Archives of Hydro-Engineering and Environmental Mechanics
Vol. 57 (2010), No. 2, pp. 105–117

Natural Evolution of Western Shore of the Sambian Peninsula on Completion of Dumping from an Amber Mining Plant

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(Received July 27, 2010; revised August 10, 2010)

Abstract

This article shows how dumping of sediments from an amber mining plant prevented erosion of the western shore of the Sambian Peninsula (in Kaliningrad Oblast). The average annual dynamics of coastal areas in the vicinity of the former dumping site of the amber mining plant is described. Nowadays the erosion is continuing after cessation of dumping. The rate of erosion was estimated by results of regular monitoring measurements, using airborne laser scanning. It was found that about 250000 cubic metres per year of local material is needed every year to prevent further erosion and retreat of the shore.

Key words: dumping, South-East Baltic Sea, coastal dynamics, Kaliningrad Amber Mining Plant

1. Introduction

The Sambian Peninsula is located in the South-East part of the Baltic Sea in the Kaliningrad Oblast, which is an enclave territory of the Russian Federation (Fig. 1). The peninsula is bounded by sea waters and two lagoons – the Curonian and Vistula lagoons. Two clearly distinct sea shores of the peninsula, the western and northern shores, are intensively eroding nowadays, as they did in historical times. Having nearly clear longitude and latitude spread, these shores form a right angle, with the Cape Taran on its tip, and it is the most eroded place at the shore with a steep cliff. Gravel beaches are very narrow (5–10 meters wide), and sand is nearly absent at the bottom slope (Boldyrev et al 1992).

Further from the Cape Taran, a cliff is lower, beaches are wider, conditions are more favorable for recreation. As erosion processes are generally existent everywhere, with varying intensity, the most popular recreation places need to be supported by beach nourishment, and a practical question is how long the results of nourishment will be sustainable.

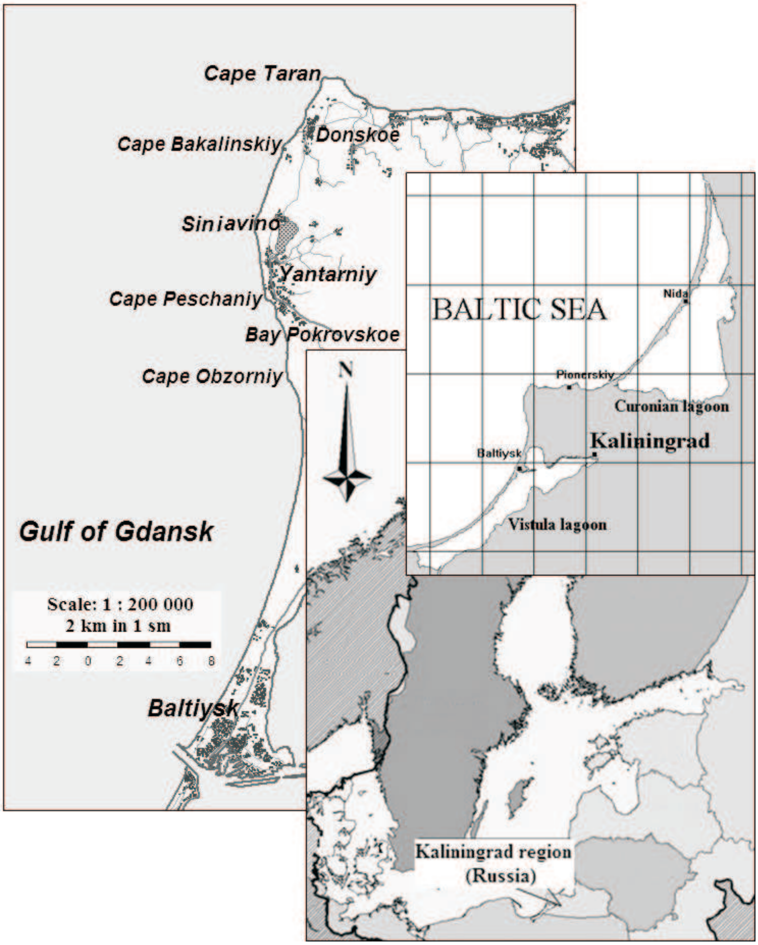

Fig. 1. Western coast of the Sambian Peninsula, the South-East part of the Baltic Sea

