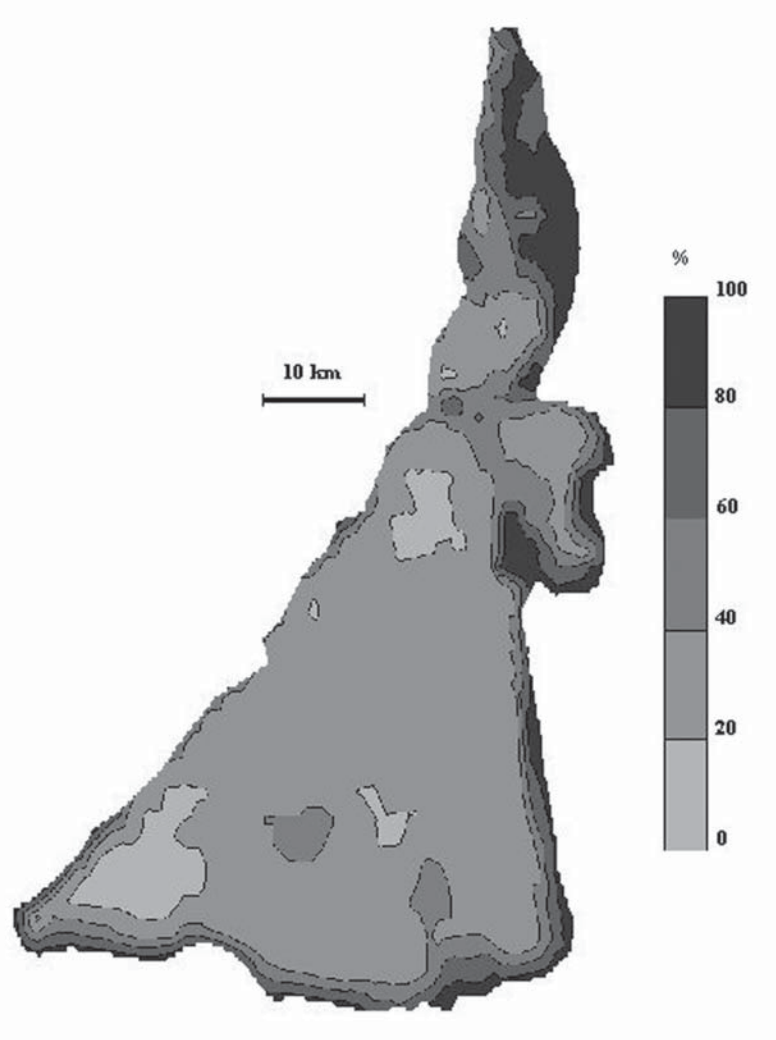

Fig 5. The recurrence (percent) of wave impact on the bottom of the Curonian Lagoon for a one year period in relative units corresponding to the maximum value in the basin.

Areas of high wave intensity largely coincide with areas of low impact recurrence. According to this, most part of the southern Curonian Lagoon is under the conditions of both high wave impact intensity and low potential resuspension recurrence.

The same conditions (correlation of spatial distribution of areas of higher intensity and lower recurrence) were revealed on a seasonal scale. The maps (January, April, June, and September) of potential impact recurrence and intensity (not shown) were constructed according to the same method, i.e. eqs. (4) and (5) by using the statistical probability for each of the 72 wind situations regarding the appropriate seasons (Hydrometeorological State 1985). It is convenient to compare numerically the potential resuspension conditions in the two lagoons on the basis of distribution functions. For instance, the distribution of area against depth shows that the regions with depths between 2 and 4 metres cover the main part of the Vistula Lagoon (Fig. 2). Regions with more than 4 metres of water depth cover less than 18% of the lagoon area. The opposite holds true for the Curonian Lagoon. The distribution reaches a peak at 5.0 metres of water depth and nearly 50% of the area has water depths equal to 4 metres or more. It might be supposed, that this difference in lagoon morphometry as well as in wind statistics (Table 2), results in a higher wave impact on the bottom sediments in the Vistula Lagoon. However, our analyses show, in fact, that the area affected by wind wave action is larger in the Curonian Lagoon (in percentage of the total lagoon area) as compared to the Vistula Lagoon. For example, the relative area of a lagoon, which is affected by wave impact of any equal intensity, is, on the average for all seasons and for any intensity gradation, 7-9% higher in the Curonian Lagoon as compared to the Vistula Lagoon.

