CHANGES OF BALTIC SEA COAST DURING THE PERIOD BETWEEN 2008 - 2015

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Abstract
The article presents the comparative, descriptive statistics analysis of the changes of the Baltic Sea coast in the territory of the Republic of Lithuania. This paper analyzes the Baltic Sea coast measurements taken during the period between 2008 and 2015. The formation of the strip of the Northern breakwater - Giruliai during this period was influenced by the Hurricane Felix on January 10 of 2015. Describing the Baltic Sea coast strip dynamics trends, the Baltic Sea coastline change during the period between 2008 and 2015 was selected and calculated on the basis of the measurements results. Analysis of the erosive and accumulation processes of the 4 km long strip from the Northern breakwater to Giruliai strip was provided.
The carried out data of the Baltic Sea coast changes analysis show that seacoast limits are constantly changing. The replenishment of the Baltic seacoast spatial data set during the period between 2008 and 2013 with the revised spatial data of the period between 2014 and 2015 showed that during the months of January during the period between 2008 and 2015 the 4 km long strip of the Baltic Sea coast decreased by 3.7075 ha, in the Ist Melnrage area, the 0.7 km long strip of coastline has moved more than 30 m inland. It was found that in the southern half of the researched section erosional processes prevailed, while in the northern part – both erosional and accumulative ones.
Key words: accumulation, spatial data set (SDS), erosion, coastal zone, coastline, shore storage.

Introduction

Article relevance. At present, a broad scientific attention and concern is paid to the state of sea coasts, at the same time and to the Baltic Sea coast, because coasts are strongly influenced by erosion and the situation is growing worse every year.

Lithuanian sea coast line is very short - 90 kilometers, therefore it is particularly important to not only protect the sea from pollution and other negative human activities, but also from the decline of coasts resulting from the natural conditions. Evaluation of the current situation of coasts, change tracking, analysis and trendsetting as well as the finding of problem solutions – is a hot topic.

The Baltic Sea has changed considerably during the recent decades, which is partly due to human influence (Loptien and Meier, 2011).

Human activities, both on the Baltic Sea itself and especially throughout its drainage area, have over the last centuries put considerable pressure on its marine ecosystem (Backer et al., 2010).

The Baltic Sea is highly dynamic and strongly influenced by large-scale atmospheric circulation, river runoff and by the restricted water exchange due to its narrow entrance area (Omstedt et al., 2004).

The Baltic Sea is a small intra-continental, shallow coastal sea under severe human-induced pressures, such as global climate change, excess nutrient release, pollution, ammunition dumping, overfishing, and various engineering-based modifications, including the strong growth of coastal settlement, hydro- and nuclear power plants, massive wind farms, gas pipelines, and various bridge and tunnel crossings (Omstedt et al., 2014).

The anthropogenic impacts are substantial and include extensive nutrient emissions, pollution from toxic substances, fishing pressure and heavy ship traffic. The Baltic Sea hosts a unique ecology, as relatively few species have had the ability to adapt to this low-salinity environment (Jutterstrom et al., 2014).

The Baltic Sea coastal erosion is accelerated by the crosswinds hurricanes and storms occuring at the Lithuanian coasts from time to time as well as by the marine indusry and human-induced factors.

The main reasons for the changes of coasts: reasons of accumulation / abrasion processes of more active coasts - natural processes (water level rise, storms) and human economic activities (urbanization, recreation, hydraulic structures) (Bagdanavičiūtė and Kelpšaitė, 2012). Intensification of abrasion processes primarily affects beaches. These processes narrow their width and decline stocks of sand, beaches become wet and little suitable for recreation. Disappearing beaches fail to protect dunes during storms, coastal sand dunes from waves as well as cliff from offensive flow. As a result, dune ridge or coastal dunes begin to degrade, cliff begins to retreat, deflation areas start to expand. In weaker places of coastal sand dunes or dune ridge breachings begin to form through which the sea water during storms can break into the rear of the coast (Butkutė, 2012).