In the second half of the 17th century open extracting of amber started at the City of Yantarniy (it was called Palmnicken before the World War II), which is located 10 km southward from the Cape Taran. Nowadays a big enterprise, the Amber Mining Plant, is located there. The amber is extracted in a huge open quarry from a layer of blue clay, which is 15–20 meters underground. The cover sediments which are free from amber, are deposited in the quarry now, but in the past they were dumped at the shoreline. So, this dumping of gob on the beach was, in fact, an example of industrial beach nourishment at the western shore of the Sambian Peninsula.

The aim of this paper is to analyze the consequences of dumping of sediments from amber mining to sandy beaches of the western shore of the Sambian Peninsula, and to estimate the rate of erosion after the completion of the dumping with a purpose to formulate recommendations for beach nourishment to achive shore sustainability.

2. Evolution of Western Shore of the Sambian Peninsula in 20th century

In the first half of the twentieth century, the western shore of the Sambian Peninsula experienced intense destruction and retreated up to 0.3 m per year at the segment between Yantarniy and the Cape Taran, 0.4–0.5 m per year just northward from Yantarniy (between Yantarniy and Sinyavino), and up to 0.1 m per year southward from Yantariy (the Pokrovskoe Bay). Actively abrasion cliffs with narrow beaches of 5–25 meters width were everywhere along 30 km southwards from the Cape Taran (Boldyrev 1999, Bass, Zhindarev 2007).

In 1857, the mine "Anna" was built between Sinyavino and Yantarniy. Sediments of the mine were dumped to the shore to protect the mine from flooding by the sea. Additionally, an earth dam was constructed on the beach, based on wooden pile bowls.

In 1883, the Palmnicken Quarry was set into operation to extract amber by an open technique (Fig. 2). Overburden stripping deposits were dumped to the beach, and, as a result, a slope wash (or dry sandbank of a cone shape) was formed with a maximal width of 200 m. This new shore made from waste soil covered the bed-rock shore and protected the cliff from destruction by the sea at the length of more than 2 km of the shoreline.

A) B)

Fig. 2. The Palmnicken Quarry (Klebs 1883) – (A), and a modern view to the quarry where amber is extracted – (B)

In the years of the second half of twentieth century, the shore also changed a lot. Since 1958, the volume of dumped material into the sea from the beach quarry and main amber quarry has increased due to the introduction of a new hydraulic method of the field amber extraction. Sandy material became dominant in the structure of the dumped pulp.

Waters with suspended solids (the pulp), after separation of the amber due to its floating, were discharged to the marine dam. During the flow across the dam to merge into the coastal water, part of suspended solids (especially larger fractions) were deposited on the dam. It is proved by a change in the percentage of fractions in the samples along the stream of the dumped pulp (Fig. 3).

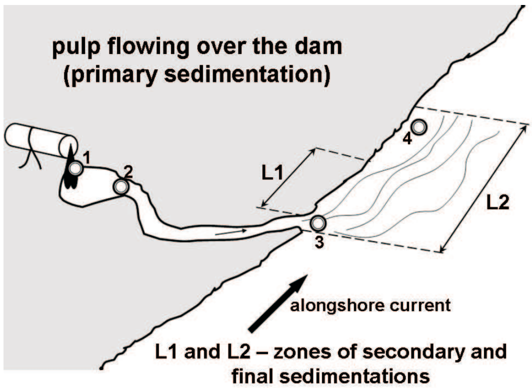

Fig. 3. Scheme of dumping of pulp (and sampling points 1–4) from a pipe line coming from the amber mining to the beach (A), grain size compositions (in %) for sampling points (B) shows the loss of coarse fractions while dumped waters are flowing over the dam (*Determination* … 1994)

