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COASTAL DEVELOPMENT OF DAUGAVGRĪVA ISLAND, LOCATED NEAR THE GULF OF RIGA

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Natural as well as anthropogenic processes impact greatly sensitive coastal areas all over the world. The spectrum of natural processes involved can be classified as meteorological, geological, marine, and lithodynamic. The Baltic Sea with its Gulf of Riga is an area in which combined sea erosion and accumulation processes, as well as alluvial processes, play significant roles in the coastal development. Major anthropogenic processes include impacts from ports and coastal protection structures, such as Riga Port hydraulic structures, fairway channels and coastal defence items. During summer also additional pressure of recreational activities has increased the effect on the coastal beach. Levelling data, historical cartographical material and beach sedimentary material granulometric analysis were used to describe natural and anthropogenic effects on development of the coastal beach of Daugavgrīva Island.

Key words: *coastal erosion, accumulation, levelling, the Gulf of Riga, granulometric composition.*

INTRODUCTION

Coastal areas are dominated by sediment accumulation, and neighbouring areas usually are used as playgrounds for recreation, tourism, and various sporting activities. Consequently, coastlines are densely populated and sometimes they are close to urbanised areas. Despite the growing anthropogenic influence on coastal environment, however, our understanding of the relationship between human actions and physical processes is insufficient (Nordstrom, 2000). Physical drivers of coastal change (sea level rise and storm frequency/magnitude) promote inundation and erosion (Webster *et al*., 2005; Bindoff *et al*., 2007). These effects may now be unfolding in locations where increased frequency of high magnitude events (storms) have reduced or eliminated dune volumes, and the lag time between events has not been sufficient for dune recovery to occur (Houser, 2009).

The Baltic Sea coastline in Latvia is about 497 km long (Eberhards and Lapinskis, 2008). There are ten ports in the coastal zone of Latvia and several small piers with no ports. Presumably due to a continuous relative rise of sea level and anthropogenic structural impacts on the coastline, the erosion has occurred in previously stable sections. Beaches are affected and the volume of sand previously accumulated in the foredune belt is decreasing. Environmental management is needed to achieve geological sustainability. It has been suggested that port structures are the main reason for observed changes in coastal processes during the 20th century (Eberhards and Saltupe, 1995). From 1987 to 2011, a monitoring system was established with several stations in the Latvian coastal zone, which made it possible to evaluate the resulting changes over years and after storms. After repeated coastal zone survey mapping and measuring results it is possible to clarify existing trends as well as develop possible scenarios for the coming decades (Eberhards and Lapinskis, 2008). The impact of global climate change phenomena to local meteorological factors also plays a yet convincingly undetermined role to the distribution of erosion and accumulation. In general: winters have become milder and shorter, the amount of precipitation has increased, and storms have become more intense.

Coastal erosion significantly affects coastal areas of the Baltic Sea and protected natural areas. According to Eberhards (2003), erosion is an issue for 62% of the total coastline length. Three coastal areas can be identified according to the intensity level of erosion (Fig. 1). Most threatened are the coasts of the Baltic Proper and southeastern part of the Gulf of Riga. The level of risk of erosion and flooding depends on shoreline exposure to strong winds during storming, incoming wave height and direction of winds, corresponding changes in water level as well as coastal geology (the type of sediments or sedimentary rocks exposed on the coastal slope) (Eberhards and Lapinskis, 2008). One of the fundamental properties of a coastline is its sediment composition; it is rarely composed of one type of sediments. Grain sizes may vary from pebbles to coarse and fine sand, silt and clay; densities show variation from

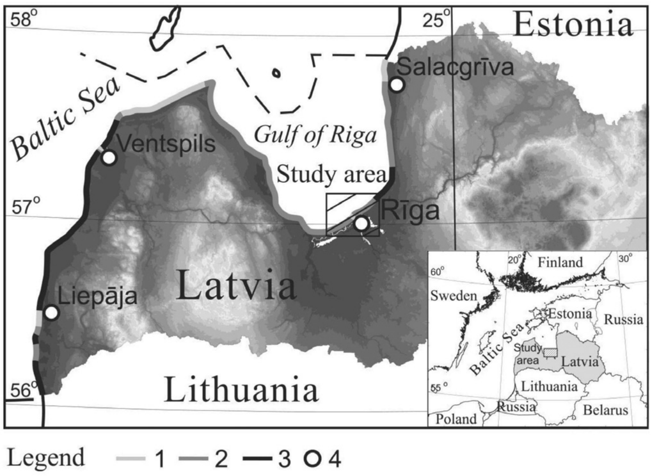

Fig. 1. The erosion risk zones of the Baltic Sea coast of Latvia (based on Eberhards and Lapinskis, 2008): 1 – high; 2 – medium; 3 – low risk zone; 4 – main coastal cities.

about 1.6 kg·L^{-1} for certain carbonates to heavy minerals as dense as cassiterite (7.4 kg· L^{-1}) (Koomans and de Meijer, 2004).

Humans modify beaches and dunes by (1) building structures on them; (2) extracting resources from them; (3) walking or driving on them; (4) modifying the surfaces to accommodate recreation; (5) redistributing sediments to remove storm deposits; (6) creating landforms and planting vegetation to increase levels of protection or restore habitats; and (7) altering surfaces to remobilise stabilised landscapes (Jackson and Nordstrom, 2011).

