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Influence of hydrotechnical structures on the dynamics of sandy shores: the case of Palanga on the Baltic coast

Vytautas Dubra

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Abstract The aim of the present paper is to survey new tendencies in coastal erosion using the example of the processes observed on the coastal area near Palanga, located on the eastern shore of the Baltic Sea. Due to the groyne that was put into action in the period 1888-1910, the shoreline moved seawards by 500 steps (each 0.7 metres long), and by 1947 it had additionally moved 100 metres. As a consequence of it, a new cape-shaped formation appeared near Palanga. In 1997-1998, after the removal of the under-pier groyne in Palanga, aggressive coastal erosion occurred there. First removed, later the groyne was brought back into the system. Even though the reconstructed groyne is smaller in its dimensions than the previous one, its influence on the coastal zone is evident. An average beach area in the dynamically most active zone of the Lithuanian coast from Birutė Hill up to the mouth of the River Rąžė (Ronžė) widened approximately by forty percent. The final dynamical equilibrium of the shoreline in the investigated zone has not formed yet. The scale of extreme cyclonic atmospheric structures and their recurrence in this region will determine the character of this process.

Keywords *Lithuanian coast, hydrotechnical structures, sand, accumulation, erosion.*

Vytautas Dubra [vdubra@gmail.com], Institute of Maritime and Cultural Landscapes, Klaipėda University, H.Manto 84, LT-92294 Klaipėda, Lithuania. *Manuscript submitted 31 March 2006; accepted 12 June 2006.*

INTRODUCTION

Lately, the rising water level in seas and oceans due to a greenhouse effect and other reasons is a problem that makes the scientists of various countries be worried. Both the general public and various strata of society are shocked by more and more frequently occurring hurricanes, tornadoes, tsunami and other dangerous phenomena. Earlier people eagerly tried to settle possibly nearer the big bodies of water, now it turned out that it was becoming unsafe. In this sense the Baltic Sea coast is not an exception either.

During last centenary the mean sea level in Klaipėda rose by 15 cm. During the hurricanes more and more often extreme water level rises and catastrophic coastal erosion events are observed. It is a very urgent problem for the east coast of the Baltic Sea. Cyclones coming from the southwest side attack sandy east coasts with a very great force. In the course of the previous forty years the highest water level rises were recorded since 1810. The measurements in 1967 were unique when after the century's strongest hurricane in the Baltic region, the sea level in Klaipėda rose up to 185 cm above the zero point of the Baltic Elevation System. The sea level reached and even passed the gauge reading of 150 cm in 1983, 1999 and 2005 too. All the cases mentioned caused enormous damages to the seacoast and infrastructure of the seaside.

In 1997-1998 after the removal of the under-pier groyne in Palanga a focus of aggressive coastal erosion occurred there. The aim of the present paper is to survey new tendencies concerning coastal erosion.

MATERIAL AND METHODS

For many years the Lithuanian shore was investigated by scientific workers of various fields: M. Daujotas (1958), V. Kirlys (1990), V. Gudelis (1998), G. Žilinskas *et al.* (2001, 2003), J. Kriaučiūnienė *et al.* (2006), R. Knaps (1966), and others, but systematic measurements of the coast and its changes were not presented. There are no data of the changes in the mainland part of the seashore either. Presently systematic shore investigations are carried out by the Centre of Marine Research of the Ministry of Environment of Lithuania, by the Lithuanian Institute of Geology and Geography, and by the Klaipėda University Institute of Marine and Cultural Landscapes.

Measurements of morphometric parameters of the beach zone and the protective dune near Palanga were carried out in spring and autumn of 2005 with a mobile DGPS receiver developed by Garmin and supplied with WAAS function, the error of which doesn't exceed 3 metres when operating in the zones that are out of direct reach of the Klaipėda Beacon differential GPS correction station, and 1 m within the zone. The measurements of the coastal line were made when the values of the Baltic Sea level were close to zero on the Klaipėda sea level gauge reading post, that is, they were close to mean multi–annual level. When performing a cartographical estimation of the changes in the configuration of the coastal line the aerial-photo-geodetic 1:10,000 pictures of the coastal zone made in spring 1998 were used. The aerial-photo-geodetic material was chosen namely of that year in order to estimate what damages the Baltic coast near Palanga had suffered when during rather a short period of five years there came two hurricanes there: "Anatoly" (December 3–4, 1999) and "Erwin" (January 8–9, 2005). The latter one is known as "Gudrun" in some other countries. The volume of damages grew after pulling down of the groyne that had been erected in Palanga, under the promenade pier. It was done in 1997–1998, after the rebuilding of the promenade pier ruined by storm in 1993. Changes, when hydrotechnical structures exist and when they don't, can be quite evidently illustrated by using research materials on the aero-photo-geodetic basis (Fig. 1).