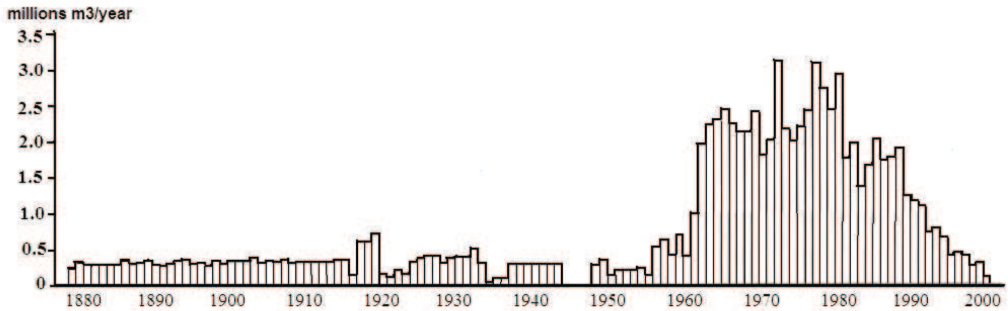

Fig. 4. Dynamics of annual discharge of dumping material from the main quarry of the Amber Mining Plant (Bass, Zhindarev 2007)

A sandy material of 1–0.1 mm grain size constitutes more than 70% in the composition of the discharged pulp. Nowadays, the composition of sandy fractions at the beach varies from north to south, with the tendency of decreasing from 0.8–0.7 mm in the Yantarniy and the Pokrovskaya Bay to 0.4–0.3 mm at the Baltiysk shore. Sediments on the nearshore of the west coast of the Sambian Peninsula are formed essentially by fine-grained sand.

The volume of discharge of the pulp reached an average of 2.5 millions m^3 per year during the period of 1961–1990, when the discharge was the most intensive (Fig. 4). It led to a complete cessation of erosion, and brought a stabilization and accumulation of the shore along the 6 kilometers nearby the place of dumping.

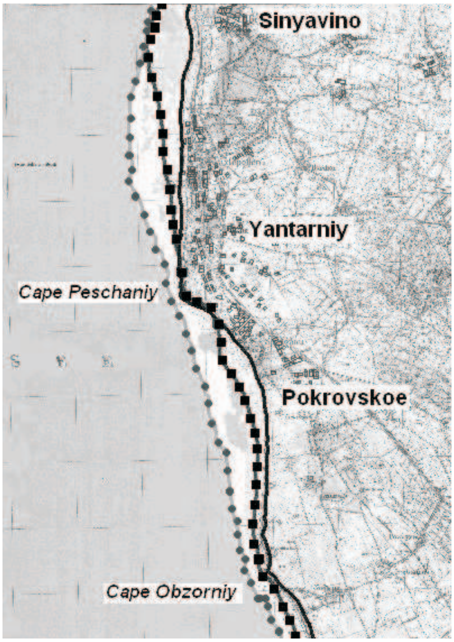

Fig. 5. Changes in position of the shoreline: solid line – shoreline in 1908 (historical map of Palmnicken); line with circular labels is a shoreline in 1992 (Landsat_TM_1992-06-17_Kaliningrad_754); line with square labels is a shoreline in 2005 (GoogleEarth)

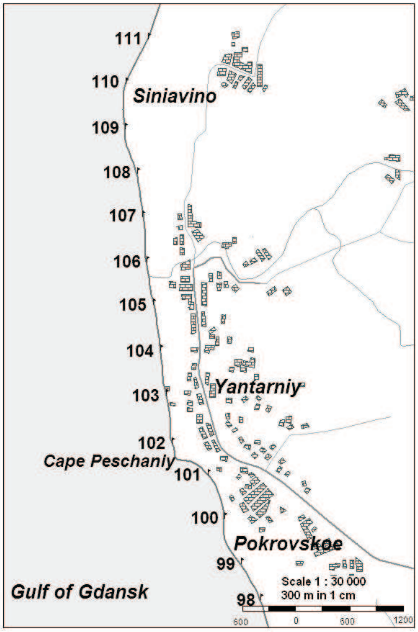

Fig. 6. Ground-based monitoring network of the study area, supported by State organization "Baltberegozastita". Numbers indicate the location of monitoring profiles

During the development of the activities of the Amber Mining Plant, a shallow Bay of Pokrovskoe, which is southwards from the Yantarniy, was quickly filled by dumped material, and the shoreline significantly moved seaward. By 1980, the still active scarp was overgrown with bushes and scrub. In the central part of the bay a sandy beach of a width of 60–70 m was formed, with arched fore-dune ridge of a height of 5–6 meters.

