Sediment characteristics and sedimentation-erosion processes on Ketenisse polder one year after levelling

I. Verbessem,* E. Van den Bergh, N. De Regge, J. Soors, W. De Belder, and R. De Groot

Institute of Nature Conservation, Kliniekstraat 25, 1070 Brussels

* *Corresponding author: Tel: +32-2-558-18-25; Fax: +32-2-558-18-05; E-mail: Ingrid.Verbessem@inbo.be*

The Ketenisse polder is a former intertidal brackish marsh of 30 ha situated between the fortress of Liefkenshoek and the Kallo sluice on the left bank of the Schelde estuary, Belgium. In the 19th century its central part was embanked as a polder. During the construction of a traffic tunnel in the late eighties, the excavated soil was dumped between a lower summer dike and the damming dike. The area was restored in 2002 as compensation for the construction of a container terminal on a mudflat in 1994-1995. The rubble of the summer dike and the dumped material were removed and the area was levelled with the intention of creating the optimal starting conditions for the development of new tidal mudflats and marshes.

Developments concerning morphology, sediment characteristics and sedimentation-erosion processes are monitored. Six transects with sedimentation-erosion plots were placed perpendicular to the shoreline. This article discusses those monitoring results, mainly for the first year after levelling.

Sedimentation as well as erosion between 0 and 30 cm was observed in the first year. Local changes in stream current patterns caused erosion on some parts of the former mudflats; sheltered depressions filled up relatively fast. Median grain size showed large variation, both spatial and temporal. Organic matter content of the sediment varied between 0.5 and 15% and was closely related to sediment median grain size.

Keywords: Schelde estuary, tidal wetland restoration, monitoring, Belgium

Introduction

The river Schelde has its source in Saint-Quentin (France) and it flows into the North Sea after 350 km. It drains some 21600 km^2 in northwest France, west Belgium and the southwest Netherlands. The prevailing climate is moderate maritime and it is characterised by abundant precipitation. Being a typically rain fed river, it's discharge varies among seasons (Ysebaert, 2002). The mean river discharge amounts to 180 m^3 s^{-1} during winter with maximum values up to 600 m^3 s^{-1}. During summer, values decrease to 60 m^3 s^{-1} (Baeyens et al., 1998).

After ages of land reclamation, harbour expansion and other anthropogenic pressures on the Schelde estuary, people have come to realize that there is an urgent need to respond to the possible negative effects of sea level rise and to restore some ecological damage (Havens et al., 2002). Tidal wetland restoration is one of the needed measures. Implementation of such a logical but also radical measure calls for a clear understanding of the expected developments. Monitoring of recently restored areas is therefore very important to observe the success of this management tool.

A polder is an area of low-lying land that has been reclaimed from a body of water and is protected by dikes. Removal of the dikes and re-levelling the area is one of the measures within the scope of tidal wetland restoration. The works at Ketenisse polder started in summer 2002 and ended in February 2003. The purpose was to level the area with a weak slope below mean high water level, creating the optimal starting conditions for new intertidal mudflats and marshes. However, removed soil was intended for dike construction works so only suitable material was taken and the old summer dike was not completely smoothed out. As a result the starting slope and level in the tidal frame differed along the site and from the restoration design.

Hydromorphologic changes, sediment characteristics, sedimentation and erosion processes were monitored at twenty sampling stations along six transects perpendicular to the shoreline (Figure 1). These stations were established and referenced gradually as the works proceeded in a downstream-upstream direction; as a consequence, the monitoring also started gradually. In this paper the monitoring results from the first year after restoration are presented.

Methodology

In the first year after levelling, most of the monitoring was carried out monthly. Sediment samples were taken with cores which were two cm in diameter. Three replicate samples were taken from the top centimetre and one replicate from the top ten centimetres. Grain size was determined by laser diffraction with the Malvern Mastersizer. The samples were further analysed for organic matter content (%). Therefore each sample was first dried at 60°C, weighted and calcinated at 550°C in 2 hours. Sedimentation/erosion processes were followed every fortnight in sedimentation-erosion plots. In each plot three level steel tubes were anchored in the mudflat in an equilateral triangle with 1.5 m-long sides. The tubes were connected by a measuring rule and the distance between the rule and the mudflat was measured every 20 cm.

