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Long-term fluctuations in the volume of beach and foredune deposits along the coast of Latvia

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Abstract Assessed in the course of this study is the sediment budget of five coastal sections with a total length of 32.5 km, along the sea coast of Latvia. These sites are important to community due to their value as a tourism and recreation areas, with possible loss of land and recreational suitability due to coastal erosion triggered by global climate change. The changes in volume of the deposits forming the relief of the exposed part of the shore slope have been determined on the basis of 57 stationary levelling transects established in 1991, 1993 and 1994.

Keywords *Coastal evolution, coast of Latvia, storms, erosion, accretion, monitoring.*

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INTRODUCTION

Similar to other coastal areas worldwide, the Latvian coastal zone is presently subjected to notable changes, presumably, due to an interconnection of anthropogenic and natural factors. These changes are the subject of this study because of necessity to evaluate probability of accelerating coastal erosion.

The changes of coastal processes activity and direction depend on the parameters of hydrological and meteorological events (recurrences of storms, sea level changes). Anthropogenic factors diminishing the drift supply and preventing the natural distribution of sediment also have the great importance to coastal system.

This paper is a review of identifiable long term depositional/accreational processes in various sectors along Latvian coastline. The main objective is to assess probable trends in sediment budget.

THE STUDY AREA

The total length of the Latvian coast is about 496 km, 253 km of which is the open Baltic Sea coast. The coastline has been straightened by continued marine erosion and deposition. The range of covered coastal environments with total length of 32.5 km includes high energy, sediment rich sections on the open coast of the Baltic Sea and Irbe strait to relatively low energy, as well as sections short in sediments in the Gulf of Riga. Beaches are consisting mostly of sandy material. Much of the coastal sections are unpopulated. The criteria governing the choice of stretches of the coast were that they should give a sufficiently long data series and should lie outside the direct influence of the hydrotechnical structures of the major ports.

BEACH AND FOREDUNE: INDICATORS OF COASTAL CHANGES

Waves breaking at the inshore cause sediment transport processes, one of the results of which is the formation of a special kind of deposit - the beach. The beach and the nearshore zone have a close dynamic relationship, since there is intensive sediment movement from one to other as storms alternate with calm periods. Along the Latvian coast, where tides are minor, partial profile beaches are typical and usually consisting of a low, wet foreshore and a high, dry backshore (Ulsts 1998; Eberhards 2003). Under very variable water-level and wave conditions, the volume of the beach, its surface relief and extent are continuously changing. A beach is virtually always present along depositional coasts, and very often also along erosional coasts. Practically along the whole length of the Latvian coast, the beach has a very important role in the coastal system. During storms, it is the location of large-scale longshore transport and, together with the foredune; it acts to ensure the stability of the system, accumulating sediment in calm conditions, and under extreme conditions supplying it to sediment-deficient zones of the shore slope, as well as dissipating and dispersing wave energy (French 2001; Rijn 1998; Komar 1998).

The relief landward of the beach, lying in the coastal zone and influenced by present-day marine geological processes, generally consists either of accreational aeolian forms, or of a bluff. The foredune belt under present-day conditions in Latvia is the only active belt of aeolian deposition and represents a dynamic relief form. Along the stretches of the coast where erosion dominates, or where incoming sediment volume is insignificant (low rate of longshore sediment transport, pebble-gravel beaches), foredunes are absent or poorly developed (Eberhards 2003).