It was found that the Ist Melnrage at the northern pier is one of the most vulnerable, the most affected by the negative effects of the hurricane. This zone is not only influenced by climate, large undulation, but by the port gate as well. The zone is constantly washed out. Scientists believe that the problem should

be solved otherwise than in the Lithuanian seaside resort of Palanga, where coast scour takes place, and the measure coast rescue – i.e. sand replenishment is applied. The above measure requires a significant investment, and the addition of sand to natural coasts is temporary, as it is done every year. For the Ist Melnrage zone at the northern breakwater scientists suggest solid measures - such as breakwaters, dikes or reinforced concrete and asphalt coast, sand while widenening the coast and designing and installing recreational, active recreation area, cafes and so on (Lietuvos pajūrio, 2015).

There are suggestions not only to deepen the port, but also to change and prolong the gates. Thus, the port will change the dynamics so that erosion will increase. The dredging of shipping channel and the prolonging of breakwaters will allow waves to freely destroy the shores.

The number of hurricanes in the Lithuanian seaside does not increase, however, it is observed that the power of hurricanes and duration are increasing, and therefore the negative effects become more and more difficult to control.

The object of the research is the strip of the Baltic Sea coast from the Northern breakwater to Giruliai.

The aim of the research is to determine changes of the Baltic Sea coast (from the Northern breakwater to Giruliai) during the period between 2008 and 2015, while clarifying and supplementing the spatial data sets of the Baltic Sea coast.

Tasks of the research:

1. To perform the adjustment of the Baltic Sea coast limits of the years between 2014 and 2015 in the strip from the Northern breakwater to Giruliai coast and to make the plan of the Baltic Sea coast limits.

2. To supplement the spatial data set of the Baltic sea coast of the years 2008 and 2013 with the revised set of spatial data of the years 2014 and 2015 as well as to determine the Baltic Sea coast limit changes from the northern breakwater to Giruliai.

3. To analyze and compare the accumulation and erosive processes of the object.

Materials and Methods

Comparative, analytical as well as statistical and logical analysis methods were used for the research.

For the research the following methods were used: field measurements results and information sources analysis, data visualization, and the Baltic Sea coast (from the Northern breakwater to Giruliai) special plan vectorization using a computer program GeoMap 2007.

In determining the Baltic Sea coast strip (from the Northern breakwater to Giruliai) dynamics trends, measurements included the period between 2008 and 2015. The formation of the strip Northern breakwater - Giruliai was influenced by the Hurricane Felix, which raged on January 10 of 2015. Describing the Baltic Sea coast strip (from the Northern breakwater to Giruliai) dynamics trends, selected from the period between 2008 and 2015, the Baltic Sea coastline change was calculated on the basis of results of measurements. This article analyzes erosive and accumulative processes occuring in the area of 4 km from the Northern breakwater to Giruliai Strip.

The prepared spatial data set of the Baltic sea coast is realized for the speed up of the decision-making processes, data collection and analysis convenience as well as visual presentation possibilities of wider range of uses.

Results and Discussion

Characteristics of the Baltic Sea coast

The general Baltic Sea coastline length makes up 8.000 km, of which 2.626 km stretches throughout Lithuania, Latvia, Estonia and Poland. Due to the dynamic formation, the coastal diversity in each Baltic Sea country is different - and here one can find the shifting dunes and sandy beaches, rocky shores, limestone and moraine scars (Ruskule et al., 2009).

Lithuania has the shortest coastline – only about 90 km, which is characteristic for sand beaches and accumulative dunes. Exclusive Lithuanian coast is the Curonian Spit - 97 km (51 km belong to Lithuania) and 3.8 km wide curved peninsula with the highest drifting white dunes in Europe (Ruskule et al., 2009).

In 2001-2002 during the reconstruction works of Klaipeda Seaport breakwaters were extended (the northern breakwater – by 205 meters, the southern breakwater – by 278 meters). It was found that in the closest to the coast breakwater section of the continent, where the coast was relatively stable during the last decade (till the port breakwater extension), after the reconstruction the coast erosion tendencies started to prevail. In the coast of the Curonian Spit, where during the last decade (till the port breakwater extension) in the closest to the coast breakwater section intensive erosion tendencies prevailed, after the reconstruction of breakwaters the coast first stabilized and then silt accumulation trends started to prevail (Jarmalavičius et al., 2011).

Changing nature and climate conditions, strong winds cause significant damage throughout the world and along the European coast, too. For example, the dunes and beaches of Palanga are being increasingly eroded by repeated battering, such as was inflicted during the January 2007 hurricane “Ervin” and this bringing down process has been dragging on for every year up to now (Vitkienė, 2007).

