Effects of extreme storms on coastline changes: a southern Baltic example

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AREA OF STUDY

Extreme storm effects on the southern Baltic coast were examined in a 13 km long section of the Polish coast along the Dziwnow Spit, one of the MICORE case study sites. There is a low dune coast from the seaside, and a flat organic coast from the lagoon side. The dune dimension is various from 50m to 150m width and from 3m to 12m height (Figure 1).

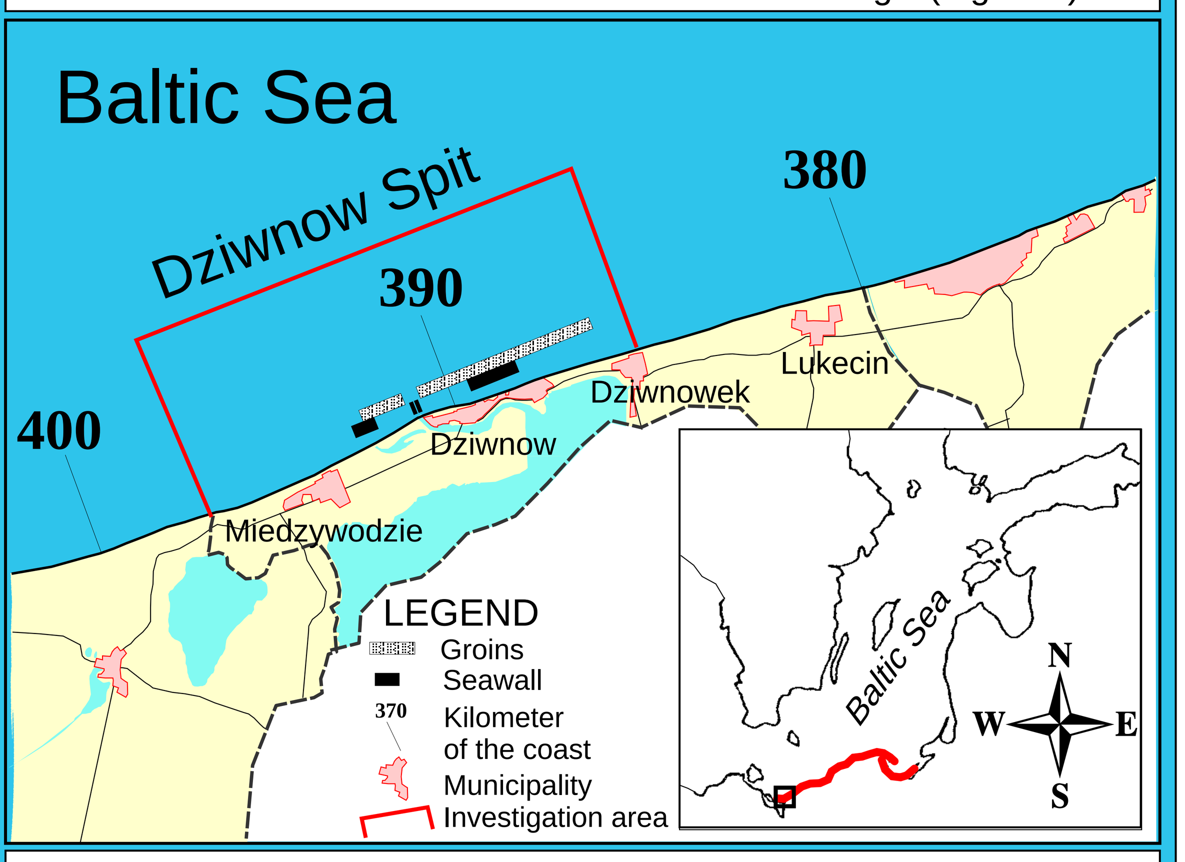

Figure 1. Area of study.