Morphological changes were followed by means of aerial photography, theodolite and GPS measurements. Full topographic levees by means of aerial photography and laser altimetry were taken in September 2003, November 2003, April 2004 and in September 2004. Elevation changes along transects were monitored with seasonal topographic levees every 10m. Additional measurements were done in April 2003 and in May 2004 to evaluate the condition of a cliff in the southern part of the study area.

In autumn 2002, the physico-chemical quality for two transects was determined using the physico-chemical part of the Triad method (De Deckere et al.,

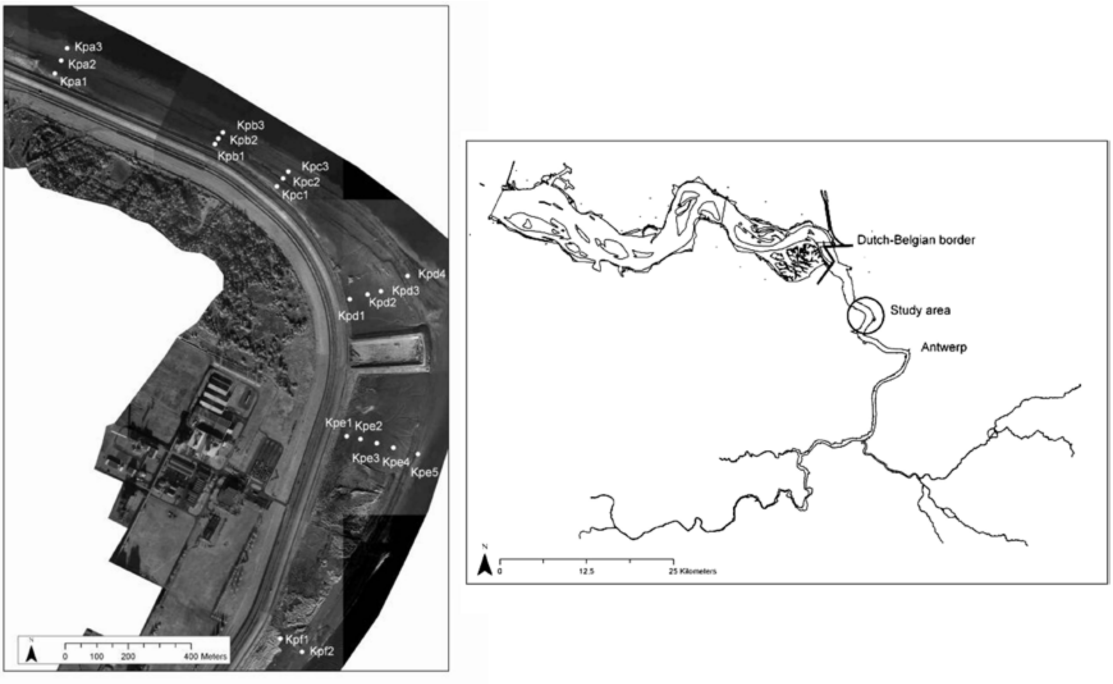

Figure 1. Aerial photo of Ketenisse polder in November 2003, with indication of the sampling stations along the six transects, and situation of the study area in the Schelde estuary. (Aerial photo by AWZ).

2001). Samples were taken with a core of 4.5 cm diameter, to a depth of 10 cm.

Results

Sediment characteristics

In the period July 2002-December 2003, the sampled stations were generally rather muddy, irrespective of the sample depth. More than 50% of the analysed samples had a median grain size (MGS) lower than 63 μ. Where the MGS distribution deviated clearly from a normal distribution, for example at Kpa2, Kpa3 and Kpd4, MGS was generally rather low. Other sampling stations such as Kpb2, Kpc2, and Kpd2 approach a more normal distribution (Table 1). The d and the f transects were generally muddy transects, but also Kpa2, Kpa3 and Kpc3 were locations with a lower MGS. The other locations were relatively sandy.

Sediment composition along the b transect showed large variations, changing from fine to rather sandy sediment in a few weeks time. These changes might be related to occasional dredging activities on the nearby "Plaat van Lillo" or excess rainfall. Also at the a transect and to a lesser degree at Kpe5, variations over time concerning MGS were relatively large.

In the first year after levelling, organic matter was maximal at KPd1, Kpd4, Kpf1 and Kpc3. Lowest organic matter content was found at the three downstream transects. Clear trends throughout the study period seemed to be absent, except for the e transect, where organic matter content decreased during the first year after levelling. A close relationship was found between MGS and organic matter content of the sediment (Spearman rank $R = -0.90$; $p < 0.05$; $N = 396$) (Figure 2).