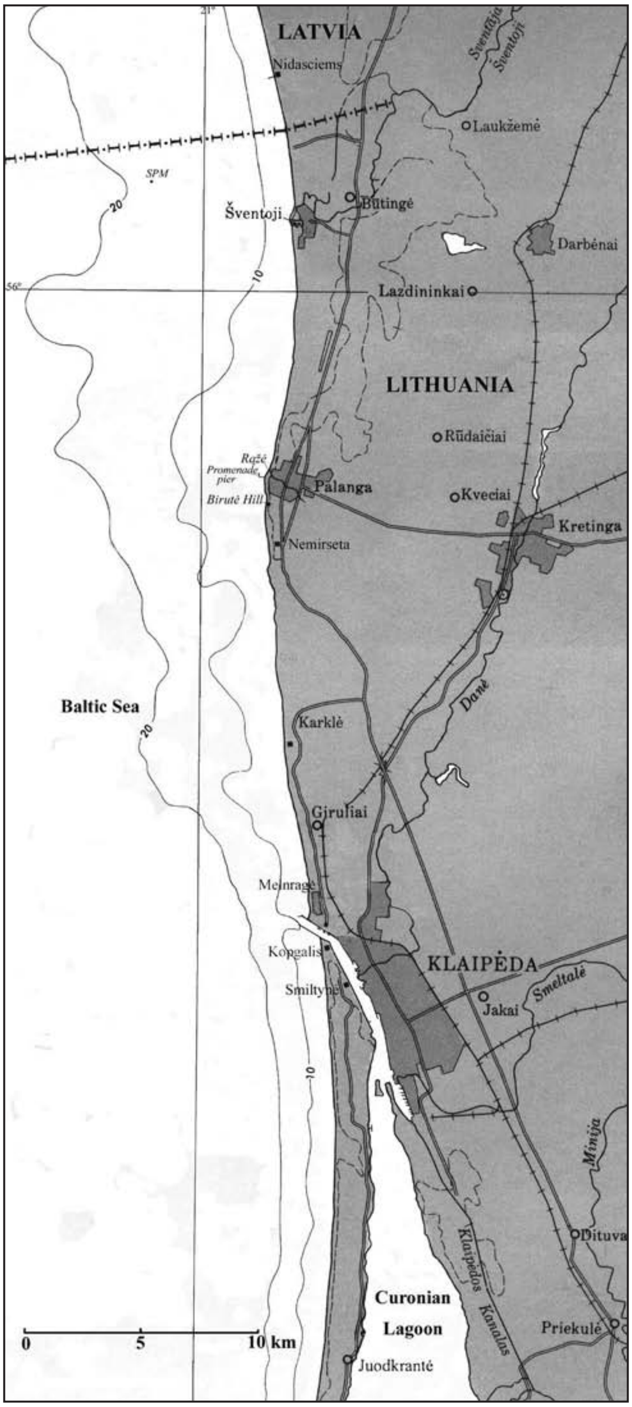

Fig. 1. Scheme of the Lithuanian Baltic coastal area.

HYDROTECHNICAL INVASION ON THE LITHUANIAN SEASIDE

According to the historical information it is supposed that a port was located northwards from the River Rąžė (Ronžė) mouth in Palanga (Kviklys 1992). In 1921 J. Šimoliūnas, after having researched the Palanga near-the-coast sea zone, declared that there seemed to be a stony wall stretching towards Birutė Hill 2–3 metres deep under the water. It was said the stony wall of about 200 metres long closed the port from the east and west, and it was left open only to the northwest direction. This construction began near Birutė Hill, stretched northwards about a kilometre and disappeared near the present promenade pier. There exists an opinion that it could be a pier of the port erected by Englishmen in the seventeenth century (Šimoliūnas 1933). However, the researchers of later period didn't come across this construction.