Anthropogenic activities are transforming coastal areas, including beaches, protected natural areas and environmental conditions in the sensitive zone, which need not be controlled. Detailed research of anthropogenic impact and analysis of historical data needs to be conducted to develop preventative actions, mitigate impact, and predict geological (erosion, accumulation) risks. Actions include monitoring of sea level changes and aeolian processes to assess actual or suspected risks. Full-scale research is on a transboundary scale, e.g., the European MAST-III project SAFE (performance of soft beach systems and nourishment measures for European coasts), which is focused on the problems of coastal retreat (Hamm *et al.*, 2002). This project aimed at the establishment of new methodologies for solving present problems and attempted to gain improved insight in the processes acting in the coastal zone for a better understanding of future protection (Koomans and de Meijer, 2004).

The studied area of Daugavgrīva Island is located in the nature park "Piejūra". There are two protected natural areas on the island: Daugavgrīva natural protected area (north-eastern part of the island) and Vakarbuļļi natural protected area (south-western part of the island). The island is affected by both natural and anthropogenic factors. The first include overflowing and eroding of the potential foredune zone during storms in a 600 m long coastal section adjacent to the Freeport area, which contributes to the salty sea water inflow into the reeds and lakes located just behind the foredune belt, where the Daugavgrīva natural protected area is located. Such a situation emerged after the storm of January 2005 when the foredune was completely washed out in a 500-m section (Eberhards, 2006). This island is also threatened by associated groundwater level rise and land paludification, as well as overgrowning with shrubs (Vimba and Kalvišķe, 2007).

Another factor threatening the nature park "Piejūra" is intensive recreational load. This impact is especially significant to dune forests and open dunes. To reduce the effect of this factor it is necessary to create suitable infrastructure for recreational purposes, as well as to control construction works close to the coastline. Anthropogenic pressure has considerably intensified in Latvia since 1991 when independence was gained and many coastal zones became open to civilians, with reduction of limitations and access. Chaotic development began in some parts of the coastal areas, as living near the seashore was considered being prestigious. This obstacle, catalysed by the lack of effective environmental management, raised various risks to coastal ecosystems. Continuous dune destruction and sand-supply deficit or vice versa are detrimental to both the protective role of the foredune belt against storm surges and the maintenance of an appropriate coastal sediment budget. The case of Daugavgrīva Island area, the small part of the Gulf of Riga coastline, can serve as a prototype for the situation in similar sandy sections of the southern and eastern parts of the Baltic Sea.

The aim of the study was to analyse coastal development trends of the Daugavgrīva Island caused by natural and anthropogenic factors.

MATERIALS AND METHODS

Maps. Historical information was restored by analysis of cartographic material. Due to the lack of equal scale, cartographic material maps of different scale were used. The base included topographic 1:750 000 maps of the 1930s, Soviet Union 1:25 000 maps of 1961 and 1:10 000 of 1982, as well as remote sensing aerophotography data from 2008. Coastline changes during four different periods were analysed using ArcMap 10 software.

Levelling. Data related to subaerial coastal slope changes of Daugavgrīva Island were obtained from the Latvian Coastal Geological Processes Monitoring (LCGPM) database, and the newest field data for this area were obtained in 2011. A coastal geological processes monitoring network was started by Eberhards and Saltupe in 1987–1990, which initially covered only the coast of the Gulf of Riga. During 1992–1996, a wider network was established with increased density.

Levelling data from Daugavgrīva Island cover the period from 1987 to 2011. Profile lines are oriented perpendicularly to the waterline and stretch across the beach with active aeolian processes. The permanent levelling profile lines were used for sections of the coastline where the widespread beaches and foredunes had developed as aeolian terrains or embryonic dunes. Profiles were spatially grouped in specific sections of the coast. Location of each group was selected to provide information on sediment balance in substantially different subsystems (workstation). Measurements were performed with levellers (laser Leica Sprinter 100M since 2007) using points of known altitude located above the maximum possible storm surge level, once a year in the late summer or fall. In order to obtain sufficiently accurate data, readings were taken at every abrupt change of microrelief and at intervals not longer than 10 m. Measurements were performed on the subaerial part of costal slopes (Eberhards and Saltupe, 1999), cross-section data are available from the University of Latvia LCGPMP database.

Texture analysis was conducted on sediment samples collected from the beach area of Daugavgrīva Island in December 2009, April 2010, September 2010, December 2010, April 2011, August 2011, December 2011, May 2012 and August 2012. One average sample was compiled from samples collected in December 2009 and April 2010. In the spring, sand was sampled from the foreshore and between foreshore and backshore to 20–30 cm depth. About 300 g of wet sand was collected and then combined in one single bag. For each collection site, 13 sand samples were collected; GPS coordinates were recorded for the sites. Additional samples were collected during the period from 2010, when each part of the beach was sampled separately, thus trippling the total number of samples in each of the seasons. In April 2011, a decision was taken to increase the total number of samples taken near the mouths of the Daugava and Lielupe rivers, including the left bank of the Lielupe River (residential territory Lielupe) and the right bank of the Daugava River (residential territory Mangaļsala) to better assess the impact of river sediments to granulometric composition of the beaches. In Mangaļsala, three new sampling areas were created along the coast on the eastern bank of the Daugava River (foreshore, between foreshore and backshore), increasing the total number of samples to nine units. Near the Lielupe River on its western bank, additional samples were collected on Daugavgrīva Island: four samples collected at distance 370 meters (nr. 1–4 in Fig. 2), starting 327 m from the Daugava River western jetty. The other four samples were collected at 940-m interdistances towards the southwest. An additional five samples were collected at 520-m interdistances from each other. The samples were dried for 1 day at 80 °C constant temperature. The dried samples were evenly mixed, and subsampled to a mass of 97.00 to 98.99 g. Then samples were sieved on a "shaker with a stand" for 15 minutes in the laboratory of rock geology at the University of Latvia. Fractions of negligible quantity (<0.16 mm and> 0.63 mm) were combined and illustrative diagrams were created.