Physico-chemical data were only available for the b and the d transects. In general, heavy metal concentrations at the b transect didn't deviate strongly from the Triad norm, except for the mercury concentrations at Kpb1 and Kpb2. Heavy metal pollution was clearly higher at the d transect, especially for cadmium and mercury. Concentrations of PAH's and PCB's were commonly higher at the b transect compared to the d transect.

Sedimentation-erosion

The combination of the shape index, the presence of peat layers and the very varied topography of the site along its length resulted in varied exposure and resistance to wave action (tidal, wind and from ships) across

Table 1. Summary Statistics for Median Grain Size for Each Sampling Station.

	N	Mean	Min.	Max.	Std.Dev.	Std.Err.	Skewness	Std.Err. Skewness	Kurtosis	Std.Err. Kurtosis
KPa1	22	201,16	10,61	348,65	67,25	14,34	−0,13	0,49	3,19	0,95
KPa2	25	66,69	22,83	340,68	62,39	12,48	3,83	0,46	16,60	0,90
KPa3	24	51,75	22,43	240,40	41,92	8,56	4,28	0,47	19,78	0,92
KPb1	23	225,14	139,88	383,51	61,72	12,87	0,75	0,48	0,19	0,93
KPb2	21	176,62	53,12	364,09	78,11	17,04	0,26	0,50	0,42	0,97
KPb3	19	142,19	26,69	255,76	68,93	15,81	−0,37	0,52	−1,04	1,01
KPc1	23	175,87	8,09	273,76	54,28	11,32	−0,89	0,48	3,63	0,93
KPc2	24	222,84	127,12	306,83	36,99	7,55	−0,12	0,47	1,33	0,92
KPc3	25	30,59	14,14	62,81	9,56	1,91	1,47	0,46	4,49	0,90
KPd1	21	19,13	12,39	36,30	6,47	1,41	1,34	0,50	1,05	0,97
KPd2	23	43,76	25,20	60,86	9,97	2,08	−0,14	0,48	−0,54	0,93
KPd3	22	48,54	19,24	111,59	19,93	4,25	1,55	0,49	3,81	0,95
KPd4	23	29,78	13,72	110,62	19,07	3,98	3,74	0,48	15,92	0,93
KPe1	22	128,68	109,56	162,72	13,45	2,87	1,09	0,49	1,04	0,95
KPe2	22	74,10	23,78	101,91	20,99	4,48	−0,77	0,49	0,20	0,95
KPe3	20	42,97	16,04	74,89	16,44	3,68	0,10	0,51	−0,82	0,99
KPe4	22	66,92	35,82	113,73	27,92	5,95	0,65	0,49	−1,19	0,95
KPe5	20	66,11	24,78	125,08	29,57	6,61	0,52	0,51	−1,02	0,99
KPf1	14	22,67	15,66	37,74	6,90	1,85	1,16	0,60	0,38	1,15
KPf2	15	57,38	31,46	80,24	14,87	3,84	−0,31	0,58	−0,87	1,12