In 1832 the north breakwater pier of the Klaipėda Port was constructed, and in 1856 the south pier came into being. Later these piers were more than once either prolonged or shortened. Due to the piers sand began accumulating in Melnragė and the shore went seawards by more than 300 metres. After all the reconstructions of these water-engineering structures the shore got stabilized only about 1883 (Elertas 2003).

In 1888 J. Tyszkiewicz erected a pier in Palanga with a timber-piling groyne. At first the construction served as a berth for shipping. After its bankruptcy the pier became a promenade for those visiting the seashore (Žulkus 1999). The groyne caused sand accumulation. In 1888–1910 the seashore line moved seawards by 500 steps (0.7 m long) (Karwowski 1913), and till 1947 it had additionally moved 100 metres (Žilinskas *et al.* 2000).

After constructing port piers in Šventoji in 1925 a sandy promontory occurred near the settlement too – the seashore line moved seawards by 150 metres. The piers influenced the formation of rather broad beaches (ever 100 m wide) to the south of the piers from where the greater part of sediment transports goes. The transported sand formed the promontory. Besides, the wind driven finest sand settles in this zone. Northwards from the mentioned above hydrotechnical structures the seashore was being destroyed and was less stable. Rough sand with shingle and gravel prevailed there.

In 1960–1964 on the basis of the data of long-term research near the Klaipėda dumping place and in some other areas, Rudolfs Knaps, a Latvian hydrotechnician, found out that the near shore streams carrying sand had the northward direction, and that a yearly amount of it was 250–500 thousand cubic metres (Knaps 1966). It was detected by using marked sand and automatic current recorders. Later V. Gudelis stated that a yearly amount of transported sand was 300 thousand cubic metres (Gudelis 1998). It is important to state that the hydrotechnical structures mentioned above stabilize the shore well only in calm periods. During strong gales and hurricanes (the definitions are given after the Beaufort scale) a very high sea water level causes precarious situations. Strong waves, currents and wind result in the deflation processes on the shore (Gudelis 1985). The recent investigations of the Lithuanian mainland coastal area show the decreased volume of the sediment transport. The studies of Žilinskas *et al.* (2003) showed that the budget of continental coastal surface sediments (in a time frame 1993–2003) was negative. The annual loss of sediments from the Lithuanian mainland coast is about 48,000 cubic metres of sand on the average. According to Kriaučiūnienė *et al.* (2006), during the average year the Lithuanian mainland beaches could accumulate 100,000 cubic metres of sediments.

The Palanga case evidently illustrates the influence of hydrotechnical constructions on the processes going on in the zones of sandy shores all over the southern, southeastern and eastern parts of the Baltic Sea coast. Similar processes of coastal erosion are observed in Germany, Poland, in the Kaliningrad Region of Russia, in Latvia, and in Estonia too. Polish sandy shore near Ustka looses a lot of sand and the damages exceed 1–2.3 metres per year. These problems are on the way of salvage by the means of arrangement of groyne fields with further-coming nourishment of the sandy beaches (Florek & Florek 1995). Western coast of the Sambian Peninsula in the Kaliningrad Region of Russia is intensively eroded as well. Here the natural coastal looses reach the mean annual values of 0.3–0.5 metres (Trimonis & Stryuk 2002). From ancient times till nowadays the residents of the Eastern Baltic shore had to fight the sand cast from the sea, coastal erosion and water trying to cut one's way through a narrow peninsula called the Curonian Spit (Kuršių Nerija). Until planting the coasts with trees, bushes and grass plants, sand storms raged not only in the Curonian Spit, but also in mainland areas such as Melnragė, Nemirseta as well. At that time means of strengthening of the shore were being applied, a grand protective fore-dune was being formed, the dunes were being planted both with local and imported plants (Gudelis 1998).

Differentiation of the currents according to the drift direction looks as the following: 55.3% of cases are of the north direction, 35.7% directed to the south, 3.3% westwards, 5.7% of cases bear the east direction towards the coast. The highest current velocities occur to be the one directed northwards and southwards. Due to the cyclonic circulation of air masses and the shore topography the maximum height waves exceeding 4–6 metres occur from southwest, northwest and especially from the west (Dubra & Dubra 1994).

After pulling down of the groyne in 1997–1998, the accumulation of sand stopped, the former excess of it obviously moved along the shore towards Latvia. Beach width narrowed from one hundred to twenty metres in some areas in Palanga, and the bottom of the protective fore-dune is only about 0.5 metres above the mean Baltic Sea level. That's why the waves even of mid-strength can reach and erode the bottom of the protective dune.