Interpolation with ArcMap 10 software was performed using Daugavgrīva Island beach sediment size composition data from the year 2010. Samples were collected from the foreshore and between foreshore and backshore 13 sites in a 8–km section along the coast. Using GIS analysis tools there were considered the dominant, fine-grained (0.1–0.25 mm) fractions, percentages of fractions.

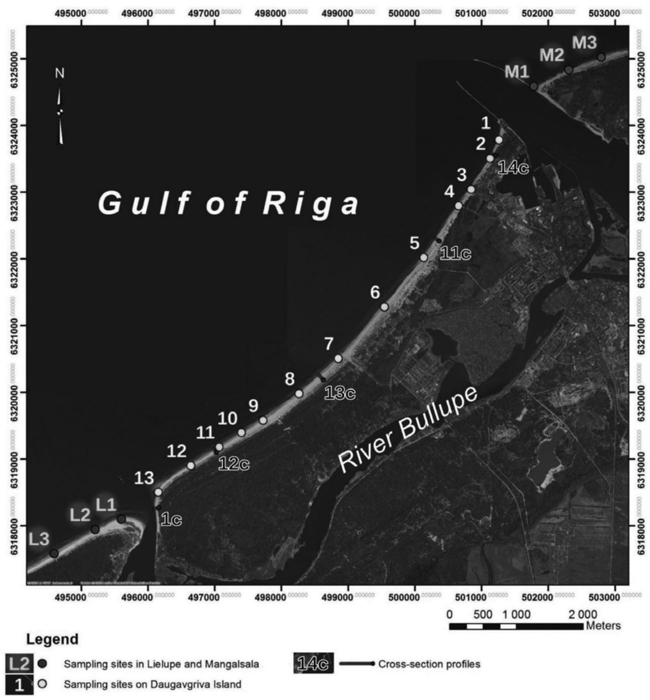

Fig. 2. Granulometric sampling sites and location of levelling profiles in the study area.

Cumulative curves were transformed into frequency spectrum space, or quartiles; the method of cumulative curve construction was used, as it is considered to be particularly suitable for statistical and graphical analysis of sediments from various fluvial processes (Kondolf and Wolman, 1993). The logarithmic graphic method (Folk and Ward, 1957) within the programme rysgran 2.0 was used to determine the mean grain size, sorting and skewness. These parameters are very important in characterizing the processes, especially the grain size, which characterises transportation of the sediment or sedimentation (Blott, 2001).

However, using interpolation with ArcMap 10 there were some difficulties in the visual perception of the result, since it was possible to see only a narrow coloured strip on the maps without detailed quality. This was due to the obvious difference between the length and the width of the studied territory: 1,135 m versus 20–15 m. Therefore, interpolation was finally conducted with Surfer 8. In the inland direction between the low, transitional belt and high beach, each part of the beach was given an inflated width to create a network of isolines that could be easily read and interpreted. Interpolations were obtained with kriging method, by making illustrative maps for different parameters of the samples.

Historical trends analysis. The present-day mouth of the Daugava River formed in 1567 during spring floods, when the river broke a new way to the sea. The new river-bed was shallow, it branched and changed its route regularly. Until the 17th century, the Lielupe River did not directly discharge into the sea, and flowed into the Daugava River through the river Buļļupe. During the spring floods of 1697, ice masses blocked the mouth of the Daugava River and waters of the Lielupe River laid a new river bed to the sea by breaking across the dune zone in the central part of the present day Buļļu or Daugavgrīva Island. A new river bed was formed to take the waters directly to the Gulf of Riga. This discharge route was called the river Ziemeļupe, sometimes the river Jāņupe. This new mouth gradually filled up with silt (Eberhards, 1994) and it existed less than 100 years. As a result, the present day bay of Ziemeļupe formed not far from the coastal dune zone of Daugavgrīva (Fig. 3) on the land side. Daugavgrīva Island formed in 1755–1757 when flood waters of the Lielupe River broke the narrow land zone in the area of the present-day mouth of the Lielupe River.

In the 17th and 18th century (Fig. 3), military infrastructures were constructed in the area of the mouth of the Daugava River and systems of dams were developed. Starting with the 18th–19th centuries, work was carried out to regulate the river-bed and reconstruct it. The Comet Fort dam was built in the period from 1781 to 1783 (Eberhards, 2003). At the end of the 19th century, both of the present day piers of the Daugava River were built, the river bed was deepened, and sand was dumped on the low, swampy islands and river arms up for the needs of the harbour. Along with these changes, the natural flow of the sand drift along the coastline in the direction to the east considerably changed. Rapid accumulation of sand occurred in the shallow zone, extending the land area in the direction west of the mouth of the Daugava River.