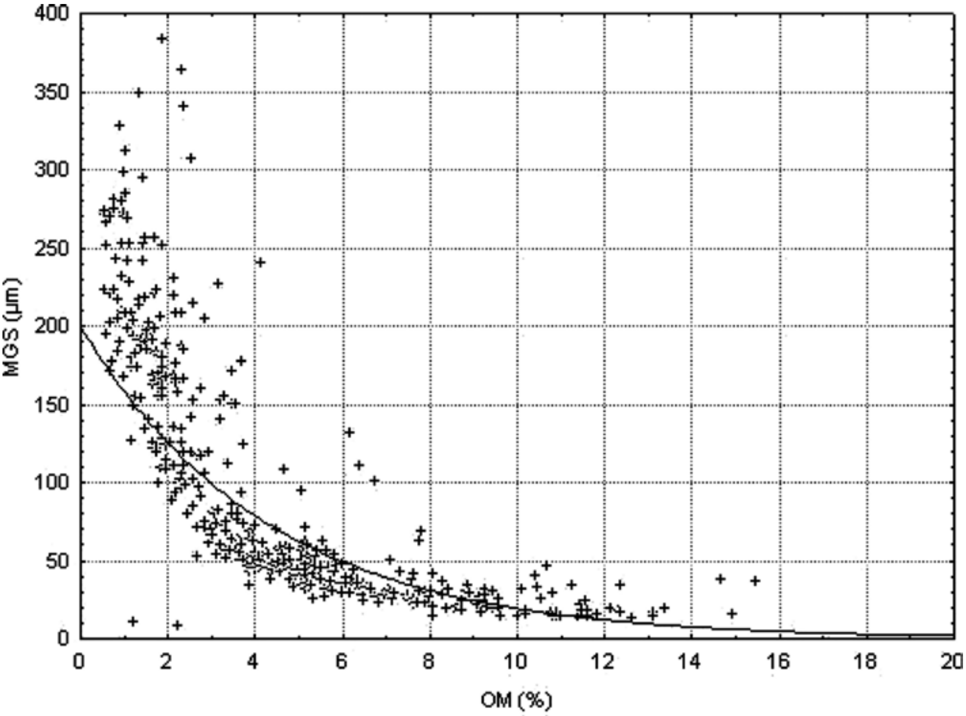

Figure 2. Scatterplot of MGS (μm) versus organic matter content (%).

the site and lead to very local specific sedimentation-erosion processes.

Sedimentation and/or erosion occurred gradually most of the time; however some 'sudden' net erosion of more than 10 cm between two consecutive measurements were observed in the very low and exposed sampling stations. Abrupt sedimentation could occasionally be explained by the presence of "fluid mud" on the station, probably originating from the dredging works nearby the study area or rainfall.

The seasonal topographic levees showed that apparently the most landward part of the downstream transects eroded more than the lower part. The d and the e transect showed a clear net sedimentation and some depressions filled up relatively quickly (Figure 3).

Topographic changes

A year after levelling, the onset for a creek network system was seen in the wider and sheltered d and e sections. Once established, the pattern of this network doesn't seem to change (Figure 4). Due to the levelling of the site, stream current patterns along the area changed causing important changes at some sections of the site. In the most upstream section, a steep cliff with a height between 0.3 and 1.5 m developed over a length of 100 m. In less than 6 months it eroded up to 2 m landwards. Afterwards, the calving continued, but less drastically.

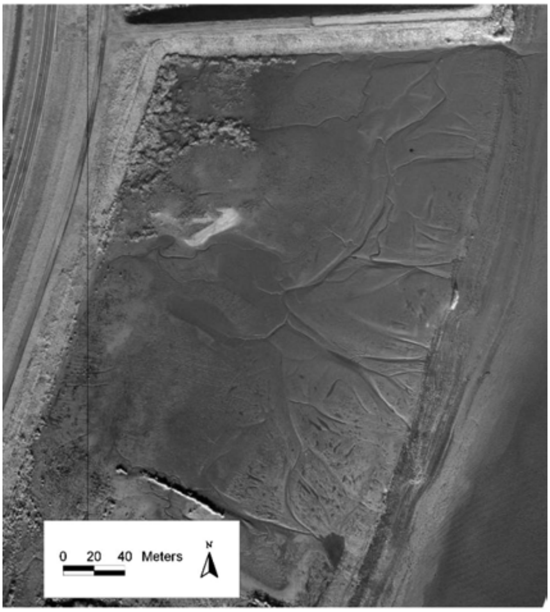

Figure 3. Seasonal topographic levees at the d transect.