Not long after the pulling down of the groyne the hurricane "Anatoly" occurred. The protective fore-dune near the promenade pier in Palanga lost over twenty metres of its width, and the mentioned pier was separated from the coastland. High waves caused considerable damages to the pier itself. After the "Anatoly" a certain amount of stones were brought and thrown down in the place of the former groyne. The process of erosion lessened a bit, but it didn't stop. At the end of 2003 the slopes of the protective fore-dune were covered with tree branches. They protected the fore-dune comparatively well during several storms, but during the hurricane "Erwin" the branch covering was washed off. The protective dune lost round ten metres. In the middle of 2005, after arranging 150 metres long stone construction, the width of beach near the pier began to increase. It's interesting to point that before the World War II a stone barrier near Nemirseta caused the formation of a cape-promontory with approximately 70–80 metres wide beaches. In March 2000 two kilometres southwards from the promenade pier a Norwegian vessel "Star Trader" was thrown onto the beach by the storm. After its salvage operation a heap of stones was left there. Due to sand accumulation caused by this stone heap the beach reached the width up to seventy metres there.

MONITORING OF THE LITHUANIAN BALTIC COAST: PALANGA CASE

Cartographic analysis of the material covering the investigating area showed that the most significant changes in coast configuration appeared after the periods of 1882–1888 and 1997–1998.

The first one was the process of the coastline movement towards the sea because of the construction of the groyne and partly the wooden pier. Both of these constructions acted for intensive accumulation of sand transport. A map issued by the General Staff of Russia in 1874 shows that there isn't any cape-like formation near Palanga (Fig. 2). The investigated area near Palanga should be marked out for the most frequent recurrence of the southwesterly stormy winds. Strong winds and storms are the main factors on which the formation of the coast within the cyclonic circulation depends. In the course of twenty years process of accumulation caused the appearance of a little cape-like formation, the farthest point of which is about 350 metres away seawards from the former water edge (Karwowski 1913). This little cape is visibly evident on the city map of Palanga that was published in 1922 (Fig. 3). In the course of time this new cape didn't change its geometrical form (Fig. 4). It was because of the cyclonic circulation. The most intensive process of transported sand accumulation took place southwards from the newly installed hydrotechnical structure. Northwards from it a little bend in the coastal line occurred. This structure of water engineering had suffered considerable damages during storms of hurricane strength. The greatest damages were made by hurricanes and storms of October 1967; January 1983; January 1993; December 1999; and January 2005.

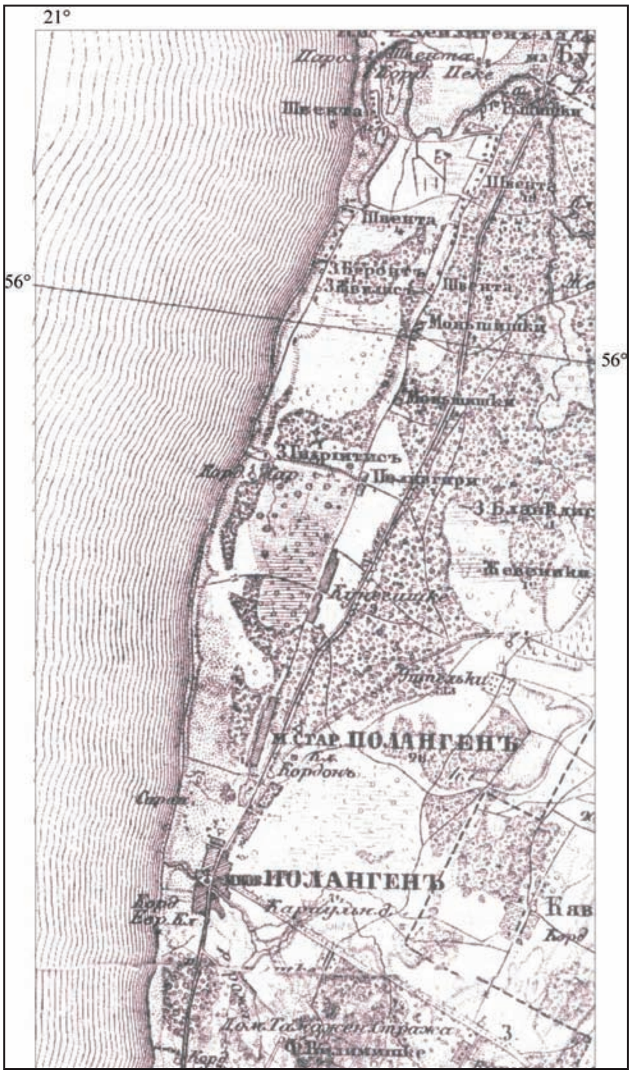

Fig. 2. Map of the suburbs of Palanga issued by General Staff of Russia, 1874 (by the courtesy of the History Museum of Lithuania Minor).