In the coast of the mainland, erosion processes predominated during the period between 2002 and 2007. In the dynamics of the coastline position change, the amount of deposits on the beach and coast negative trends were determined. During the period between 2007 and 2013 accumulation trends already dominated - coastline shifted more to the sea, higher silt content accumulated in the beach and protective beach dune ridges (hereinafter - the dune ridges). During the period between 2002 and 2013 the mainland coast remained relatively stable (except in the strips of moraine cliffs, south Melnrage and coast strips situated north from Palanga Bridge), but accumulation in some coast sections occurred at the expense of the erosion of other coast sections.

The highest accumulation was found on the south side of the Šventoji recreational zone, in Palanga recreational zone and in the southern coast strip as well as in Giruliai – the IInd Melnrage recreational zones. Accumulation processes in Palanga recreational zone occurred only due to the coast replenishment with the sand (Lietuvos pajūrio, 2015).

Spatial data creation of the Baltic sea coast

For the implementation of the research and the determination of the object changes, the measurements of the Baltic Sea coast section were arried out using GPNS receiver *DAP Technologies M9000* with GPNS antenna *SATLAB iSURVEY SL500*. GPNS receiver and antenna were configured by means of the *Bluetooth* connection. RTK mode was used to switch to LitPOS network. 4 km strip of the beach, which is situated from the Northern breakwater to Giruliai, was measured twice: in August of 2014 and in January of 2015 aftermath of Hurricane Felix. The strip of the researched object was divided into 8 sections of 0.5 km each.

The Baltic Sea coastline turning points were coordinated using GPNS receiver *DAP Technologies M9000* with antenna GPNS *SATLAB iSURVEY SL500*. 25S-1522 geodetic point was also recorded, spatial coordinates are as follows: x = 6181097.313; y = 316,799.583; z = 4.55 m (in the LKS-94 coordinate system). The spatial data set of the coast limits was supplemented by the indications of GPNS receiver: the coordinated points of the Baltic Sea coast and dunes.

Table 1

The data of the Baltic Sea coast changes (from the Northern breakwater to Giruliai) from the period of the months of January of the years between 2008 and 2015

Plot No.	Process	Period of 2008 and 2010; area, m^2	Period of 2010 and 2012; area, m^2	Period of 2012 and 2014; area, m^2	Period of January of 2014 and 2015; area, m^2	Period of January of 2008 and 2015; area, m^2
1.	erosion	5599	5862	1093	3408	14644
	accumulation	437	-	761	120	-
2.	erosion	2587	4568	642	3298	8610
	accumulation	1062	-	1241	182	-
3.	erosion	956	4163	147	516	2986
	accumulation	771	-	2022	250	247
4.	erosion	794	4643	-	1757	3908
	accumulation	2007	-	2237	1163	2121
5.	erosion	5957	3289	-	3845	6489
	accumulation	2633	417	5309	131	1888
6.	erosion	1465	4518	73	4254	2866
	accumulation	4854	13	5285	184	2892
7.	erosion	1475	2991	544	4815	2858
	accumulation	3652	395	3083	370	533
8.	erosion	552	3095	674	3394	3758
	accumulation	1837	189	2843	451	1363
In the strip of 4 km, area, m^2	erosion	19385	33129	3173	25287	46119
	accumulation	17253	1014	22781	2851	9044
In the strip of 4 km, the coast area, m^2; increased (+) or decreased (-)		- 2132	- 32115	+ 19608	- 22436	- 37075
Most erodible strip		Plot No. 5	Plot No. 1	Plot No. 1	Plot No. 7	Plot No. 1
Most accumulated strip		Plot No. 7	Plot No. 7	Plot No. 5	Plot No. 4	Plot No. 6

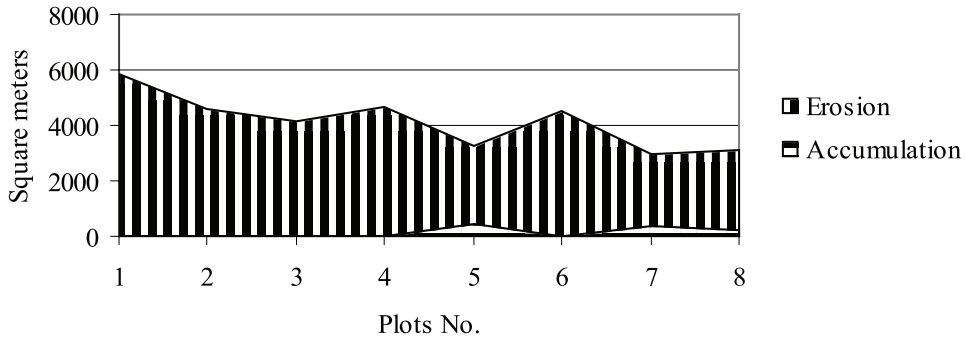


Figure 1. The Baltic Sea coast change during the period between 2010 and 2012, area in square meters.