STORM DEFINITIONS

An **extreme storm** occurs when the wind force exceeds 8 Bft. A **storm surge** occurs when the mean sea level is exceeded by 70 cm or more (MAJEWSKI *et al.*,1983). "**Warning state**" and an "**alert state**", determined individually for each harbour by Maritime Office. In the Dziwnów harbour the **warning state** occurs when the mean water level is exceeded by 60 cm and the wind force is above 8 Bft. The **alert state** is declared when the mean water level is exceeded by 80 cm and the wind force is above 9 Bft. **A 100-year storm** definition has been developed jointly by the Polish Academy of Sciences' Institute of Hydro-Engineering and the Maritime Institute. Its parameters have to meet specific criteria, different for each part of the Polish coast. In the Dziwnów area, a 100-year storm occurs when the sea level is 1.5 m and more above the mean, the wind blows, at a velocity of 18 m/s or higher, from a sector perpendicular to the coast for at least 4 hours, the waves are at least 1.71 m high, and the wave swell at the undeveloped shore is at least 1 m (PRUSZAK *et al.*, 1999).

This definitions raises a question of what parameters describe an extreme storm, i.e., what storm can be regarded as an extreme one, and how often it can occur.**For the purpose of this study, it was assumed that a storm deemed significant causes noticeable sand dune erosion.**

MATERIALS AND METHODS - storm surges

WISNIEWSKI *et al.* (2008) analysed the annual occurrence of storm surges along the entire Polish coast (Figure 2a) and observed an increasing trend. Assuming that the sea level during a storm is of fundamental importance for the magnitude of changes in the shoreline, an analogous analysis was conducted on the number of alert states declared at least at one station.

The analysis showed a similar, but slightly less conspicuous trend (Figure 2b). When only those stations located in the western part of the coast (Swinoujscie and Kolobrzeg) were considered, the resultant increasing trend was still less distinct (Figure 2c).

If the analysis is restricted to situations when the alert state was declared at all the stations, the trend line is horizontal (Figure 2d). This reflects the southern Baltic water fill, a key factor responsible for quantitative storm-induced coastline changes. Noteworthy in this context is the year 1995 with as many as three storm surges causing simultaneous declaration of the alert state at all the stations.

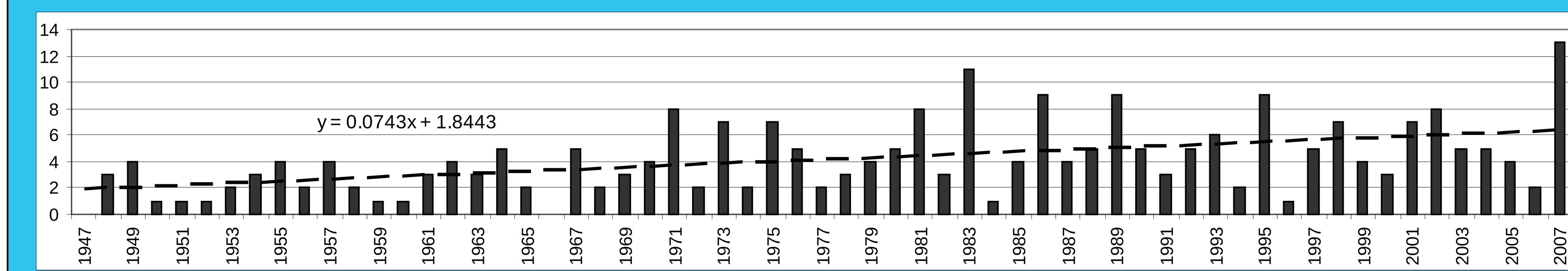

Figure 2a. Number of storm surges recorded along the entire Polish coast (WISNIEWSKI *et al*, 2008).