In 1993 winds of hurricane strength so badly damaged the promenade pier that it was decided to put up a new, concrete promenade pier. In the process of construction a groyne between the piles of the new pier was not arranged. The remnants of the former groyne were removed. It turned out that it was a bad mistake what drew a great public attention and caused anxiety. The case provoked discussions on Governmental level. After the removal of the artificial obstacle what stipulated the accumulation of sediment drifting from the south to the north (this direction occurs in 2/3 of all cases) (Dubra & Dubra 1994) all the amount of the accumulated matter moved northwards. It became evident after the hurricane "Anatoly" on November 3–4, 1999. South and southwest direction winds of hurricane strength raised the sea level, and high waves stipulated intensive processes of the coastal erosion. It can be predicted that taking no additional hydrotechnical measures to protect the coast would lead to the situation in which the destructive process will continue until the coastal line reaches its former position similar to that in 1882, when the promenade pier construction was begun. This way Palanga would loose the cape-like peninsula, the area what makes about eighty hectares. Namely at this promontory the greatest changes, in comparison to other zones of the coast, belonging to Lithuania, are recorded. A great amount of sand eroded from the coast and abraded from the protective dune is lost. At approximately eight hundred metres southwards from the Palanga promenade pier the wind has already deflated about fifty metres of the protective dune and it is a halfway towards the park alleys and other urban infrastructure. The course of this process has gained a systematic character. After every storm the coast looses a certain amount of its sand reserve. It is very obvious on the southwest side of the cape shaped promontory. Had no hydrotechnical measures to stop the destructive processes been taken the newly formed cape would have been doomed to vanish from the future cartographic materials. In winter 1999 the very first attempts to rearrange the construction stabilizing the coast were made, but the scale of works was not sufficient to very improve the situation. It was evident after the “Erwin”. The loss of sand was less in comparison to the loss in December 1999. But it could be the consequence of more favourable meteorological conditions. Firstly the strength of “Erwin” was less, the duration of the storm was shorter that during the “Anatoly”. Secondly, the wind was not from south–southwest as it happened to be during the previous hurricane; this tame the wind was only of southwest direction which stipulated a minor water rise near the Baltic coast belonging to Lithuania. In spring 2005 a hundred fifty metres long stone construction was made near the promenade pier. However it is possible that this structure will not completely replace the former sand depository groyne.

Field investigations of spring and autumn 2005 show the coast formation tendencies after a new hydrotechnical construction has been implemented. During the cartographic processing of the data, describing the changes of the Lithuanian Baltic Sea coastline the aerial geodetic photographs (of scale 1:10,000 taken in spring 1998) were used (Fig. 5). It is evident that first the sand accumulation on the beach zone and the sequent widening of the beach due to cyclonic character of the near-the-shore currents circulation have first of all started to the south from the hydrotechnical construction, and the process is still step by step continuing. An average beach area on the most dynamically active zone of the Lithuanian seacoast, from Birutė Hill to the mouth of the River Rąžė (Ronžė), has widened by from seven to eleven hectares. If to take the spring 2005 situation, to the north from the groyne there is a visible seacoast line still being parallel to the protective dune line. Studies in autumn 2005 situation show that a new coastal line shaping like a new small bight has appeared. It could be explained as the influence of the newly mounted construction. As a consequence, the influence zone of the construction turned out to be shorter to the north in comparison to one protected by the previous groyne. It’s clearly seen when strong southwest wind exercises its might northward. At first it was expected that the new water engineering structure would be as long as the newly constructed promenade pier, that it would cover all the length dimension of the promenade under it. If it were so a great amount of sand would be accumulated and the pier itself would be better protected from wave attacks and washouts.