In August of 2014, in the Baltic coast strip Ist Melnrage – IInd Melnrage – Giruliai, 115 points were coordinated that were received in coordinating the coast limits.

In January of 2015, aftermath the Hurricane Felix in the analysed strip: Ist Melnrage – IInd Melnrage – Giruliai, 438 points were coordinated that were received in coordinating the coast and dunes limits.

For the identification of the coastline the software GeoMap 2007 was used. Using this program ortophoto images were uploaded in the program and the Baltic Sea coastlines of 2014 and 2015 were identified.

For the evaluation of the most damaged and problematic areas the coastline turning points coordinates were determined.

Using the data obtained, the plans of the Baltic Sea coast changes (from the Northern breakwater to Giruliai) of the months of January of the years between 2008 and 2010, 2010 and 2012, 2012 and 2014, 2014 and 2015 as well as between 2008 and 2015, were drawn.

According to the drawn plans, the summary of the Baltic Sea coast changes of the years between 2008 and 2015 (from the Northern breakwater to Giruliai) was made (Table 1).

After calculations, specific areas of the Baltic Sea coast, which are exposed to erosion and accumulation processes, have been determined.

Analysis of Baltic sea coast changes

Based on the above mentioned data of the Baltic Sea coast (from the Northern breakwater to Giruliai), the coast changes diagrams from the period of the months of January of the years from 2008 to 2010, 2010 to 2012, 2012 to 2014, 2014 to 2015 as well as from 2008 to 2015 were created.

It was found that in the period between 2008 and 2010 the Baltic Sea coast erosion was at its maximum in the areas of plots No.1; No.5, the maximum accumulation was in the strips of plots No.6 and No.7.

After analysis, it appears that in the period between 2008 and 2010 the Baltic Sea coast (from the Northern breakwater to Giruliai) erosion and accumulation processes are almost the same: the erosion process made up 53 percent, and accumulation - 47 percent.

During the period between 2010 and 2012 the Baltic Sea coast (from the Northern breakwater to Giruliai) witnessed the rapid erosion throughout the area, especially in the strips of the plots No.1, No.4 and No.6, and a slight accumulation ranged in the the strip from the plot No.4 up to the plot No.8 (Fig. 1).

During the period between 2010 and 2012 from the Northern breakwater to Giruliai dominated erosive processes: erosion process made up 97 percent and accumulation – 3 percent.

During the period between 2012 and 2014 the Baltic

Sea coast (from Northern breakwater to Giruliai) witnessed the rapid accumulation throughout the area, and particularly in the strip from the plot No.4 up to the plot No.7, and erosive processes, as usual, showed up only in the strip of the plot No.1 (Fig. 2).

During the period between 2012 and 2014 accumulation processes dominated in the coast of the Baltic Sea (from the Northern breakwater to Giruliai): erosion process made up 12%, and accumulation - 88%. In January of the years 2014 and 2015, similar erosion prevailed throughout the coast in the analyzed object, except the strip of the plot No.3. During the period of January of 2014 - 2015 erosive processes were strongly influenced by Hurricane Felix. Blurry accumulative processes were observed in the area from the plot No.2 to the plot No. 8. The maximum accumulation was observed only in the coast strip of the plot No.4 (Fig. 3).

In January of 2014 and 2015, erosion processes prevailed in the coast of the Baltic Sea: the erosion process made up 90 percent, and accumulation – 10 percent.

It can be said that during the periods of the months of January between 2008 and 2010, 2010 and 2012, 2014 and 2015 rapid erosion took place, and the 2012 - 2014 year period was characteristic for accumulation processes.