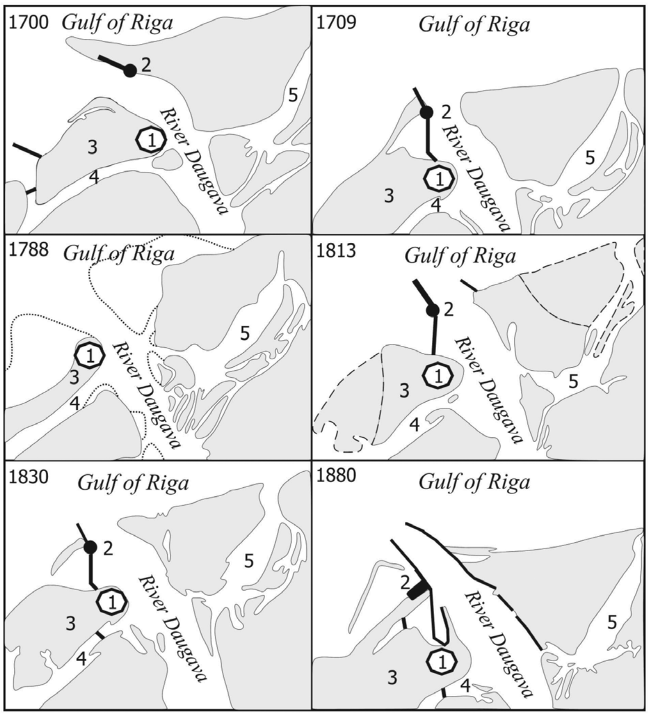

Fig. 3. Change of the Daugava River and coastline of the Gulf of Riga from 1700–1880: 1 – fortress of Daugavgrīva; 2 – fortress of Komēta (Comet Fort); 3 – Daugavgrīva Island; 4 – the river Buļļupe; 5 – previously mouth of the Daugava River; main jetties are marked as black lines (according to Eberhards, 2003).

Decrease in the total load of sediments carried by the Daugava River was observed after the construction of Ķegums HES (1936). After the construction of Pļaviņas (1965) and Rīga (1974) HES on the lower reaches of the Daugava River, the river bed lost its natural features and, changed into a regulated channel with total sediment load 2–3 times lower than the previous natural levels (Ulsts, 1998).

Along the western bank of the Daugava River, the land area of Bolderājas ship repair yard was extended by disposal of building refuse that was then covered with sand. This zone of reed beds with shallow small lakes was filled up, forming dry meadows that are no habitat for several rare species. Now this area is intensively overgrowing with shrubs.

The sewage treatment plant of Riga on Daugavgrīva Island was opened in 1991. During the construction of the discharge dyke of the sewage treatment plant of Riga, a high growing foredune in a 70–80 m broad zone in the central part of the island was completely destroyed (Eberhards and Saltupe, 1993).

RESULTS

During the last 70 years, the coastline in the island's northeastern part of the Daugava River entry has retreated and the former coastal microlagoon has disappeared. The coastline in the middle part of Daugavgrīva Island since the period of 1938–1961 has intensely increased. Later, in the beach area there was little expansion of the coastal zone due to erosion of the northeast part. Since the period of 1938–1961, the Lielupe River entry moved 200 m to the east, and later, in 1982–2007, the coast near the mouth of the Lielupe River shifted a little more than 50 m to the south (Fig. 4).

Leveling profiles. The most characteristic levelling profiles from the years 2002, 2005, 2009, and 2010) were used in this paper.

Cross-section profile 1 (Fig. 5; see location at Fig. 2) shows that in the period between 2002 and 2005, coastal processes had relatively little impact on the parameters of the beach, but a storm on 15 January 2007 caused the coast to deviate by 30 m, resulting in increase of the backshore from 2–25 m by 2009. The new embryonic foredunes present in 2002 were almost completely destroyed by a storm in 2005, and a storm of 2007 destroyed them completely. On 26 March 2010, the bank of the Lielupe River was excavated in order to restore the Lielupe River flowrate, thus reducing the impact of spring floods in Jelgava and Kalnciems and reducing the potential threat to Jūrmala City, which is a very important recreational centre located west of the Lielupe River mouth. After the Lielupe River floods in March 2010, 40–45 m of the beach and dune area was washed away, resulting in the formation of nearly 4-m high

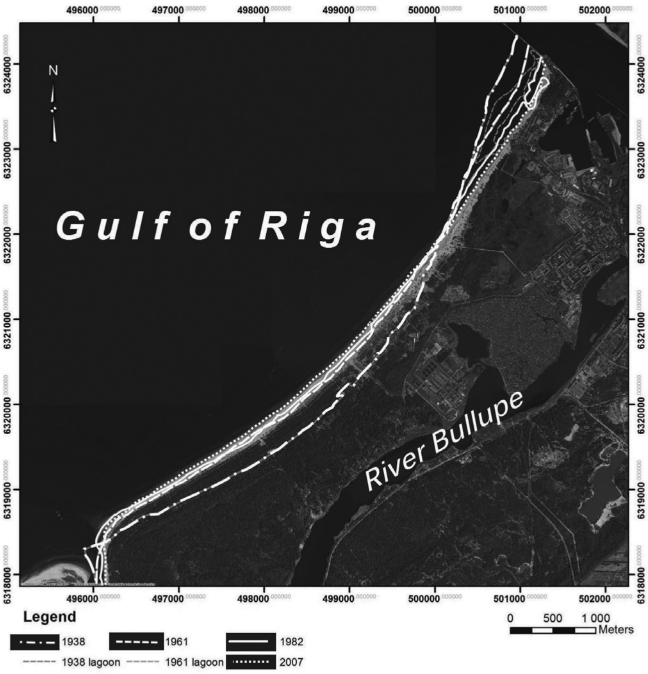

Fig. 4. Coastline changes on Daugavgrīva Island in 1938–2007 according to the analysis of historical cartographic materials.