If we consider the distribution of a share (in percentage) of the Vistula and the Curonian Lagoons bottom areas potentially being impacted, along the relative time of impact, it is shown (Fig. 7) that 33% of the Vistula Lagoon is exposed to wave impact almost nearly 30% of the time. The relative time of impact is the ratio between the time interval over which the area experiences wave impact and the one-year reference period. Meanwhile, practically the same relative area of the Curonian Lagoon (36%) experiences the impact during 37% of the time. It shows that the potential resuspension processes in the Curonian Lagoon can be stronger, and that a comparatively larger area is more frequently affected by wave action in this lagoon.

The effects discussed above are the results of the interaction between wind conditions and morphometry of the lagoons, and the study shows that the main reason for the differences in potential wind-wave impact between the two lagoons is their morphometry. On average, the wind conditions for the year as a whole are stronger for the Vistula Lagoon, but there are only two wind directions (southwest and northeast) along which the waves can develop freely, whereas the wave fetch is limited for all other directions (Fig. 1). In contrast, waves developed by all wind directions have nearly the same fetch in the southern part of the Curonian Lagoon.

As a verification of this statement, Figure 8 shows the distribution of the

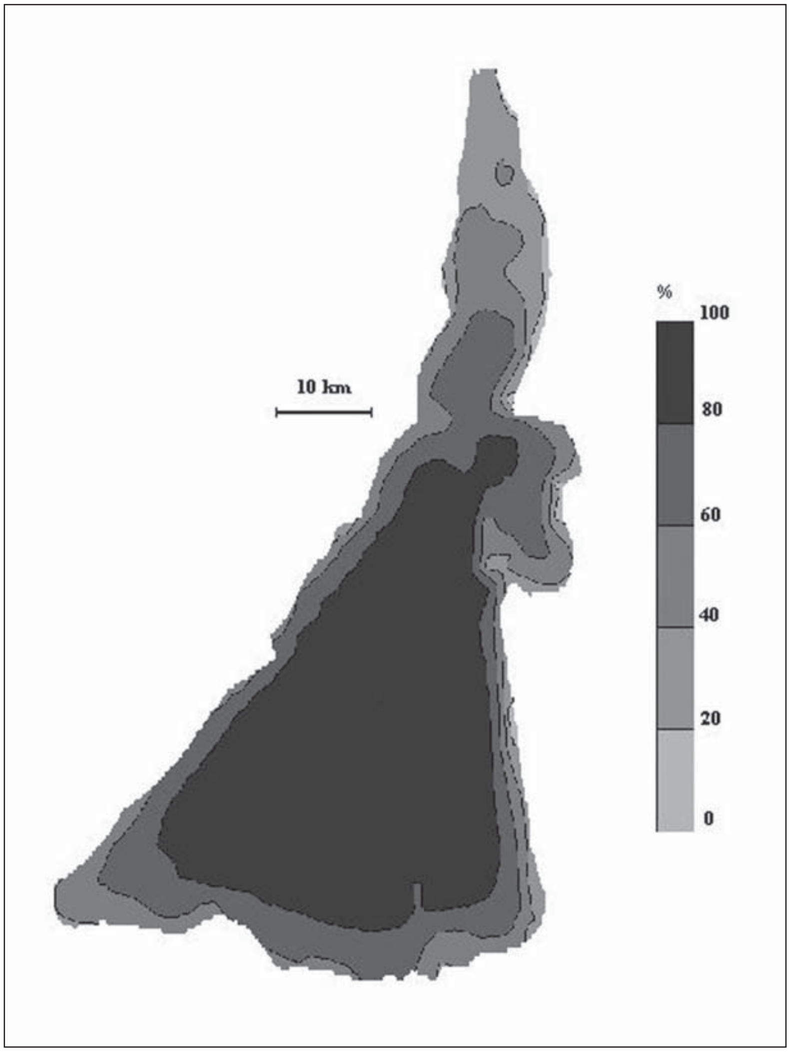

Fig 6. The average intensity (percent) of wave impact on the bottom of the Curonian Lagoon for a one year period in relative units corresponding to the maximum value in the basin.