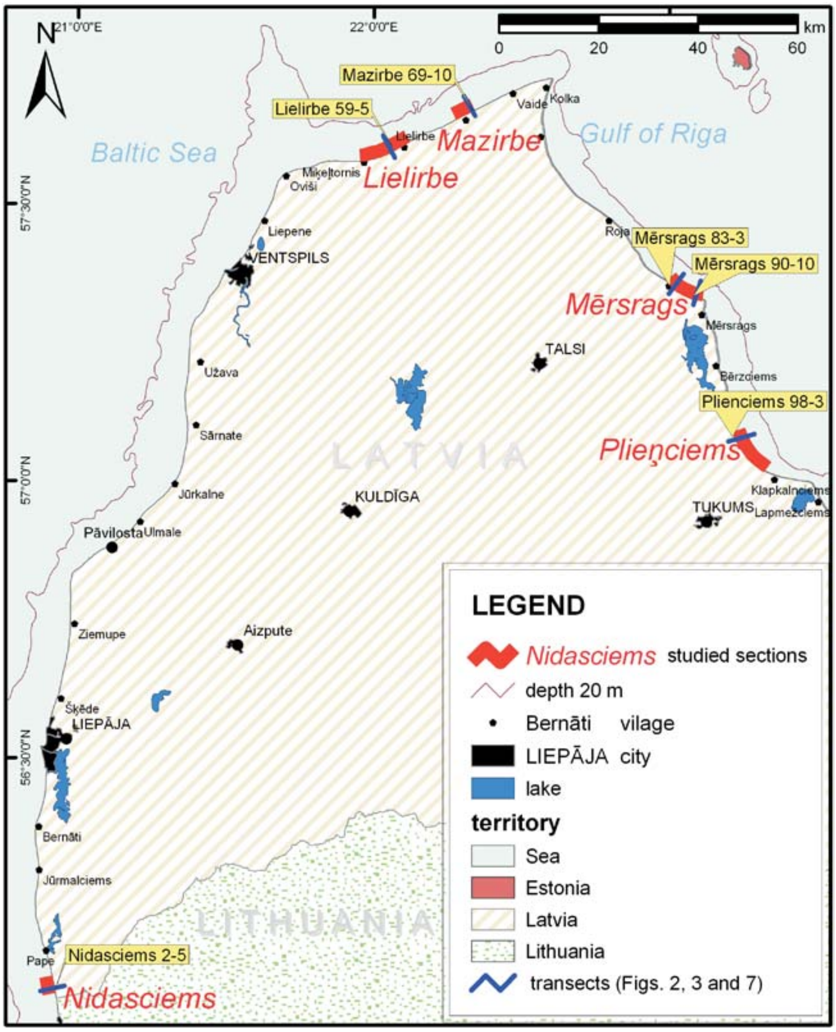

Fig. 1. The location of the investigated stretches of the coast along the Baltic Sea, the Irbe Strait and the Gulf of Riga. Transects shown in Fig. 2, 3 and 7 is located with off-scale marks.

MATERIALS AND METHODS

In order to assess possible relationships in those stretches of the Latvian coast where sediment dynamics are determined mainly by natural conditions, coastal processes monitoring data were analysed for the period from 1991 up to and including 2003. Measurements were taken along fixed profiles using an optical level on an annual basis, with one-year interruptions at particular profiles (Eberhards & Saltupe 1999). A total of 57 levelling profiles included in the monitoring system were chosen, located in five stretches of the coast of the Liepāja, Ventspils, Talsi and Tukums districts, where regular measurements have been taken at least since 1994 (Fig. 1; Table 1). The distance between profiles within particular stretches of the coast ranges between 200 and 2000 metres. The profile lines are perpendicular to the coastline. In the survey processes, the beach leveling is adjusted to the mean sea level datum using local fixed benchmarks of known elevation.

Analysis of changes in the volume of sediment, calculating the cross-sectional area, was undertaken separately for the beach and the active aeolian relief employing a least squares technique. Taken as the upper limit of the beach was the foot of the foredune or embryonic dune. The upper limit of active aeolian relief was taken as the point where vertical changes

Table 1. Sections of the coast of Latvia investigated in the study.

Coastal section	Year of establishing	Section length (km)	Quantity of transects
Nidasciems	1994	3.0	11
Lielirbe	1993	10.5	11
Mazirbe	1993	4.5	9
Mērsrags	1991	5.5	11
Plieņciems	1991	9.0	15

Table 2. The sediment budget for the investigated sections of the coast in the period since the establishment of the leveling transects (Table 1).