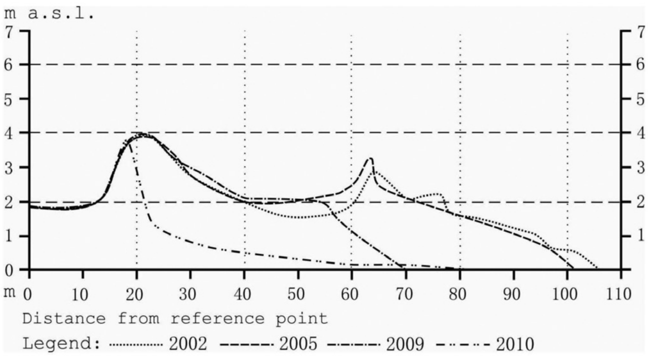

Fig. 5. Cross-section profile 1 (see Fig. 2) near the Lielupe River mouth.

cliffs. By October 2010, the beach area had again increased to the width of 55 m.

The levelling cross-section of profile 12 shows a relatively small positive sediment accumulation rate. The beach at lower parts has height 0.5 m, width of about 20 m, height of backshore exceeds 1 m, width 20–30 m. Measurements made in 2009 showed that the beach expanded by 5 m, which can be explained by storm events in 2005 and 2007, when the dunes were partly washed away and sand accumulation in the high part of the beach took place. A small increase of accumulation occurred in the lower part of the beach in 2010, as it expanded towards the sea by slightly more than 10 m. The foredune only minimally lost volume, and on the backshore embryonic dunes have been slowly evolving (Fig. 6).

Levelling cross-section profile 13 (Fig. 7) shows accumulative effects in the middle part of the coastal area of Daugavgrīva Island. Sand material flows from areas closer to

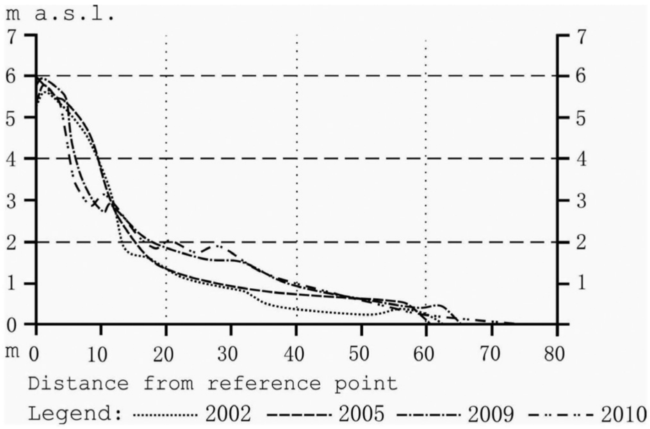

Fig. 6. Cross-section profile 12 (see Fig. 2) approximately 1 km eastwards from the Lielupe River mouth.

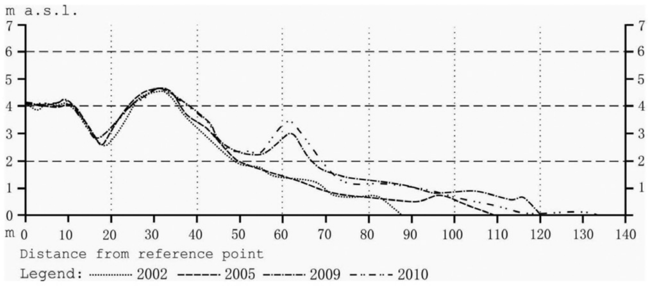

Fig. 7. Cross-section profile 13 (see Fig. 2) approximately in the middle between the rivers Lielupe and Daugava.

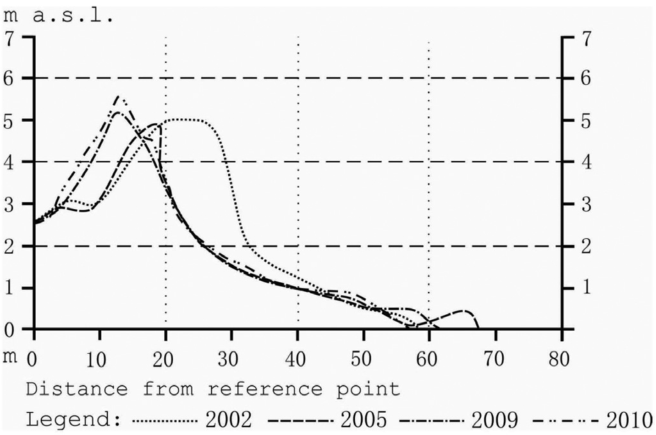

Fig. 8. Cross-section profile 11 (see Fig. 2) 2 km westwards from the Daugava River western jetty.

the Lielupe River mouth, and accumulation has been positive. New embryonic dunes are forming further inland from the foredune.