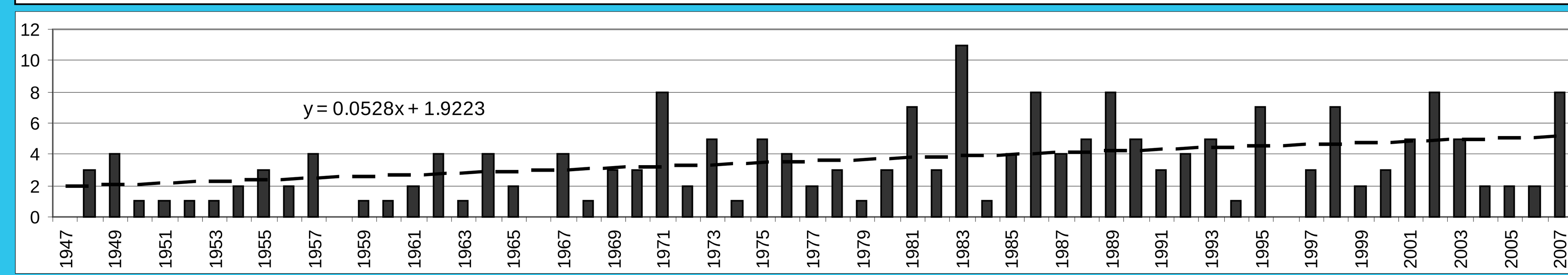

Figure 2b. Number of storm surges causing declaration of alert state at least at one station along the entire Polish coast. Prepared by authors on a base of data from WISNIEWSKI *et al*, 2008.

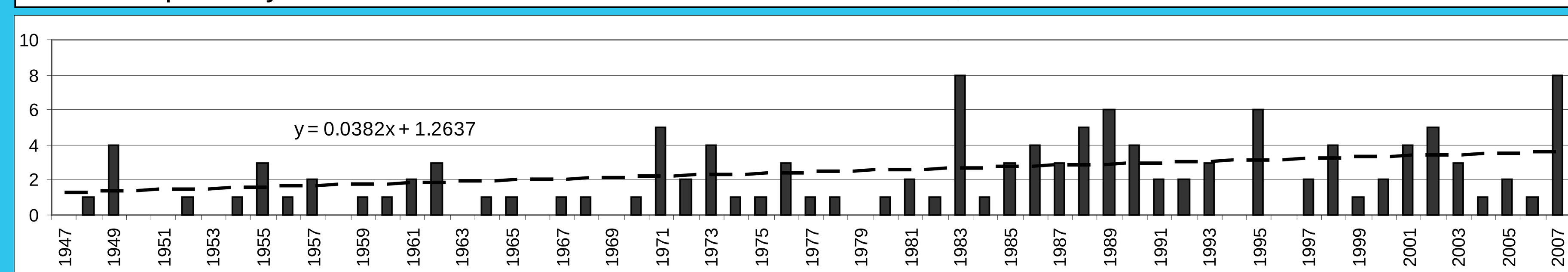

Figure 2c. Number of storm surges causing declaration of alert state at least at one station on the western Polish coast (Swinoujscie and Kolobrzeg). Prepared by authors on a base of data from WISNIEWSKI *et al*, 2008.

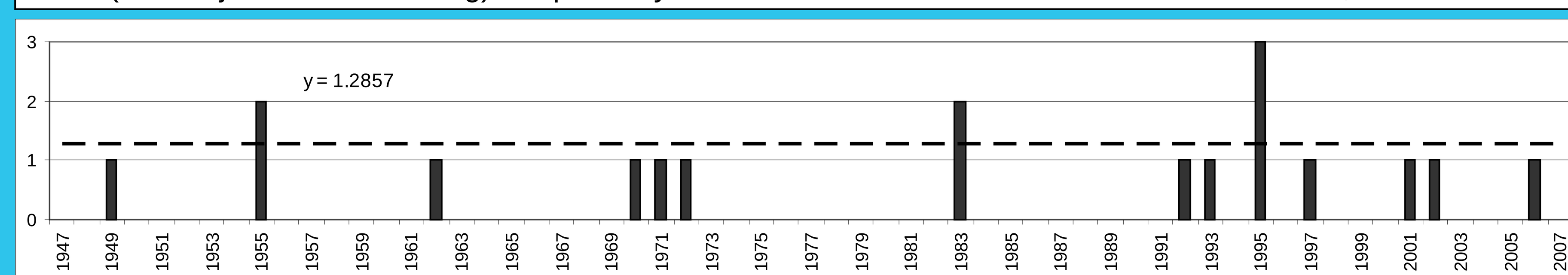

Figure 2d. Number of storm surges causing declaration of alert states at all the Polish coastal stations. Prepared by authors on a base of data from WISNIEWSKI *et al*, 2008.