The shoreline moved into the sea in concavities at 200–500 meters in average. The slope wash between Yantarniy and Sinyavino moved into the sea at 850 meters (Fig. 5).

From 1971 to 1995 about 16 million cubic meters of sandy soil was dumped into the sea. This provided a stable state for the shore. The segment where dumping was made (dumping segment) was gradually flattened and slowly shifted to the south. By 1998 the dumping segment was shifted by 1.5 km southward from its former position in 1972.

During the period of amber extracting started in late 19th century, and until the late 20th century, the volume of the material dumped in the coastal zone of the west coast achieved 85 million cubic meters (Boldyrev 1999). Other estimations, by Bass, Zhindarev (2007), give 94.5 million and 107 cubic meters from 1879. Such a mass dumping at the sea is a powerful factor which affected the morphodynamics of the coastal zone. New beaches were formed into two concave segments of the shoreline, and they directly defended the coast for over 10 km (from Cape Bakalinskiy up to Cape Obzorniy). The dumped material migrated southwards, and stabilized the coast over 25 km as well.

After the cessation of dumping of the material from the Amber Mining Plant in the late 1990 s, a growing erosion started at the shore segment of Sinyavino-Yantarniy-Pokrovskoe.

3. Development of the Shoreline in 2007–2008

A modern digital elevation model for the shore of study area (with the accuracy of 20–30 cm) was reconstructed using the data of air laser scanning made in June 2007 and July 2008 (Report 2007, 2008). The scanning accompanied by video recording was fulfilled during air survey at the height of 500 m. Year-to-year dynamics of the beach and fore-dune were estimated using the annual ground-based profiling monitoring (Fig. 6).

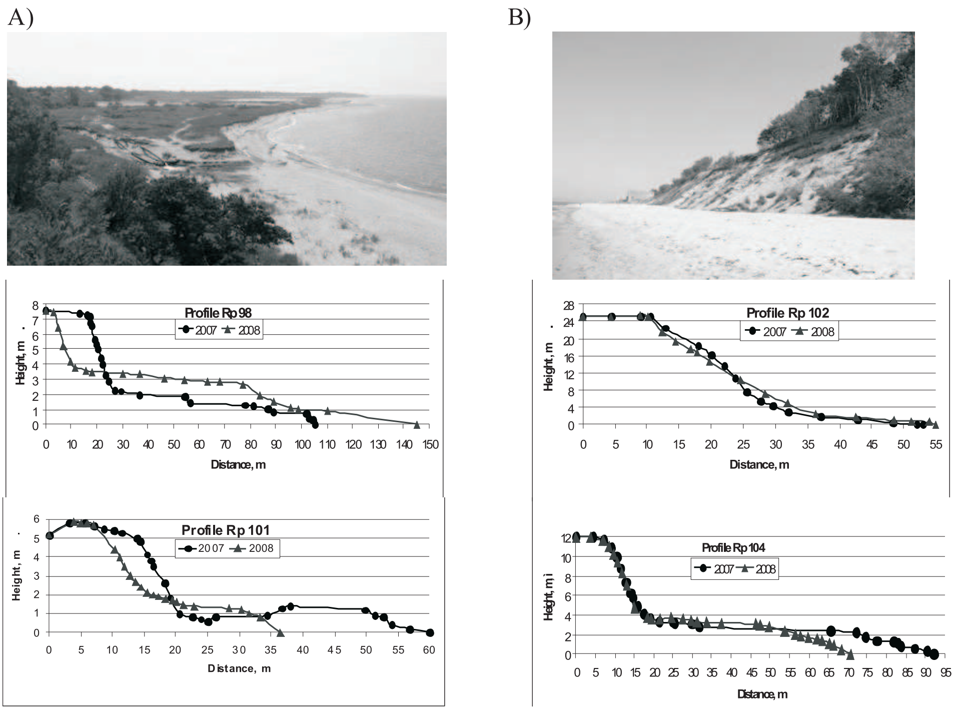

Fig. 7. Views and characteristic altitude profiles for 2007–2008 for the Bay of Pokrovskoe (A) and the cliff in Yantarniy (B)

The maximum retreat of the coast according to the aerial laser scanning is up to 15 meters, and according to the annual ground-based profiling monitoring more than 20 meters per year. The fore-dune in the northern part of the Bay of Pokrovskoe is covered with vegetation, with a pronounced abrasion steep slope (Fig. 7). The shoreline of the Bay of Pokrovskoe (profiles 98–101 in Fig. 6), for the period 2007–2008, was shifted landward by 5–5.5 meters. The width of a beach varies from 30 to 100 meters.