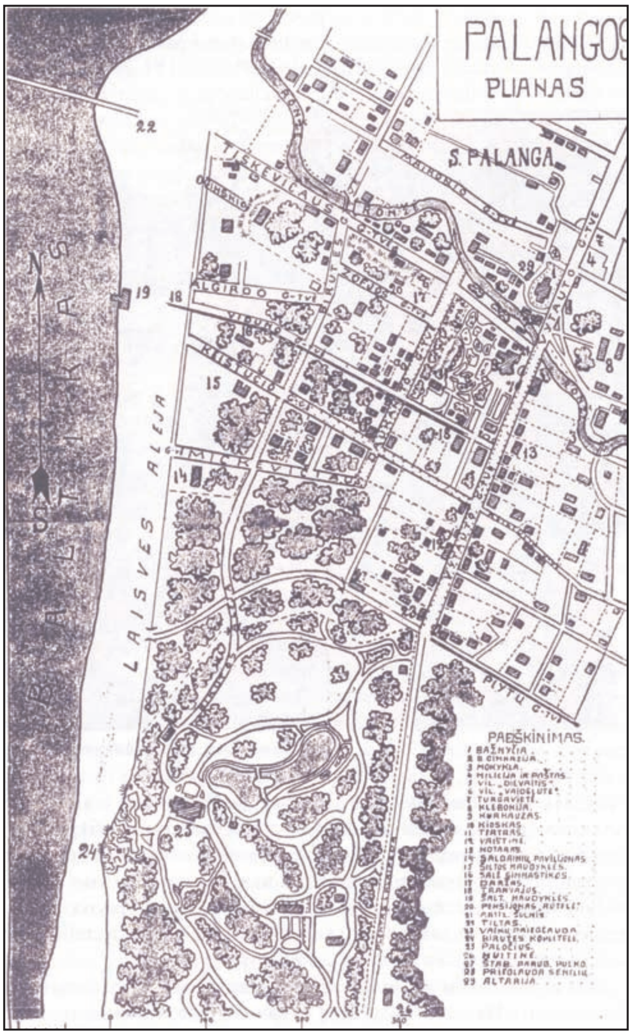

Fig. 3. City scheme of Palanga, 1922 (by the courtesy of the History Museum of Lithuania Minor).

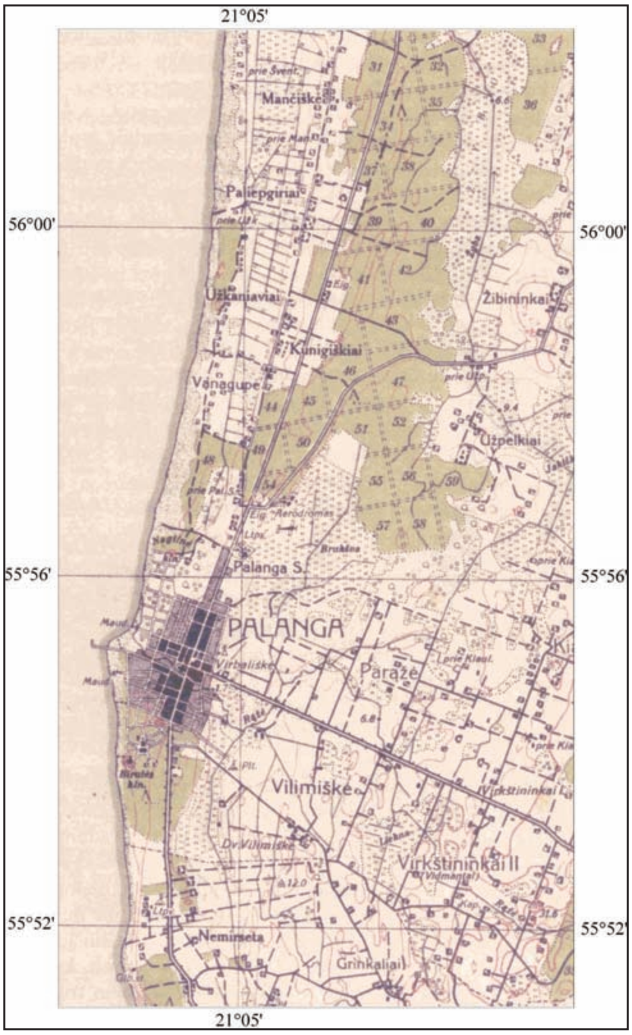

Fig. 4. Military topography map of Palanga, 1939 (by the courtesy of the History Museum of Lithuania Minor).

