HISTORICAL EVOLUTION OF MUD DEPOSITION AND EROSION IN INTERTIDAL AREAS OF THE SCHELDT ESTUARY (BELGIUM AND SW NETHERLANDS)

CHEN WANG(1, 2), JORIS VANLEDE(3), WOUTER VANDENBRUWAENE(3), YVES PLANCKE(3) & STIJN TEMMERMAN(2)

1. INTRODUCTION

The mud dynamics in an estuary are recognized as an important element of estuarine functioning, because increasing suspended sediment concentrations may be both harmful for ecological functions (e.g., biomass production by phytoplankton) and deteriorative for human functions (e.g., by siltation of shipping channels). Considering the potential risk of increase in suspended sediment concentration in the Schelde estuary, this study aims to quantify the mud deposition/erosion in different time periods since 1930 to present, different intertidal ecotope types, and different zones along the Schelde estuary, including the Westerschelde and Zeeschelde. We analyzed the height change, volume change, eroded or deposited mud mass, and the overall mud balance. Our results suggested that net mud deposition occurred in intertidal areas in both the Westerschelde and Zeeschelde in almost all time periods. The mud deposition in stable marshes plays an important role. A large amount of mud deposition is also observed in stable intertidal flats and areas that shifted from intertidal flat to marshes or from subtidal zone to intertidal flat. Over 90% of mud erosion is observed in areas that shifted from intertidal flat to subtidal zone. Mud erosion is also observed in areas that shifted from marsh to intertidal flat.

Keywords: mud deposition, mud erosion, intertidal areas, Scheldt estuary, GIS

2. DATA AND METHODS

We analyzed the height change, volume change, eroded or deposited mud mass, and the overall mud balance in between time steps of around 1930, 1960, 1990, 2000 and 2010. Ecotope maps of different years were compared to get the difference maps of ecotope changes between the different time steps. Elevation data were compared between different years to get the elevation change between the different time steps. Height change in the different ecotope change classes were extracted based on the combination of elevation change maps and ecotope change maps. Volume change in the different ecotope change classes were calculated by multiplying the height change in the different ecotope change classes with eroded or deposited mud mass. Mud volume change was calculated by multiplying the mud volume change with dry bulk density data. The Digital Terrain Models (DTMs) in the Westerschelde and Zeeschelde of different time steps were interpolated from the bathymetric data, topographic data and LIDAR data provided by Rijkswaterstaat, aMT (afdeling Maritieme Toegang) and INBO (Instituut voor Natuur- en Bosonderzoek) (Van der Puijim et al., 1998; Van Heerd et al., 1999; Alkemade, 2004; Temmerman et al., 2004; Rijkswaterstaat, 2011; Van Braeckel et al., 2012; Van Ryckegem et al., 2014). The ecotope maps of marsh, intertidal flat and subtidal zone were generated based on vegetation maps of Westerschelde from Rijkswaterstaat and detailed ecotope maps from INBO, which were extracted from aerial photographs and hydrographic maps (Huijs, 1995; Van der Puijim et al., 1998; Reitsma, 2006; Rijkswaterstaat, 2011; Van Braeckel, 2013). Sediment grain size data were collected from different sources, including the data from MOVE project (Plancke et al., 2011), from INBO (Speybroeck et al., 2014) and UA-ECOBE (Temmerman et al., 2003, 2004; Teuchies et al., 2013; Jongepier et al., 2015) during several projects. The dry bulk density is estimated based on measurements on sediment samples from the Scheldt estuary with high mud content, in particular marsh samples (Temmerman et al., 2003; Teuchies et al., 2013). Since no spatial trend in bulk density was observed along the estuary, an average dry bulk density of $500 \pm 100 \, \text{kg/m}^3$ was used for all zones.
Figure 1. Study area. (A) Location within NW Europe. (B) Location of the Westerschelde (west of the Dutch-Belgian border) and Zeeschelde (southeast of the Dutch-Belgian border). Ecotope changes are mapped for the Westerschelde (2004-2010) and Zeeschelde (2001-2010).