Coastal section	Changes of sediment volume at an average m^3/m/year	Percental changes of sediment volume at an average in one year
Nidasciems	min -1.0; max -1.5	min -1.5; max -2.0
Lielirbe	min +2.0; max +3.5	min +1.0; max +2.5
Mazirbe	min +2.0; max +3.5	min +1.5; max +3.0
Mērsrags	min +0.15; max +0.3	min +0.1; max +0.5
Plieņciems	min +0.05; max +0.2	min + 0.2; max +1.0

resulting from aeolian processes do not exceed a few centimetres. Along certain levelling transects on the coast of the Irbe Strait, dune hummocks stabilised by vegetation had formed on the upper part of the beach during a long storm-free period, and these were treated as part of the active aeolian relief. The calculated data from each section are arranged in 2-D graph, where X is the year of survey, and Y is the eroded/accreted sediment volume relative to time of profile establishment. This permits the determination of annual changes in sediment budget.

RESULTS AND DISCUSSION

The volume of sediment along the stretches of the coast little affected by hydrotechnical structures can remain relatively unchanging for a very long period. On the other hand, the distribution of sediment in terms of zones of the shore slope fluctuates considerably (Rijn 1998). Along the open Baltic Sea coast of Latvia, active coastal bluffs and the shoreface represent the most significant source of new material in the system. The main ways in which material is removed from any particular coastal cell are: longshore transport, movement to depth below storm wave base as the result of storm currents and aeolian accretion outside of the active coastal system. The redistribution and transport of this material is mainly the result of wave action, the energy source for which is the movement of air masses over the sea and the littoral zone. So long as the climate in general remains unchanging, each coastal cell is characterised by a certain volume of sediment participating in the geomorphologial processes characteristic of the coastal zone. However, even very small changes in the sediment budget can lead to significant migration of the shoreline and transformation of the relief (French 2001). Unfortunately, the quantitative determination of separate elements of the sediment budget is methodologically very difficult. The assumptions that