The coastline from the cape Peschanij up to the old beach quarry (profiles 102–105 in Fig. 6) shifted landward in average up to 0.2 meters during 2007–2008 (Fig. 8a). An average beach width varies from 20 to 70 meters. The old beach quarry is now filled by water. The coastline of the sand dam fencing the beach quarry from the Baltic Sea (profiles 103–109 in Fig. 6) shifted landward up to 5.4 meters. The beach width there varies from 20 up to 80 meters.

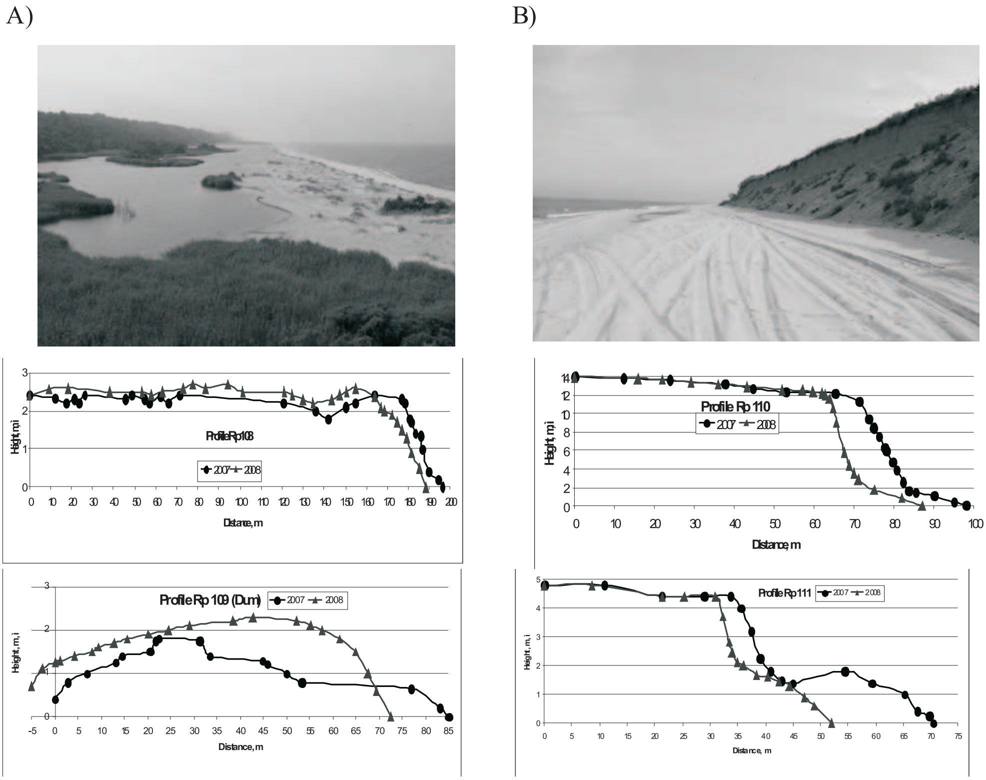

Fig. 8. The old beach quarry filled by water and bounded by a dam from the sea, with observed erosion of the dam (A) and an unprotected beach with a cliff in Sinyavino under permanent erosion (B)

The cone of Sinyavino (profiles 110–111 in Fig. 6) recedes up to 5.1 meters for the period 2007–2008. An average beach width varies from 15 to 20 meters (Fig. 8b).

The total average recession of the shore at the coastal segment Pokrovskoe-Yantarniy-Sinyavino was 3.9 meters for the period of 2007–2008. The beach width varies from 15 to 100 meters.