share (in percentage) of the Vistula and the Curonian Lagoons bottom area along effective wave fetch, *i.e.* the weighted average of wave fetches according to the annual wind probability (analogous to (4) and (5)). More than 90% of the Vistula lagoon area is covered with waves, which have a weighted average wave fetch of less or equal to 10 kilometres. In the Curonian Lagoon, such waves occur only in about 20% of the basin, whereas other parts of the lagoon are exposed to waves with a fetch of 10-35 kilometres.

A similar comparison of the distribution of the share (in percentage) of the Vistula and the Curonian lagoons bottom area, along effective wave height, clearly shows the effects of the differences in fetch between the lagoons, where comparatively higher waves occur in the Curonian Lagoon (Fig. 9). The effective wave height is determined similarly to effective wave fetch, *i.e.* as a height, averaged according to the annual wind probability (analogous to (4) and (5)).

It is remarkable, that distribution functions (Fig. 10) for the relative wave penetration depth, *i.e.* the penetration depth normalised to its maximum in the lagoon area, are quite similar to the distribution functions for the lagoon depths in both lagoons (Fig. 2). As wave penetration depth depends only on wave parameters, and not on the depth field, it is hypothesised that the historical genesis of the depth fields in the Curonian and the Vistula lagoons might be directly related to the wind wave impact on lagoon sediments. The average residence time for fresh water (a ratio of freshwater runoff to lagoon volume) is estimated to be 3.3 and 7.6 months for the Curonian and the Vistula lagoons, respectively. With a wind time scale of hours and days (Hydrometeorological State 1985), and a time scale of horizontal mixing of weeks, river sediments can be distributed in all parts of the lagoons by currents, assuming that average retention time for sediments is not shorter than freshwater residence times. The sediments can be re-accumulated and re-suspended several times before they are transported out of the lagoon. Accordingly, the occurrence of deep water areas in the Curonian Lagoon in the case that the Neman River transports much more sediment to the Curonian Lagoon than is transported into the Vistula Lagoon from the catchment area, this shows the direct influence of wave activity in the Curonian Lagoon.

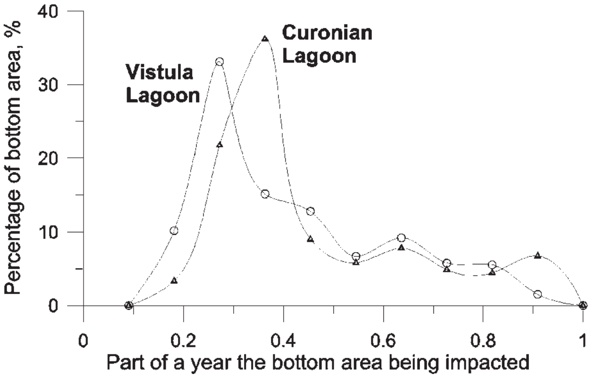

Fig 7. The distribution functions of a share of the Vistula and the Curonian lagoons bottom area against the time this share is undergo by wind impact during a one year period.

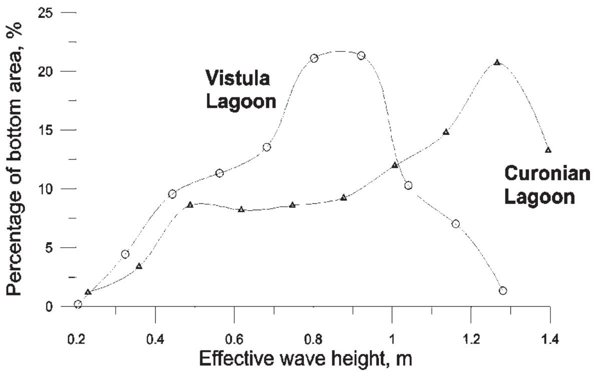

Fig 9. The distribution functions of a share of the Vistula and the Curonian lagoons bottom area against wave height for the Vistula and the Curonian lagoons for a one year period.