Cross-section profile 11 (Fig. 8) and other profiles in the direction of the Daugava River, with the exception of the profile closest to the river (profile 14), tend to have a negative budget. A storm washed away most of the foredunes (10 m wide) and the material accumulated in the foreshore. In 2009 and 2010, foredunes had negligible changes, but aeolian accumulation occurred behind the ridge. Coastal slopes after storms have not recovered so it can be concluded that

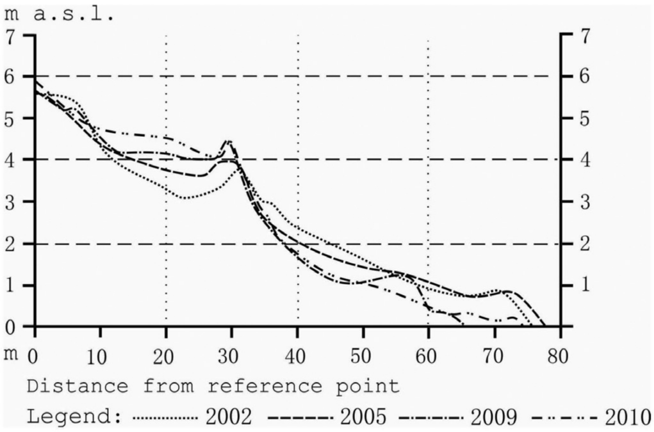

Fig. 9. Cross-section profile 14 (see Fig. 2) nearby the Daugava River western jetty.

here is the beginning of sediment deficit area typical for northeastern Daugavgrīva Island. In general, during the observation period, the amount of sediments in these profiles has reduced. Recreational activities have a high impact on these areas; during summer, huge amounts of visitors visit these areas. Foredunes and vegetation in areas behind ridges are trampled, which causes fordune destruction and intensification of aeolian processes.

Cross-section profile 14 (see location at Fig. 2), located near the Daugava River jetty, showed slight accumulation and increased height, but the width of the beach decreased by 10 m from 2005–2009. The foredune slightly increased in size in 2010 and the beach regained the lost 10 m, but the beach in its middle part became lower in height. The amount of sediments generally has reduced in cross-profile (Fig. 9).

The storm of 2005 left the most devastating effects on the coast of Daugavgrīva Island. This can particularly be seen in cross-section profile 11 near the Daugava River (Fig. 8) and in adjacent profiles. Southwestern and western winds prevailed during this storm. Western winds were the strongest and the maximum wind speed was up to 30 $m \cdot s^{-1}$, duration of the storm phase reached 9 hours.

In the middle of Daugavgrīva Island, storms of 2005 and 2007 did not leave a significant long-term effect — cross-section profile 13 and profiles adjacent showed continuous accumulation of sand, beach expansion and increase of height.

Cross-section profiles 1 and 12 (see locations in Fig. 2) and profiles adjacent to them at the mouth of the Lielupe River were much affected by the storm in 2007. Maximum speed during this storm was 28 $m \cdot s^{-1}$ and storm phase duration was four hours. Hence, the western phase of the two storms was shorter, and maximal influence was from southwestern and northwestern winds. According to the geographical exposition, southwestern winds have greater effect on the coastline near the Daugava River mouth, while northwestern winds affect more the Lielupe River mouth area.

Granulometric composition. The results of interpolation of sediment granulometric composition of the beach sediment indicated five zones in the study area: the Lielupe River or the Lielupe River western coast samples L3–L1 (see the location in Fig. 2), the western part of Daugavgrīva Island or the eastern coast of the Lielupe River (samples 13–9), the middle part of Daugavgrīva Island (samples 8–6), the eastern part of Daugavgrīva Island or the western coast of the Daugava River (samples 5–1) and Mangaļsala or the eastern coast of the Daugava River (samples M1–M3). Interpolation maps reveal both distinct seasonal features and traits characteristic to chronological development. Especially clearly they are seen in the isoline maps of mean grain size.

Granulometric composition of the Daugavgrīva Island beach sand is mainly dominated by fine 0.125–0.25 mm (52%) and middle coarse 0.25–0.5 mm (43%) fractions of sand. The foreshore in all profiles has sand with a greater proportion of coarser grains than between foreshore and backshore.

Beach sediment near the Lielupe River mouth mainly consists (90%) of a fine-grained fraction, up to 0.25 mm, and less than 10% of the soil consists of middle coarse and coarse-grained (grain size above 0.25 mm) sand. The beaches of the middle part of the island are composed of fine-grained (slightly more than 50%) and middle coarse and coarse-grained sand (below 50%). The beach near the west jetty of the Daugava River consists mainly of middle coarse and coarse-grained sand (total > 90%) and less than 10% is fine-grained material, thus indicating that this area is characterised by sediment deficit conditions and that this is the part of the coastal slope where erosion takes place actively. Fine-grained sand dominance near the Lielupe River indicates strong influx of sediment from both the Lielupe River (solid river run-off) and along-shore sediment drift from the sea coastal stream moving along the coast towards the north-east, resultings in predominance of sand accumulation (Fig. 10) in the south end of Daugavgrīva Island.

Characteristics of the mean grain size (Fig. 11A). In the period from December 2009 to September 2012, the mean grain size of the sediment in the Lielupe River was 1.73–2.54 α, which corresponds to medium-grained and fine-grained sand, on Daugavgrīva Island the mean size was 0.68–2.60 α, which corresponds to coarse grained, medium-grained and fine-grained sand. The mean size of grains at Mangaļsala was 0.61–2.09 α, similar to that on Daugavgrīva Island).