4. Winds and Storm Regime, June 2007–July 2008

Data measured at the oil platform D6, located at a distance of approximately 30 km from the shore of the Curonian Spit, is the most reliable data set which characterizes the undisturbed wind conditions near the Sambian Peninsula (Stont, Chubarenko 2009). The more than one year data set of hourly wind measurements there shows that the wind regime during the period between the airborne laser scanning (June 2007–July 2008) was dominated by westerly winds, the most probable wind speed was in the interval of 6–9 m/sec (Fig. 9). The wind speeds of more than 15 m/s were observed mainly for winds of the western quarter (repetition more than 60%), the western wind had a maximum repetition (35%), the repetition of the south-west wind was about 18%, north-west, south-east and south winds had repetitions of 10–12%. Strong winds ($\geq$ 22 m/s) came only from the west, north-west and north (1.4%, 0.5% and 0.5% respectively). In comparison with historical 40-years data, the 1-year period (June 2007–July 2008) was characterized by a more strong wind regime (Fig. 9b).

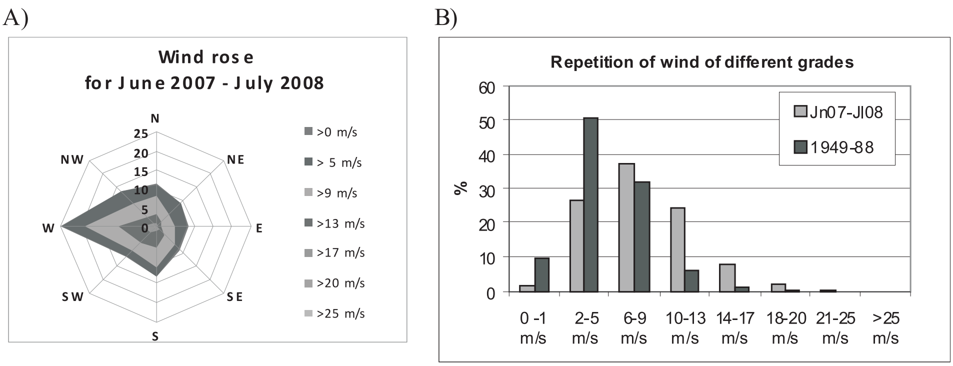

Fig. 9. Wind statistics for June 2007–July 2008 (A) for the off-shore station at the oil platform D6, in comparison with historical wind statistics for 1949–1988 (B)

Considering the conditions when the wind speed exceeded 12 m/sec as a storm, the statistics show that the maximum of storminess occurred during the autumn-winter period (Table 1). There were 7, 9, 10 and 8 storms in September and November 2007, January and February 2008, respectively. A maximum measured wind speed varies between 18 and 25 m/sec, the wind speed in gusts is up to 28 m/sec.

Introducing the conventional value of specific wind 'action' (WA) of dimension of [m/sec $\times$ hour], which is equal to summation of multiplicative pairs of wind speed

Table 1. General characteristics of stormy weather in the period of June 2007–July 2008. Wind speed more than 12 m/sec

Year	2007							2008						
Month	VI	VII	VIII	IX	X	XI	XII	I	II	III	IV	V	VI	VII
Number of storms	2	2	3	7	3	9	4	10	8	4	–	–	3	–
Total duration, [hours]	62	25	36	106	47	195	152	341	195	59	–	–	31	–
Maximum of measured wind speed, [m/sec]	21	17	18	18	22	22	23	25	23	22	–	–	16	–
Maximum of wind speed in gusts, [m/sec]	24	20	20	24	24	26	27	26	24	28	–	–	20	–
Monthly cumulative wind ‘action’, [m/sec × hour]	967	353	496	1499	704	3006	2220	5278	2937	916	–	–	414	–

and its duration for subintervals of the storm ($WA = \sum(w_i \cdot \Delta t_i)$, $i=\overline{1,n}$, w_i is an average wind speed for the i-th time subinterval Δt_i), one can compare different storms, which are characterized by various winds during time subintervals (see Table 2 for detailed characteristics of each storm). The summation of wind ‘action’ for different directions during the analyzed period of June 2007–July 2008 and for every month (regardless the wind direction), gives two diagrams in the Fig. 10, which express the statistical domination of the winds of SW direction (Fig. 10a), and the wind action during different months (Fig. 10b).