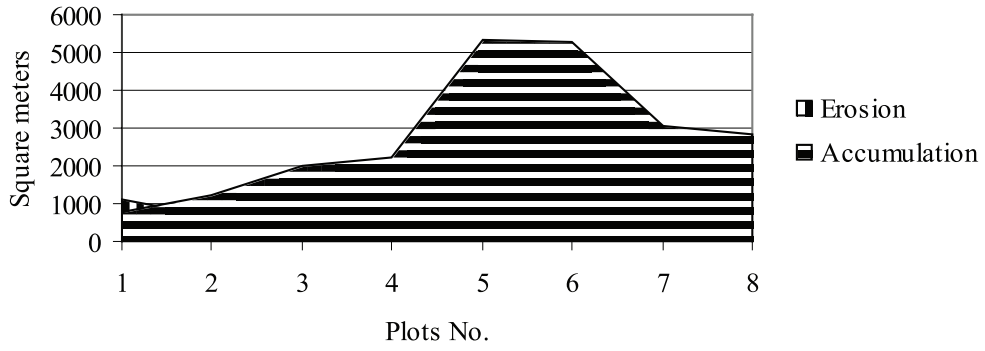


Figure 2. The Baltic Sea coast (from the Northern breakwater to Giruliai) change during the period between 2012 and 2014, area in square meters.

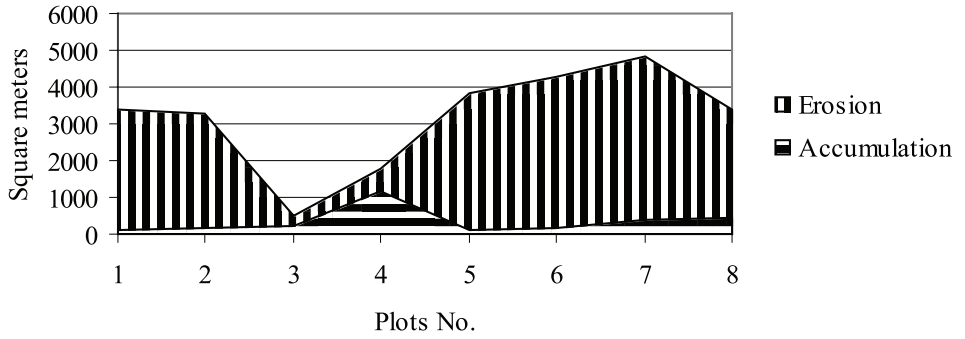


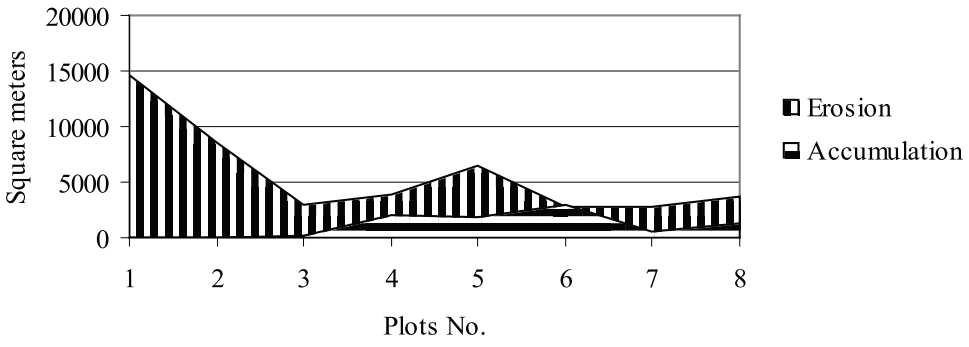
Figure 3. The Baltic Sea coast (from the Northern breakwater to Giruliai) change during the period between 2014 and 2015, area in square meters.

After setting up and analysing the data of all periods of erosion and accumulation processes, the results obtained from the period of January months between 2008 and 2015 showed that coastal erosion (from the Northern breakwater to Giruliai) took place throughout the strip, especially in the plots No.1 and No.2; i.e. in the area of the Ist Melnrage. Accumulative processes were observed in the strip from the plot No.3 to the plot No.8, the maximum accumulation was observed in the area of the plot No.6 (Fig. 4).

After analysis, it was found that during the seven-year period (from the period of the months of January between 2008 and 2015) erosional processes prevailed in the Baltic Sea coast (from the Northern breakwater to Giruliai): erosion process made up 83 percent, and accumulation - 17 percent.