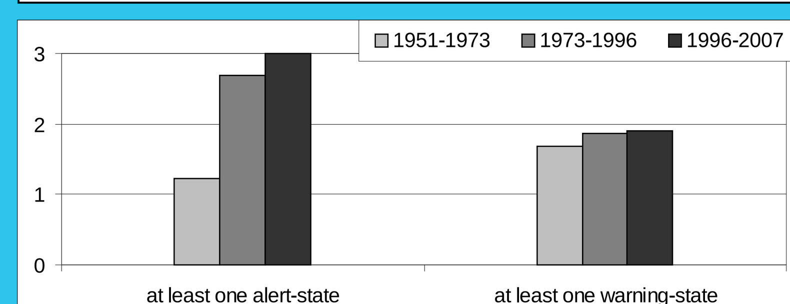

Figure 3. Average annual number of alert state- and warning state-causing storms registered in Swinoujscie and Kolobrzeg in different periods of time.

It is evident that the annual number of surges shows a tendency to increase with time; the increase in the number of alert state surges was small, as opposed to a significant increase in the number of alert state surges.

MATERIALS AND METHODS - assessment of changes to sand dunes

Significant changes to the coast after each major storm were analysed based on 1978-2008 reports on coastline changes after each storm, made available by the Maritime Office in Szczecin. The reports focused on a 13-km long stretch of the coast along the Dziwnow Spit. Of all the storms reported on, 34 storms that had caused dune losses were singled out for the analysis. The outcome is presented as a graph showing the dune volume eroded per 1 km of coast (Figure 4).

The values at the bottom and at the top of the graph are the coast length (km) and the sum total of dune volume eroded (m^3) at the coast kilometre as a result of all the storms. To the left of the graph there is the storm date, the column to the right showing the total dune volume (m^3) eroded by that storm (the graph in Figure 6 shows the latter values in thou. m^3). The magnitude of erosion caused by each storm at the individual coastline kilometre is colour-coded in the graph.

Data	The total dune volume (m^3) eroded by every	ID	Distance from previous storm (day)	Water level (cm)	2.5 > Hs >= 1.5 (m)	Hs >= 2.5 (m)
30-11-1978	145 600	133		580	43	
8-11-1981	400	148	1058	597	53	18
26-10-1986	1 690	10001	1788	595		
20-12-1986	14 270	175	54	613	2	
6-01-1987	700	10002	16	610	20	
2-11-1988	150	181	656	586	15	
29-11-1988	79 115	182	27	632	17	12
27-11-1989	7 875	10003	358	607	16	3
9-12-1989	1 000	10004	12	614		
2-03-1990	1 000	197	83	586	17	
24-12-1991	1 300	201	652	587	22	
17-01-1992	13 036	205	23	628	20	
22-01-1993	10 354	210	365	582	31	
21-02-1993	81 220	213	29	632	51	14
3-01-1995	6 327	217	672	618	12	
23-03-1995	400	10005	80	585		
28-03-1995	1 400	220	5	579	17	8
7-04-1995	35 185	221	9	614	24	
31-08-1995	25 820	222	144	593	36	19
3-11-1995	547 200	223	63	650	16	24
11-04-1997	113	228	518	606	31	11
31-01-1998	2 300	233	290	585	35	
18-01-2000	1 500	243	708	600	90	15
21-01-2000	2 200	10006	3	598	69	15
22-11-2001	8 920	251	661	598	31	5
2-01-2002	15 300					
21-02-2002	21 748					
8-10-2002	2 100					
6-04-2003	1 050					
6-12-2003	5 532					
23-11-2004	52 890					
1-11-2006	60 228					
31-12-2006	6 400					
30-10-2008	4 995					

The coast length (km)	397	396	395	394	393	392	391	390	389	388	387	386	385	
sum total of dune volume eroded (m^3)	43 483	48 147	66 907	90 190	63 881	37 317	81 395	94 860	89 990	169 300	105 340	85 330	82 070	2 316 235

<1000 | 1000-5000 | 5000-20000 | 20000-50000 | >50000

Figure 4. Dune volume eroded (m^3) per 1 km of the coast.