A) B)

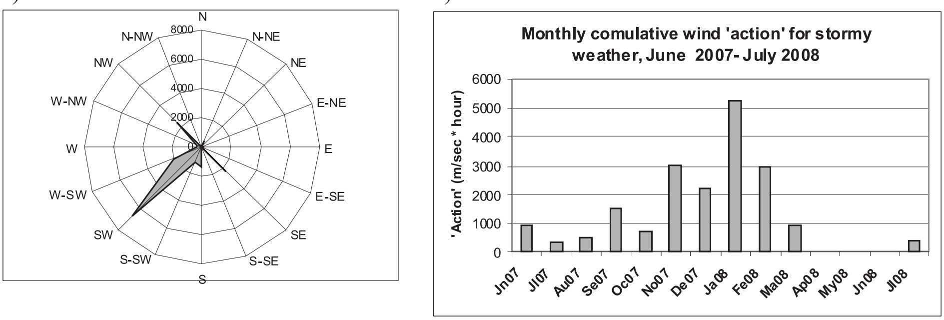

Fig. 10. Total maximal wind ‘action’ during the period of June 2007–July 2008 was observed for storms of SW direction (A), W-SW and NW are other directions for which wind ‘action’ was considerable for this period. The biggest monthly cumulative stormy ‘action’ was for November 2007–February 2008 (B)

The major wind ‘action’ was observed for the period of November 2007–February 2008 (Table 1, Fig. 10b). Due to the storm from SE (01–06.01.08), the wind ‘action’ for January 2008 was nearly 2 times higher than for November 2007 and February 2008. Considering only storms from western directions, the period of November 2007–February 2008 is characterized by 67% of the wind 'action' input. Regarding the whole period from June 2007 to July 2008, the SW direction is characterized

Table 2. Characteristics of wind conditions in the period June 2007–July 2008

Data	Maximum wind speed, m/sec	Duration of the storm, hours					Wind direction
		12–14 m/sec	15–18 m/sec	19–21 m/sec	≥ 22 m/sec	Total	
15–16.06.07	17	10	3	–	–	13	E–NE
27–29.06.07	21	22	11	16	–	49	W–SW
9–10.07.07	17	6	7	–	–	13	W
24.07.07	15	11	1	–	–	12	SW
31.07–01.08.07	17	5	2	–	–	7	W
25.08.07	14	14	–	–	–	14	SW
27–28.08.07	18	9	6	–	–	15	W–SW
01.09.07	17	3	5	–	–	8	NW
2–3.09.07	17	16	7	–	–	23	SW
14–15.09.07	16	4	1	–	–	5	SW
15–16.09.07	24	6	8	2	1	17	NW
19.09.07	18	5	5	–	–	10	NW
20–21.09.07	16	27	2	–	–	29	SW
28–29.09.07	14	14	–	–	–	14	E
08.10.07	14	11	–	–	–	11	NW
11–12.10.07	17	2	12	–	–	14	SW
12–13.10.07	22	11	8	2	1	22	N–NE
1–2.11.07	16	24	8	–	–	32	SW–NW
3.11.07	19	1	10	4	–	15	SW
5–6.11.07	18	9	19	–	–	28	S
7.11.07	19	2	5	4	–	11	S
9–10.11.07	19	5	3	1	–	9	S
10–11.11.07	22	2	5	2	1	10	NW
25–26.11.07	18	12	24	–	–	36	S–NW
27–28.11.07	19	7	19	1	–	27	NW
28–29.11.07	17	12	15	–	–	27	SW
3–4.12.07	22	13	9	5	1	28	S–NW
5–6.12.07	15	23	2	–	–	25	SW
7–8.12.07	21	6	36	2	–	44	S–SW
27–31.12.07	16	49	6	–	–	55	SW
1–6.01.08	20	33	72	20	–	125	SE
8–9.01.08	16	5	15	–	–	20	SW
10–11.01.08	16	21	3	–	–	24	SW
13.01.08	17	12	3	–	–	15	W
15–16.01.08	17	23	11	–	–	34	S
19.01.08	20	6	14	2	–	22	S–SW