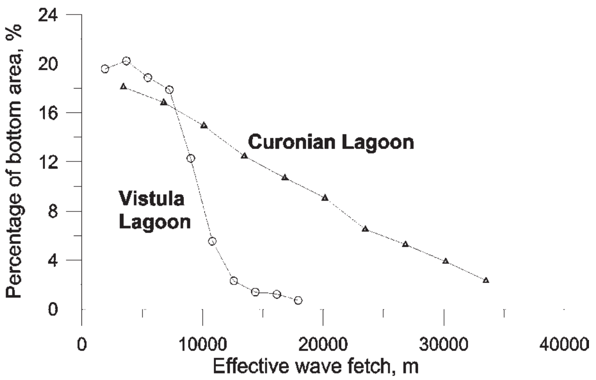

Fig 8. The distribution functions of a share of the Vistula and the Curonian lagoons bottom area against effective wave fetch for the Vistula and the Curonian lagoons for a one year period.

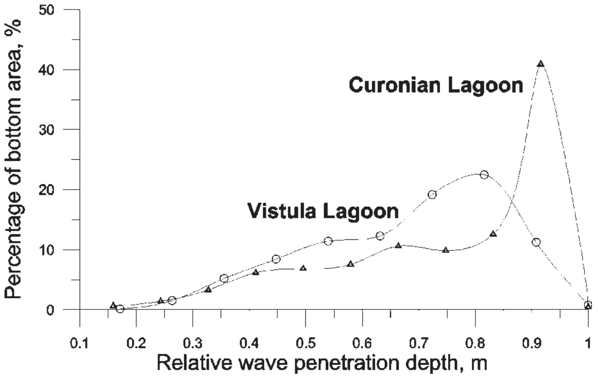

Fig 10. The distribution functions of a share of the Vistula and the Curonian lagoons bottom area against wave penetration depth for the Vistula and the Curonian lagoons for a one year period.

CONCLUSIONS

A comparative analysis of wind-wave impacts on the sediments in two Baltic lagoons (Curonian and Vistula) could be fulfilled, on the basis, of theoretical analysis. The response of the lagoon sediments to wind-wave impact is determined by both a penetration of wave induced water motion at the lagoon bottom and by sediments composition. The first one defines the potential impact and the second one the actual response. The comparative analysis of potential wave impact in the two lagoons of different morphometry and wind exposure must be carried out in terns of a comparison of (i) the zones of potential wave impact, and (ii) the distribution functions of indicator parameters. These are wave fetch, height, penetration depth and depth averaged in time and normalised to their maximum value in the lagoon area. As for the present case, the spatial distributions of potential wave impact were analysed in terms of developing average statistical maps for the wind-wave impact recurrence and intensity for the year as a whole. Each of these spatial patterns was constructed, on the basis, of 72 wind-wave field simulations (8 wind speed and 9 wind direction gradations) that were further averaged by using their statistical seasonal and annual probability of occurrence. It was shown that the interaction between the three factors, which control wind-wave impact on bottom sediments in both lagoons, (i) wind conditions, (ii) bathymetry, and (iii) morphometry, that defines the wave fetch, together increase the probability of resuspension in the deeper Curonian Lagoon than in the more shallow Vistula Lagoon. It is suggested that the enhanced wave impact in the Curonian Lagoon counteracts the accumulation of suspended material transported by the Neman River, which thereby maintains the more deep water regions in this lagoon. It is hypothesised that the general historical genesis of the depth fields in the Curonian and the Vistula lagoons might be directly related to the wind-wave impact on lagoon sediments.

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