Sorting (Fig. 11B). Minimum and maximum mean sizes of grains in samples collected in nine seasons were used to evaluate sorting. On the western coast of the Lielupe River sorting values were 0.26–0.53 α, which corresponds to very well, well and moderate well sorting. In the western part of Daugavgrīva Island sorting values were 0.26–0.57 α, in the middle part of the island: 0.28–0.55 α. In these three segments, minimum and maximum sorting values were similar. On the eastern coast of the island the values were 0.29–0.74

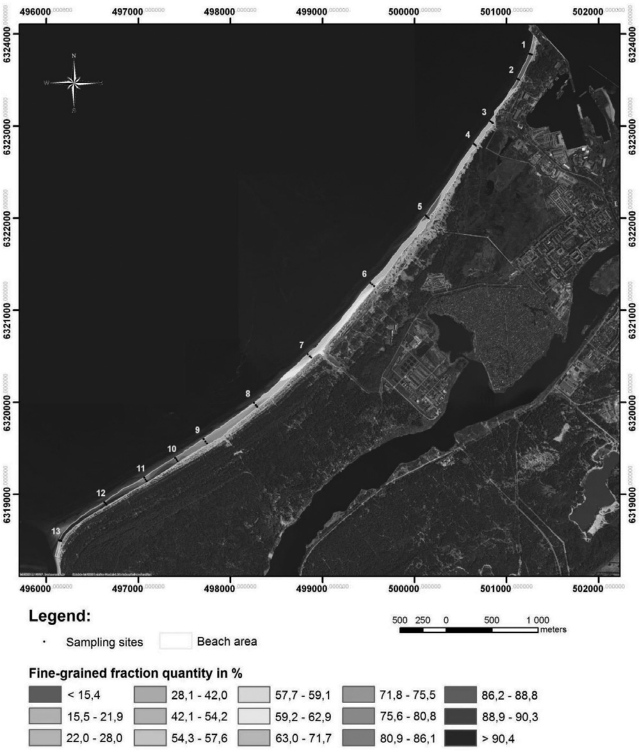

Fig. 10. Interpolation of fine fraction dominance in % in the beach zone of Daugavgrīva Island using ArcMap 10 "kriging" method.

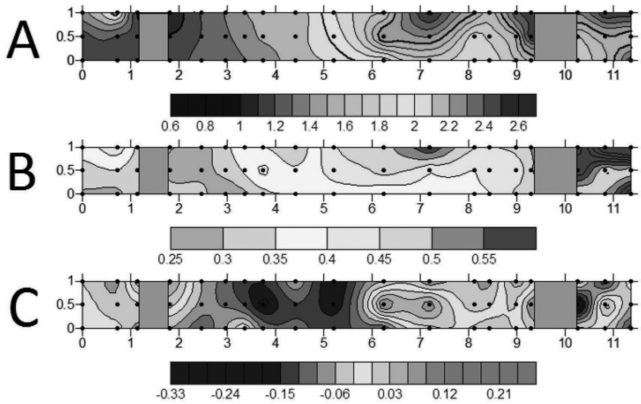

Fig. 11. Interpolation of beach sediment parameters on the beaches of Lielupe, Daugavgrīva and Mangaļsala. (Rivers Lielupe and Daugava are marked with grey rectangles: the Lielupe River is between numbers 1/2; the Daugava River is around numbers 9/10). A – mean grain size; B – sorting; C – skewness.

α (sorting from very well to moderate), where the minimum value was similar to that of other segments; the maximum value was close to the maximum sorting value in Mangaļsala. The sorting values in Mangaļsala were 0.35–0.93 α (sorting from well to moderate); the minimum value was larger than that on Daugavgrīva Island. As sorting values larger than 0.55 α were comparatively few in the territory, and in order to make interpolations easier to be read, they were marked only with isolines with interval 0.05 units.

Skewness. Values of skewness in the study area varied from –0.34 to +0.25. Mapping of skewness (Fig. 11 C) showed that symmetric skewness dominated on both sides of the Lielupe River (samples L1, L2, L3, and 13) and on the western coast of the Daugava River (samples 6–1), while negative symmetry dominated in samples 12–6a.

Samples from the backshore, collected in September 2010 and September 2012, were used to evaluate granulometric distribution in 13 profiles from the mouth of the Daugava River and along the coast to the Lielupe River mouth. Cumulative curves for the backshore (Fig. 12) confirm the interpolation calculations made by "kriging". Profiles closer to the Daugava River have generally smaller a values, indicating that these profiles are characterized by coarser material than those situated more southwest.

Coastal slope changes in a levelling cross-section analysis show that the amount of sediments 0.5 km NE of the mouth the Lielupe River have tended to decrease slightly, in the middle of the island intense accumulation of sediments has taken place, and the north-eastern part of the island's beach near the Daugava River western jetty is a sediment deficit area. Historical cartographic material indicates major changes in the coast line of Daugavgrīva Island during the last 70 years — a section 2 km long in the northeast part has deviated, particularly in a 1-km long area close to the western jetty of the Daugava River, where the coastline has deviated by 500 m. In the middle part of the island, very intense accumulation of coastal sediments has occurred.

The research results show that the Daugava River mouth is a sediment deficit area. The historical map material and levelling cross-section analysis indicate that the middle part of the island's coast is an accumulation zone. Granulometric analysis showed coastal dynamic equilibrium conditions. Cartographical and levelling data analysis identified a zone of coastal erosion near the Lielupe River mouth. Granulometric analysis indicates growth of the beach. Sedimentation flows have been affected three hydroelectric stations on the Daugava River.