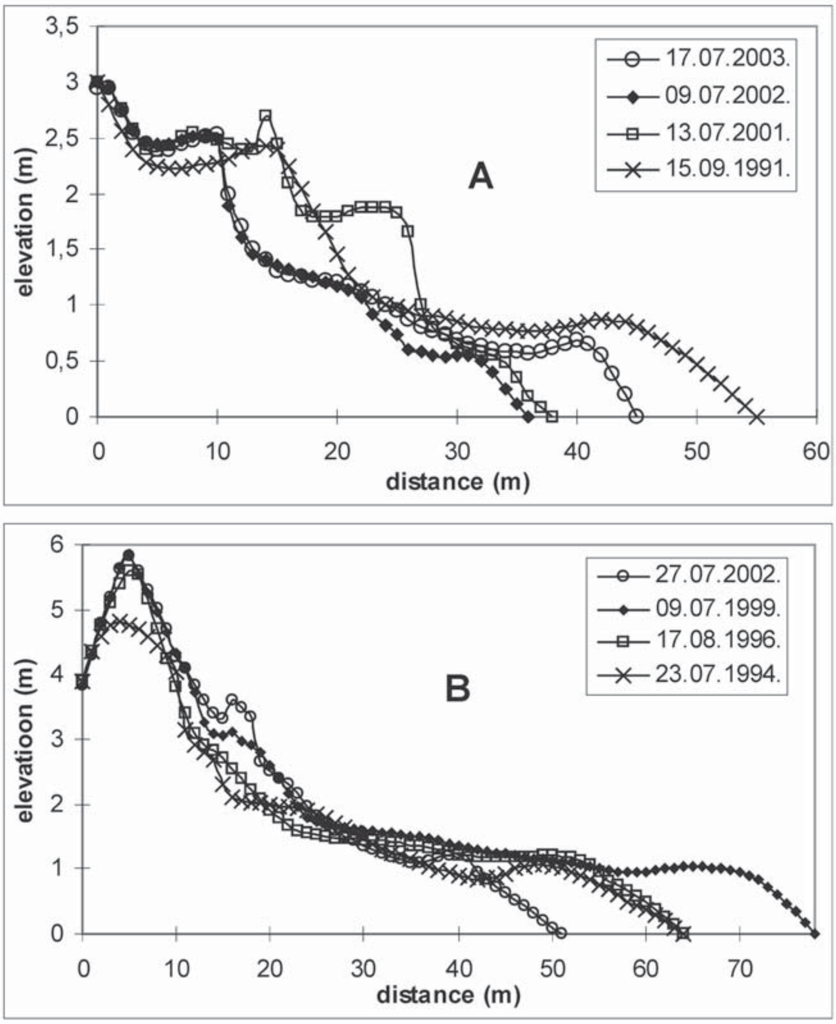

Fig. 2. A - Stationary levelling transect of the exposed shore slope *Mērsrags 83-3* (2 km SE of the mouth of the Grīva River). B - Stationary levelling transect of the exposed shore slope *Mazirbe 69-10* (0.5 km E of the mouth of the Mazirbe River). Location – see Fig. 1.

are unavoidably inherent in each method lead to errors. When the results of the calculations are applied to larger spatial or chronological units, the errors are summed and confidence in the results is reduced. Most of the recognised methods of calculation are based on the results of short-term regional, or even local, studies, and consequently offer limited possibilities of generalisation (Carter & Woodroffe 1994). Moreover, there is considerable uncertainty in distinguishing the effect of possible sea level changes on sedimentation processes for different time and relevance scales – the classical relevance-frequency problem of geomorphology. Another unanswered question is: What will be the product of interaction between long term sea-level change and large scale climatic changes, for example – changes in incidence of synoptic storm events (Eberhards 2003; Healy 1996).

A time series of at least ten years regarding the volume of material forming the beach and the active aeolian relief (if present) allows each coastal cell to be assigned to a certain type of dynamic change, and permits determination of its sediment budget (Table 2). Long-term monitoring permits forecasts as to the reaction of this cell to extreme meteorological phenomena.

For the majority of analysed profiles, the volume of beach sediment has fluctuated from year to year by five to ten m^3/m, corresponding to a few tens of percentage points around the mean (Fig. 5). Exceptions in this regard are the first years after a storm event, when the volume of beach-forming material has in many places been modified by more than 50 percent**.** Along certain transects, the maximum observed amount exceeds the minimum more than twofold (Fig. 2).

In the majority of cases, this might be explained in terms of local, seasonal fluctuations in the plan of the shoreline, characteristic of sandy coasts, as well as the parameters of storm currents and storm surges, influenced by the specific locational characteristics of nearshore sand bars and other depositional forms on the underwater slope. Unfortunately, more detailed assessment and study of this phenomenon is impossible owing to the very inadequate data on the underwater slope. It should be noted that even within the limits of particular coastal sections, transects separated by only a few kilometres are characterised by very significant differences in sediment dynamics and overall sediment budget (Fig. 4).

In the Mērsrags and Plieņciems sections, compared with the open Baltic Sea coast, the cumulative fluctuations in sediment volume are very small. This indicates much lower cross-shore and longshore

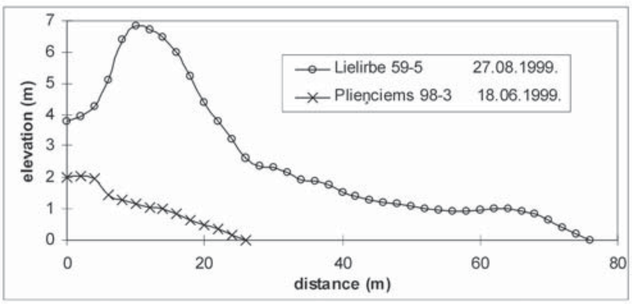

Fig. 3. Comparison of typical cross-sections of the active part of the exposed shore slope within the Plieņciems and Lielirbe cells. Location – see Fig.1.