3. RESULTS AND DISCUSSION

Our results suggested that net mud deposition occurred in intertidal areas in both the Westerschelde and Zeeschelde in almost all time periods (Figure 2 and Table 1). For the total mass of mud deposition, intertidal mud deposition is slightly larger in the Westerschelde (on average $42.6 \times 10^3$ ton/year averaged over all time periods) than in the Zeeschelde (on average $36.2 \times 10^3$ ton/year), because the intertidal areas of the Westerschelde is much larger than that of the Zeeschelde. The average mud deposition rate in all the intertidal areas is the largest in the periods of 1963-1992 in the Westerschelde ($79.5 \times 10^3$ ton/year) and 1930-1960 in the Zeeschelde ($72.0 \times 10^3$ ton/year). In terms of the relative role of different intertidal ecotope types, the mud deposition in stable marshes plays an important role in both the Westerschelde (on average $68.7 \times 10^3$ ton/year) and Zeeschelde (on average $44.3 \times 10^3$ ton/year). The mud deposition in stable marshes in the Westerschelde mainly takes place in Saeftinghe (with 3000 ha the biggest intertidal area in the estuary), especially in the earlier periods before 2004, with mean mud deposition rates of $62.3 \times 10^3$ to $77.8 \times 10^3$ ton/year. A large amount of mud deposition is also observed in stable intertidal flats (on average $43.0 \times 10^3$ ton/year) and areas that shifted from intertidal flat to marshes (on average $22.0 \times 10^3$ ton/year) or from subtidal zone to intertidal flat (on average $227.3 \times 10^3$ ton/year) in the Westerschelde. Over 90% of mud erosion is observed in areas that shifted from intertidal flat to subtidal zone in the Westerschelde (on average $307.6 \times 10^3$ ton/year) and in the Zeeschelde (on average $11.1 \times 10^3$ ton/year). Mud erosion is also observed in areas that shifted from marsh to intertidal flat in the Westerschelde (on average $10.9 \times 10^3$ ton/year).
Figure 2. Boxplots of mud balance in the intertidal areas, marshes and Saeftinghe in the Westerschelde and Zeeschelde in different periods. Intertidal areas = onshore tidal flats + offshore tidal flats + tidal marshes. The upper bound and lower bound indicate the 5th percentile and 95th percentile of the values. The box indicates the 25th and 75th percentile. The thick line indicates the 50th percentile, and the cross indicates the mean value. The 95th percentile of the values in the Westerschelde in 2004 - 2010 and 1992 - 2004 are $407 \times 10^4$ ton/year and $249 \times 10^4$ ton/year, respectively, which are outside of the range of the x-axis.

Table 1 – Average mud erosion/deposition rates in mass and mass per unit area in different ecotope types of all sub-division zones in the Westerschelde and Zeeschelde.

<table>
<thead>
<tr>
<th>Location</th>
<th>Stable marsh</th>
<th>Stable intertidal flat</th>
<th>Marsh -&gt; Intertidal flat</th>
<th>Intertidal flat -&gt; Marsh</th>
<th>Intertidal flat -&gt; Subtidal zone</th>
<th>Subtidal zone -&gt; Intertidal flat</th>
<th>All intertidal areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass (ton/year)</td>
<td>Westerschelde 68,742</td>
<td>43,081</td>
<td>-10,916</td>
<td>21,964</td>
<td>-307,587</td>
<td>227,345</td>
<td>42,629</td>
</tr>
<tr>
<td></td>
<td>Zeeschelde 44,332</td>
<td>-5,228</td>
<td>1,241</td>
<td>20</td>
<td>-11,135</td>
<td>6,988</td>
<td>36,219</td>
</tr>
<tr>
<td>Mass per unit area (ton/ha/year)</td>
<td>Westerschelde 33</td>
<td>4</td>
<td>-59</td>
<td>27</td>
<td>-199</td>
<td>143</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Zeeschelde 68</td>
<td>-4</td>
<td>-11</td>
<td>50</td>
<td>-75</td>
<td>3</td>
<td>20</td>
</tr>
</tbody>
</table>

The mud deposition rate per unit area (Table 1) is much larger upstream in the Zeeschelde (with an average of 20 ton/ha/year) than downstream in the Westerschelde (4 ton/ha/year). The same as the total mass of mud deposition, the mass per unit area is also the largest in the periods of 1963-1992 in the Westerschelde (7 ton/ha/year) and 1930-1960 in the Zeeschelde (36 ton/ha/year). The mud deposition per unit area is the highest in stable marshes in both the Westerschelde (33 ton/ha/year) and Zeeschelde (68 ton/ha/year). High deposition rate per unit area is also observed in areas that shifted from subtidal zone to intertidal flat in the Westerschelde (143 ton/ha/year) and areas that shifted from intertidal flat to marshes in the Zeeschelde (50 ton/ha/year). The highest mud erosion rate per unit area is observed in both the Westerschelde (199 ton/ha/year) and the Zeeschelde (75 ton/ha/year) in areas that shifted from intertidal flat to subtidal zone. High erosion rate per unit area is also observed in areas that shifted from marsh to intertidal flat, especially in the Westerschelde (59 ton/ha/year). A positive correlation is expected between the suspended sediment concentration and the deposition rate, because of higher sediment availability for deposition (Temmerman et al., 2003; Vandenbruwaene et al., 2011).
4. CONCLUSIONS

In conclusion, there is a net mud deposition in intertidal areas in both the Westerschelde and Zeeschelde in all time periods from 1930 to 2010. The total mud deposition is slightly larger in the Westerschelde than in the Zeeschelde because of the much larger intertidal area in the Westerschelde, although the mud deposition rate per unit area is the opposite. Both the highest total mass and the highest mass per unit area of the mud deposition are observed in the periods of 1963-1992 in the Westerschelde and 1930-1960 in the Zeeschelde. Stable marshes play an important role in mud deposition, especially in Saeftinghe. Large amount of mud deposition is observed in areas that shifted from subtidal zone to intertidal flat and areas that shifted from intertidal flat to marshes. Large amount of mud erosion is observed in areas that shifted from intertidal flat to subtidal zone and areas that shifted from marshes to intertidal flat. A positive correlation is expected between the deposition rate and the suspended sediment concentration.

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REFERENCES