During the months of January of the period between 2008 and 2015, the Baltic Sea washed 2.8194 ha of the Ist Melnrage beach area, in some places of this strip the coast beach area increased by 0.1307 ha. This means that the coast limit moved to the land thus reducing beach area.

In the 0.7 km strip of the Ist Melnrage area coastline has moved more than 30 m inland, and in the 0.4 km strip the coastline shifted from 4 to 14 m into the sea. Comparing the Baltic coast limits from the



Fiure 4. The Baltic Sea coast (from the Northern breakwater to Giruliai) change during the period between 2008 and 2015, area in square meter.

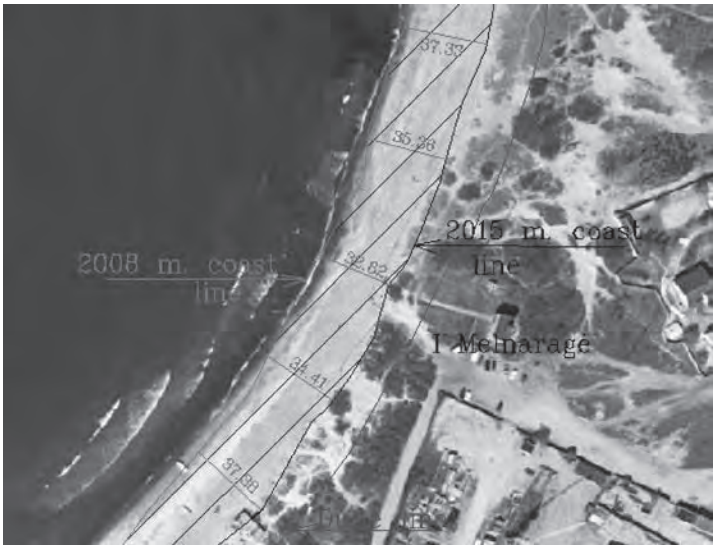


Figure 5. The shift of the Baltic Sea coast during the months of January in the period between 2008 and 2015.

period between 2008 and 2015, it was observed that in 2015 the Baltic Sea coast rapidly shifted towards land (Fig. 5).

With reference to the coast measurements data of the period between 2008 and 2015, it was found that during the period between 2008 and 2015 in the area of the IInd Melnrage beach 1.1 km long strip decreased by 1.9567 ha and the Baltic Sea coast limit in some places has moved 25 m inland, and in 0.6 km long strip in some places of the IInd Melnrage beach was supplemented with sand in 0.6374 ha and the coast limit has moved about 30 m into the sea.

Comparing the Baltic Sea coast limits of the years between 2008 and 2015 in the area of Giruliai, it was noticed that in 2015 the Baltic Sea moved 27 m inland, and up to 14 m – into the sea. In 2015, the area of Giruliai beach decreased by 0.3758 ha in some places, in other places it has increased by 0.1363 ha.

When analyzing the coast measurements data of the period between 2008 and 2015, it was determined that during the months of January of the period between 2008 and 2015 the 4 kilometer long strip of the Baltic Sea coast (the Northern breakwater – Giruliai) has decreased by 3.7075 ha. It can be argued that Melnrage beaches are particularly vulnerable, especially the area of the Ist Melnrage, where there almost no accumulation processes occur.

Conclusions

1. The measurements of the Baltic Sea coast limits from the Northern breakwater up to Giruliai Strip were performed with the help of GPNS receiver "DAP Technologies M9000" with GPNS antenna "SATLAB iSURVEY SL500" in the LKS-94 coordinate system. In the strip of the Baltic coast in August of 2014, 115 points were coordinated, which had been received during the coordination of coast limits and in January of 2015, 438 points were coordinated during the coordination of the coast and dune limits. The Northern breakwater - Giruliai Strip plan was made by means of GeoMap 2007 software in the LKS-94 coordinate system, in the Baltic height system.
2. During the period of the months of January between 2008 and 2015, the 4 km strip of the Baltic Sea coast (Northern breakwater - Giruliai) decreased by 3.7075 ha, in the 0.7 km strip of the Ist Melnrage area coastline has moved more than 30 m inland.
3. During the seven-year period (during the months of January between 2008 and 2015) erosive processes dominated in the Baltic Sea coast (from the Northern breakwater to Giruliai): erosion process made up 83 percent, and accumulation process made up 17 percent.

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