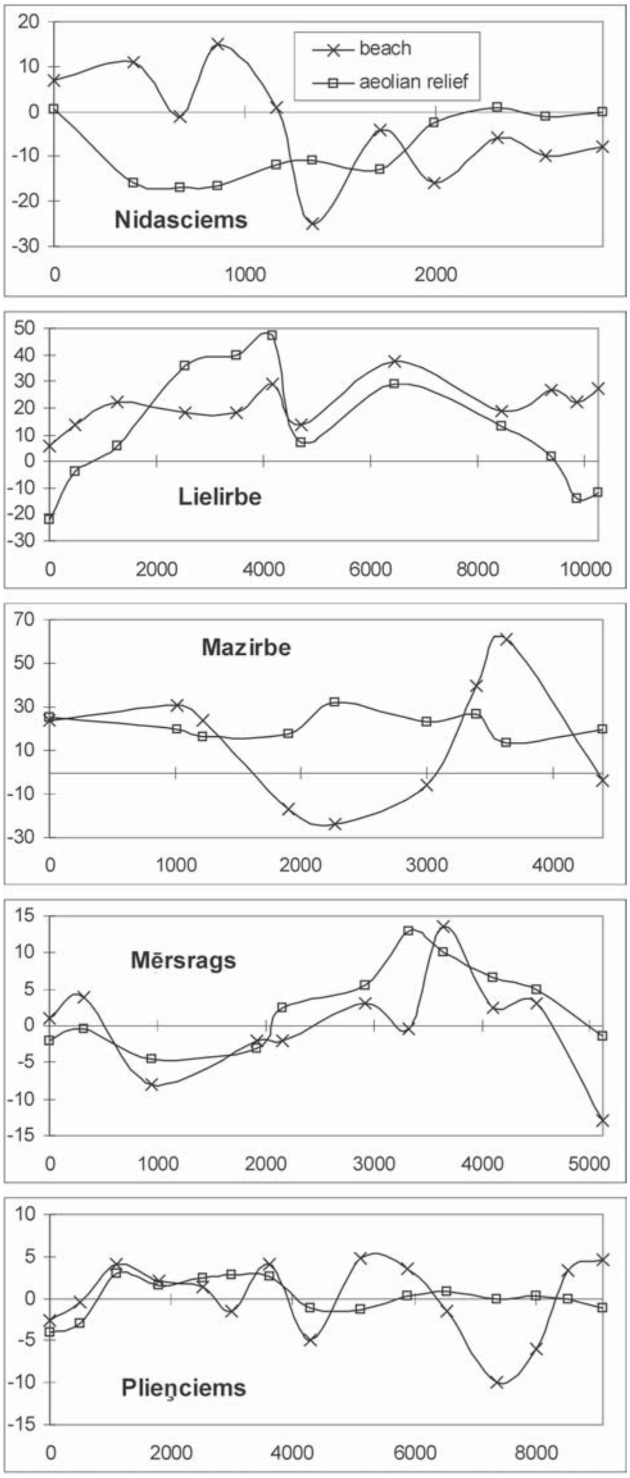

Fig. 4. The sediment budget of the beach and the active aeolian relief in the investigated coastal cells in 2003, compared with the first year of record. X axis: distance from the beginning of the stretch (m); Y axis: budget of sediment volume (m^3/m).