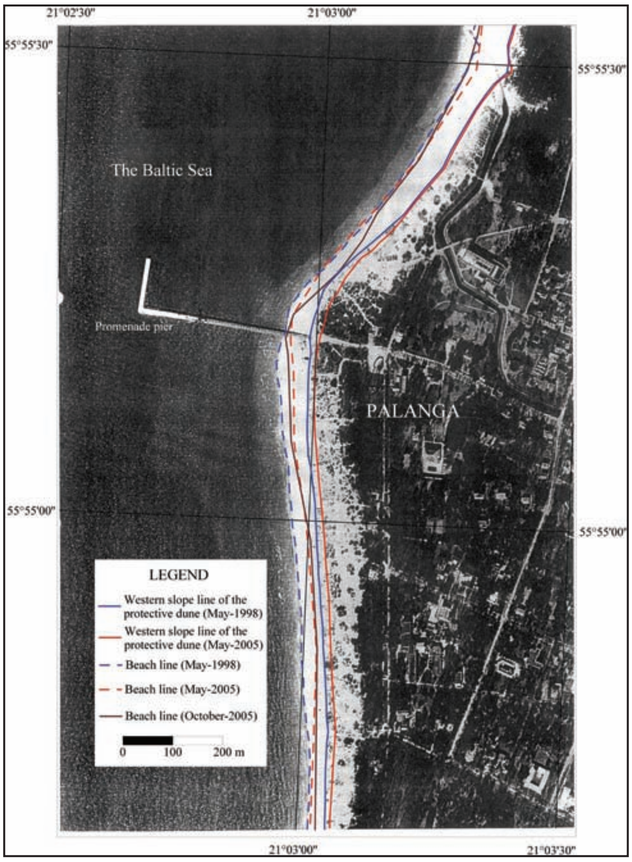

Fig. 5. Digitized aerial photograph of the Baltic coast near Palanga (spring, 1998) supplemented with the latest situation of spring and autumn, 2005.

It is possible that stormy southwest direction winds with strength of 14–17 m/s prevailing in the middle August 2005 have played an active role in the formation of a new bight. The configuration of the coastline of the mentioned bight has not reached the dynamic equilibrium yet and it will be changing in the future. The processes of the sandy coast formation are determined by cyclonic circulation of the atmosphere masses. Cyclonic circulation acted at the most intensiveness during the recent winters of 1999–2000, 2001–2002 and 2004–2005. Due to cyclic tendencies of the natural processes they are occurring at relatively regular periods and are partly repeating the ones from preceded 10–11 years ago. The winter of 2005–2006 partly repeated the weather conditions of the winter of 1995–1996. These seasons could be characterized as the periods of weakened cyclonic activities with frequent anti-cyclonic cold weather conditions. Thus the impact of natural factors on man-made structures was minimized lately. The same refers to the coastal zone, too.

CONCLUSIONS

Hydrotechnical intervention into the natural processes always causes some upcoming changes. A promontory near the Palanga coast has consequently formed due to the implementation of the hydrotechnical means at this coastal area in 1888. An exclusion of any segment out of the system, being characterized as of stable dynamic equilibrium, results in sequential regressive changes in the system. When forcing the coastal and near the coast area with the invasive hydrotechnical means exerting influence on the dynamic equilibrium, it is necessary to implement auxiliary means enabling to keep looking after the construction. Due to regular extreme impact of hydrometeorological factors the groyne constructed at the Lithuanian marine coast in Palanga will undergo more or less significant damages. Prevailing stormy winds of southwest direction cause the cyclonic character of currents and sediment transport in the south-eastern and eastern coastal area of the Baltic Sea. After the exclusion of the hydrotechnical construction from the balanced sea-and-coast system the erosion processes have become prevailing on the coastal part of the newly created cape shaped promontory in Palanga. The removed groyne had to be returned to the system. The reconstructed groyne is smaller in its parameters than the previous one. Still, its influence on the coastal zone is evident. Approximately an average beach area in the dynamically most active zone of the Lithuanian seacoast in Palanga (from Birutė Hill to the mouth of the Rąžė (Ronžė) River has widened by forty percent. The final dynamical equilibrium of the seacoast line in the investigated zone has not formed yet and the scale of extreme cyclonic atmospheric structures and their recurrence in this region will define the character of this changing situation.

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