DISCUSSION

Coastal slope changes in cross-sectional analysis showed that the amount of sediments near the Lielupe River mouth have much eroded, while accumulation has increased in the north-eastern direction. In the middle of Daugavgrīva Island there is an intense accumulation of sediments, but sediment deficit appears closer to the Daugava River mouth. These processes are affected by storms as well as various causes of anthropogenic origin. Historical cartographic material analysis indicated major coastline changes during the last 70 years — in a section of 2 km length in the northern part, the coastline has retreated by 500 m. The middle part of the coast of the island has been and still remains an area of intense accumulation of sediments. Beach sediment granulometric analysis, cumulative curves and GIS analysis showed that sediments on the beach were coarser in the northeast direction from the Lielupe River mouth to the Daugava River. On both coasts of the Lielupe River, fine grained, very well

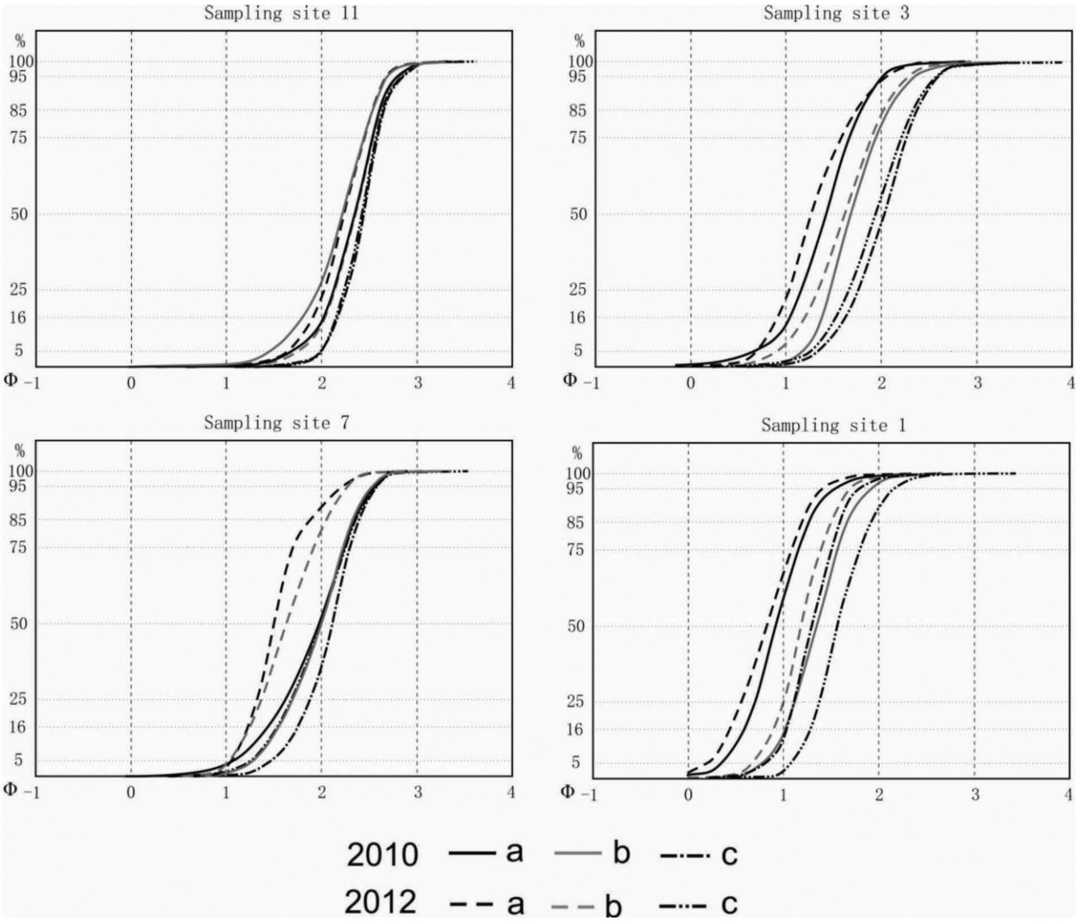

Fig. 12. Cumulative curves for the backshore on Daugavgrīva Island (see profiles 1–13 in Fig. 2) according to log granulometric scale: a – low; b – average; c – high.

sorted sand was characteristic, indicating sediment accumulation; medium grained, well sorted sand dominated in the middle of the island. This indicates stability of processes in this segment of the coast. On either side of the Daugava River dominance of medium grain size and coarse-grained sand was observed. Sorting is also quite characteristic there, indicating higher intensity of water energy causing the coastal erosion. Analysis of the cross profiles of levelling indicated similar division of the study area depending on the dominating processes. The main coastal geological and environmental risks are natural processes, such as dune erosion (storms), global sea level rise in the future, eventual saltwater inflows in protected natural areas and anthropogenic influence — sediment deficit due to uncontrolled construction activities and poor maintenance of hydrotechnical structures. These processes can lead to coastal erosion, trampling of dunes and vegetation as well as sand and dune movement towards the inland areas. Decision makers should ensure risk assessment of projects before giving permission for construction works in coastal areas.

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RĪGAS LĪČA PIEKRASTES KRASTA ATTĪSTĪBA DAUGAVGRĪVAS SALĀ

Pētīta un analizēta Daugavgrīvas salas izcelsme un to ietekmējošie dabiskie un antropogēnie faktori. Darbā izmantoti jūras krasta ģeoloģisko procesu monitoringa dati, analizēts vēsturiskais kartogrāfiskais materiāls, veikta pludmales sanesu materiāla granulometriskā analīze un datu interpolācija. Pētījumu gaitā tika noskaidrots, kuros posmos dominē sanesu akumulācija un kuros — krasta erozija, kā arī tas, cik lielā mērā antropogēnā darbība ietekmē sanesu sastāvu un krasta attīstības procesus. Pie Daugavas ietekas jūrā dominē sanesu deficīts, vidusdaļā — akumulācija, bet pie pašas Lielupes grīvas notiek neliela krasta erozija.