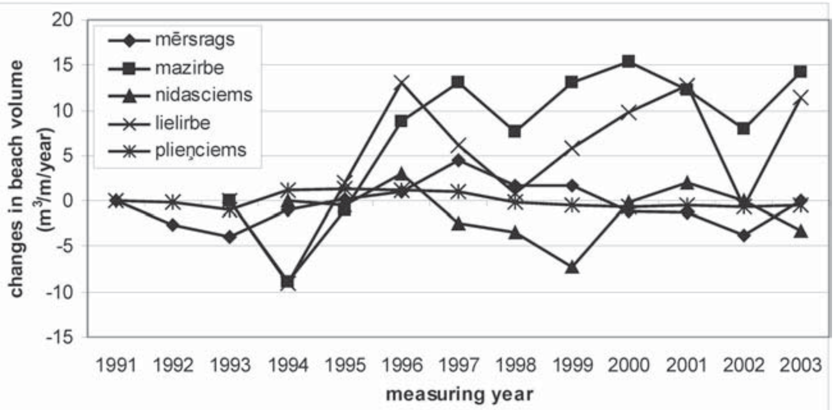

Fig. 5. Cumulative change in the volume of beach-forming sediment in relation to the first record for all levelling transects in each of the five investigated stretches of the coast.

transport due to lower energy wave conditions. Owing to the pattern of prevailing winds and typical storm directions, the Kurzeme shore of the Gulf of Riga very

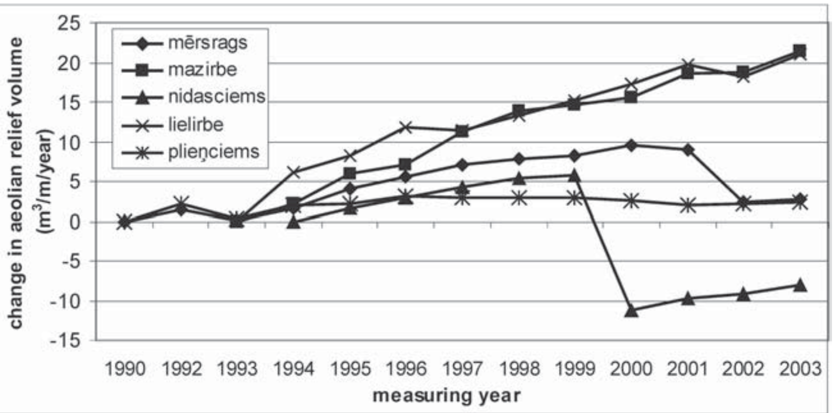

Fig. 6. Cumulative change in the volume of sediment forming the active aeolian relief in relation to the first record for all the levelling transects in each of the five investigated stretches of the coast.

rarely sees high-energy wave conditions. It should be borne in mind that the volume of sediments forming the beach and the foredune in the Mērsrags and Plieņciems sections is also several times smaller than, for example, in the Lielirbe section (Fig. 3).

Certain particularly stormy autumn/winter seasons have played a very important role in the fluctuations of sediment volume:

- 1992/1993 (coast of the Baltic Sea and Irbe Strait),
- 1999/2000 (Baltic Sea coast),
- 2001/2002 (coast of the Irbe Strait and the Gulf of Riga).

The volume of the aeolian relief has gradually increased during the whole period of observation, compared with the first year of record (Fig. 6). Only in the Nidasciems and Mērsrags stretches a considerable amount of material has been transported seawards from the dune. In certain coastal sections, the volume of the aeolian relief has been reduced by 20–30 (40) m^3/m (Fig. 7).

In the Nidasciems stretch, recovery of the foredune is occurring at a particularly slow rate, since there is very limited supply on the underwater slope, and thus also on the beach, of sand needed for dune accretion. Accordingly, the characteristic relief behind the backshore of the Nidasciems section cannot be classified as a typical foredune. This is a zone of minimal aeolian accretion, which does not regenerate in the same place after storms, but instead is gradually shifting landward.