Table 2. Continued

22–23.01.08	17	6	11	–	–	17	NW
24.01.08	16	17	3	–	–	20	SW
25–26.01.08	25	6	2	5	6	19	SW–W
26–27–28.01.08	20	12	28	5	–	45	SW–W–NW
31.01 & 1–2.02.08	20	35	16	2	–	53	SW
03.02.08	17	7	9	–	–	16	SW
14.02.08	18	12	6	–	–	18	NW
15.02.08	18	5	3	–	–	8	N–NE
21–23.02.08	23	10	21	3	3	37	W
24–25.02.08	17	12	16	–	–	28	SW
27–28.02.08	21	8	7	9	–	24	SW–W
29.02.08	15	10	1	–	–	11	SW
2.03.08	19	4	7	2	–	13	NW
6.03.08	22	4	9	9	1	23	SW
21.03.08	15	12	2	–	–	14	SE
28–29.03.08	13	9	–	–	–	9	SE
10.06.08	14	10	–	–	–	10	SW
11.06.08	15	14	1	–	–	15	SW
23.06.08	16	4	2	–	–	6	W

by an absolute maximum of the wind ‘action’, while W-SW and NW are two other directions which are characterized by the relatively big wind ‘action’.

The most significant erosion of the shore near the Yantarnyi occurred in the period from November 2007 to February 2008. By the spring the number of storms had decreased, in March, only 3 storms were observed with a duration of less than one day, but with wind gusts of 28 m/sec. In April–July 2008 another 3 storms were observed only (all of them in June 2008), which led to the restoration of the broad beach before the holiday season.

5. Concluding Remarks

Many years of dumping of sediments by the Amber Mining Plant on the shore near Sinyavino, Yantarniy and Pokrovskoye led to the reclamation of this shore segment. Significant accumulation of a sandy material in the natural concavity of the coastline occurred, and was followed by the appearance of small dunes (2–4 lines) at the foot of the former highly eroded cliffs (Fig. 11).

From 1958 to 1972 (14 years) about 35 million m^3 of sands material were dumped on the beach near Sinyavino, and the shoreline moved seaward by 850 m. The average accumulation rate for this period amounted to approximately 60 meters per year.

The coastline of the Bay of Pokrovskoe moved seaward up to 450 meters during 15 years (from 1974 to 1989). Average accumulation rate was 30 meters per year. Sediments completely filled the Bay of Pokrovskoe from Yantarniy to cape Obzorniy.

Fig. 11. Young dunes in accumulative area in the Bay of Pokrovskoe

The shoreline near the protection dam of the old beach quarry moved seaward up to 320 meters for the period from 1974 to 1989 (15 years). The average accumulation rate for this period amounted to 21 meters per year.

Due to intensive dumping of a terrigenous material on the shore from the Amber Mining Plant, the average resultant move of the shoreline seaward, for the whole segment, is about 37 meters per year, including accumulation (up to 41 m) and erosion (up to 4 meters). So, the rate of accumulation during intensive dumping was nearly 10 times greater than the rate of erosion (loos of 4 meters per year, could be considered as an upper limit of the average rate), estimated for this area using the data of the period of 2007–2008, when wind conditions were stronger than the historical average.

Using this data we may roughly estimate that a single action of dumping the material on the shore of an amount of 2.5 million m^3 per year will provide a resultant move of the shore seaward by 37 meters, which gives the 'margin of safety' for the shore for the next 9 years, even for wind conditions similar to those in 2007–2008. Or, in other words, about 250000 cubic meters per year of adding of a new material is needed every year to prevent further erosion and protect the shore against retreat. This is maximum estimation, as to enhance an efficiency of reclamation and to preserve the coastal zone from further erosion, it is necessary to build beach-save structures, together with the dumping of a sandy material.

Acknowledgements

The authors are grateful to Prof. Pruszak for valuable remarks, to Dr S. Navrotskaya for the photo of a modern view of the amber quarry. This work was partly supported by grants of the Russian Fund for Fundamental Research (No. 08–05–01023, 08–05–92421), and was fruitfully stimulated by mutual work with colleagues from the

Institute of Hydro-Engineering of the Polish Academy of Sciences (Dr R. Ostrowski, a Polish national research project N306 280535).

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