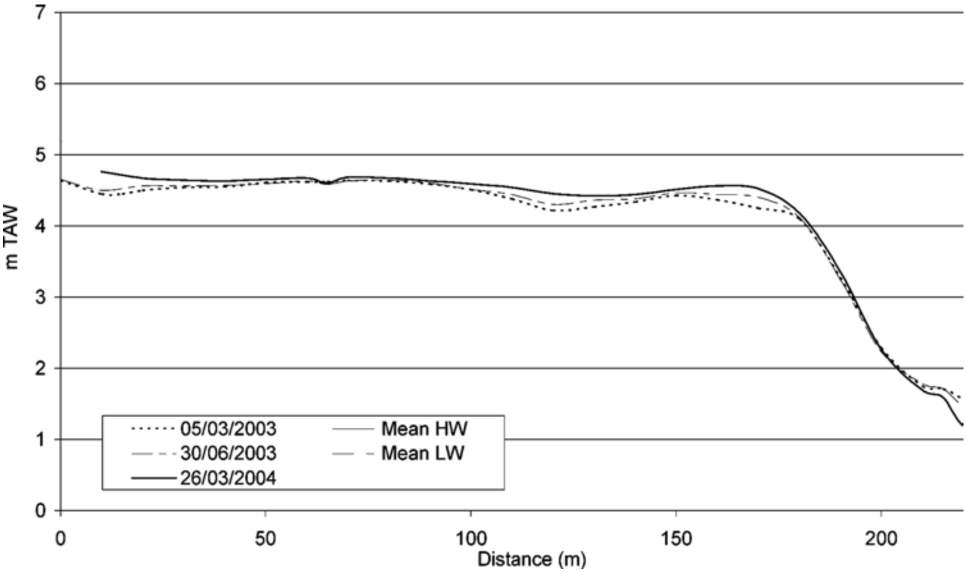

Figure 4. The creek network system at the d and e sections of Ketenisse polder in November 2003 (a). (Aerial photo by AWZ).

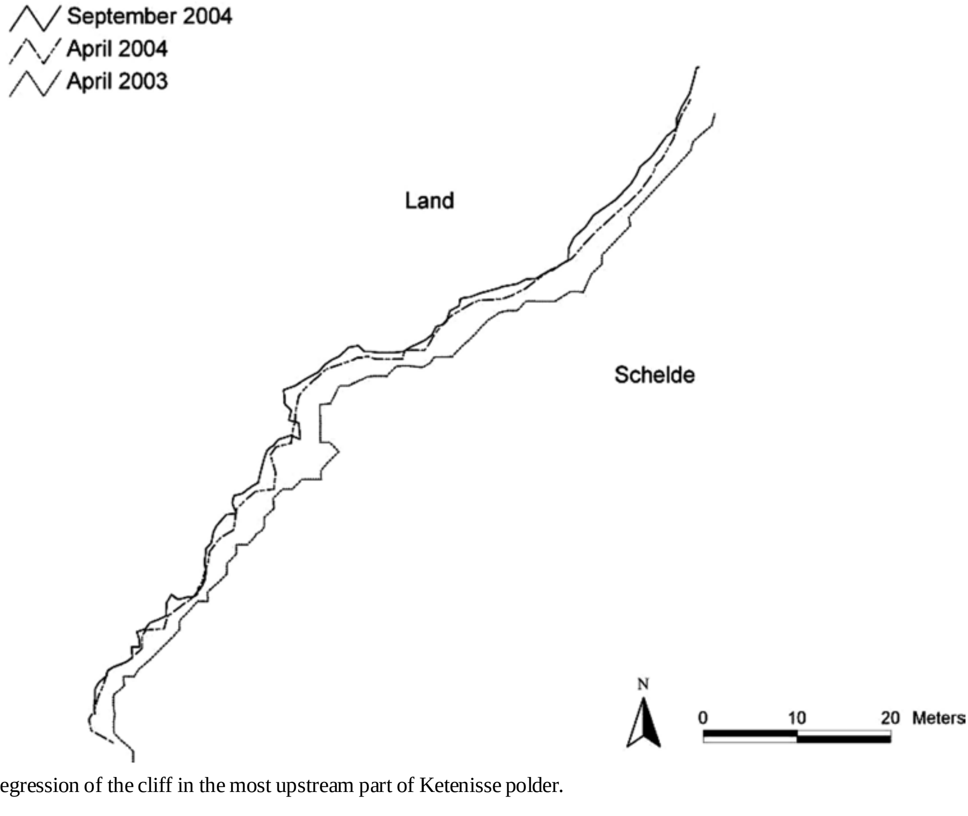

Figure 5. Regression of the cliff in the most upstream part of Ketenisse polder.

Conclusions

The described results show that the way the works are finalised determines to a great extent the developments on a levelled area. Differences in the starting conditions were reflected in the differences in evolution across the site. Erosion of the higher sections of the downstream transects might indicate that the initial slope was too steep. On the sheltered and wider Kpd and Kpe sections in general net sedimentation was observed with sediments of low MGS and high organic matter content. The other, more dynamic sections also show erosion in some parts, generally having higher MGS and lower organic matter content.

Morphological changes seem to start very soon after the levelling. One year after the works a creek network is established; some depressions were filled and also the regression of a cliff in the most upstream part of the area was primarily observed in the first year.

Acknowledgments

The restoration works, aerial photographs and the monitoring program for Ketenisse polder are funded by the Administration of Waterways and Maritime affairs, Zeeschelde division of the Flemish government. We specially thank Ir. Stefaan Nollet and Ir. Albert Frans for their support and advice.

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