The relief of all shore slopes tends to adapt to the prevailing wave conditions and the amount of available sediment. The profile of the shore slope is very poorly adapted for storm conditions, when wave energy considerably exceeds the mean level, and so it rapidly obtains a gentler slope, at the expense of material from the upper part of the slope. Under low-energy wave conditions, the shore slope regains its previous condition, with a gradual landward movement of sediment, thus making the profile as such steeper and in better equilibrium with the hydrodynamics of low-energy wave action (Rijn 1998; Komar 1998). Immediately after the end of maximum storm intensity, accretion of mobilised material begins on underwater bars. In the first year after the storm, beach face, back beach and foredune usually regains 30–50 percent of the lost volume, and during the 3–4 years that follow, the profile stabilises completely. However, if the storm-free period continues, the supply of new sediment falls off, while the reworking of beach sand into aeolian landforms continues. As a result, 4–5 years after the storm, the beach profile may become steeper and the volume may fall off. Evidence of this is seen in the reduction observed in 1998 and 1999. In 2000 and 2001, after the storm of December 1999 “Anatoly”, beach recovery was particularly rapid, since in many places the foredune had been wave-washed, thus mobilising a considerable amount of material, which had for a brief interval been removed from circulation, contributing to aeolian accretion. After the storms of autumn and winter 2001/2002, beach recovery in the Gulf of Riga and the Irbe Strait is occurring much more slowly. Several major storms and several relatively minor storms were observed during the season, which have possibly led to the transport of sediment further down the underwater slope than would ordinarily be the case.

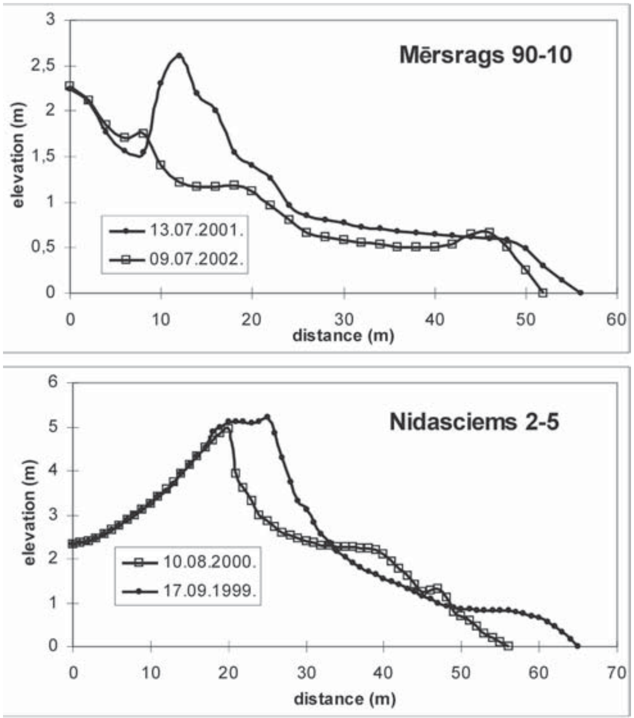

Fig. 7. Changes in the relief of the exposed shore slope brought about by a major storm, observed in the transects *Nida 2–5* (1.0 km N of the border with Lithuania) and *Mērsags 90–10* (1.2 km NE from the top of Cape Mērsrags). Location – see Fig. 1.

CONCLUSIONS

The volume of beach sediment along most of the analysed transects remains fairly stable in the long term, so that the cumulative values for ten or more years are much lower than the short-term fluctuations possible within one year or even one season. Beaches and foredunes in Latvia are characterised by periodic, short-term volume fluctuations, resulting from storm events.

The development of aeolian relief is also very largely dependent on the wind regime. Regardless of the total sediment budget of each particular coastal cell, aeolian processes become significantly more active in the first years after each major storm, and this also occurs in those cells where the storm has not done any damage to the shore and/or coastal relief. This points once again to the importance of longshore transport (particularly in the Irbe Strait).

The length of the time series used in the study (10–13 years) cannot be regarded as sufficient for identifying large-scale cyclic or other systematic regularities in the dynamics of sediment distribution. Since the establishment of levelling transects, only two major storms have been recorded in each coastal section, and the reaction of the coastal system to them differed markedly, so the results of the study cannot be absolutely generalised in order to draw far-reaching conclusions, and only indicate the main trends in the sediment budget (Table 2).

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