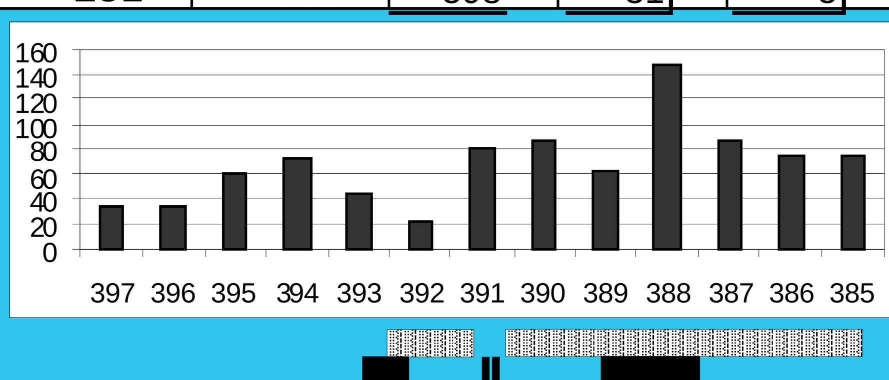

Figure 5. Sum total of dune volume eroded (thou. m^3) at coastal kilometre indicated as a result of all storms.

CONCLUSIONS

The analysis showed the post-storm coastal damage reports made available by the Maritime Office in Szczecin, even though providing a very approximate assessment of dune loss, are suitable for developing a rough picture of spatial distribution of the magnitude of coastal erosion.

The most extensive post-storm changes are associated with those parts of the coast featuring heavy-duty coastal protection facilities and/or hydro-engineering constructions. Their presence enhances erosion in their vicinity and induces attempts at its mitigation by increasingly intensive interventions.

The largest coastline changes are caused by storms occurring in sequences, with short (1-2 months) time intervals between storm events. A cumulative effect of a storm sequence within a year is disastrous, particularly when assessed in the aftermath of the last storm in the series (as in 1995).

The extent of coastal erosion, i.e., the effect of an extreme storm, depends mainly on the magnitude of the storm surge involved as well as on the time between the storm in question and the preceding one.

The magnitude of the southern Baltic coastline damage is exacerbated by the very high water level maintained over a prolonged period of time.

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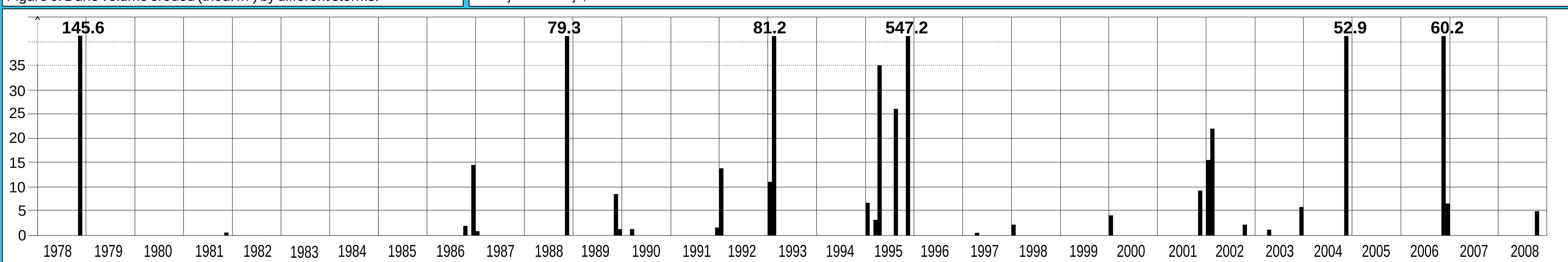
Figure 6. Dune volume eroded (thou. m^3) by different storms.



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