Salt marshes: applied long-term monitoring

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1. Introduction

Time series of vegetation succession, sedimentation and relative water levels (high tide fluctuations and soil subsidence) in Netherlands salt marshes (Table 1) provide sound data for conservation strategies, site management and impact assessment (Bakker *et al.*, 2005).

2. Methods for time series in salt marshes

2.1 Transects Ameland and Peazemerlannen (14-22 years)

The monitoring includes 4 transects of ca. 1 km long from sand dunes or seawall to intertidal flats. The transects include 60 permanent plots of 2 x 2 m for sedimentation measurements twice a year, vegetation recording annually and elevation every 2 years. Sedimentation is recorded with a 17 pins SEB (Sedimentation Erosion Bar; Figure 1) with a 95 % confidence interval of ca. 1.5 mm (Boumans and Day, 1993).

2.2 Transects Friesland and Groningen mainland (50 years)

25 experimental fields of ca. 50 ha are monitored along 50 km mainland coast of The Netherlands Wadden Sea. Each field includes ca. 50 fixed 100 m transects for levelling at 4 year intervals and ca. 50 permanent plots of 100 x 100 m for yearly vegetation recording. For elevation and accretion each mean record from a fixed 100 m transect has a confidence interval of ca. 1.5 mm (Dijkema, 1997; Dijkema *et al.*, 2001, 2009).

Years	Scale	Location	Monitoring Goal	Organisation
30	1:5/10,000	All NL salt marshes	Area + biodiversity	Rijkswaterstaat DID
50	2 regions 25 transects	Friesland & Groningen mainland	Restoration	Rijkswaterstaat & LNV & IMARES Texel
22	2 sites Transects	Ameland barrier island	Effect of soil subsidence due to gas extraction	IMARES Texel & NAM
14	2 sites Transects	Peazemerlannen mainland & summerpolder	Autonomous development (from 2007: effect soil subsidence)	IMARES Texel & NAM

Table 1: Time series in salt marshes in The Netherlands discussed in this paper.

2.3 Vegetation mapping of all salt marshes (30 years)

Mappings are made at scale 1:5000 or 1:10,000 with 6-year intervals. Input is from remote sensing (interpretation of stereo false-colour photographs) and fieldwork. For the classification of vegetation, a standard typology is used (SALT97, de Jong *et al.*, 1998).

3. Sedimentation and sea level rise

Sedimentation is both related to large-scale zonation (mainland; Figure 2) and to small-scale patterns (barrier island Ameland; Figure 3) and is also events-driven (*e.g.* storm). The distance to sediment sources (creeks, sea) and local drainage

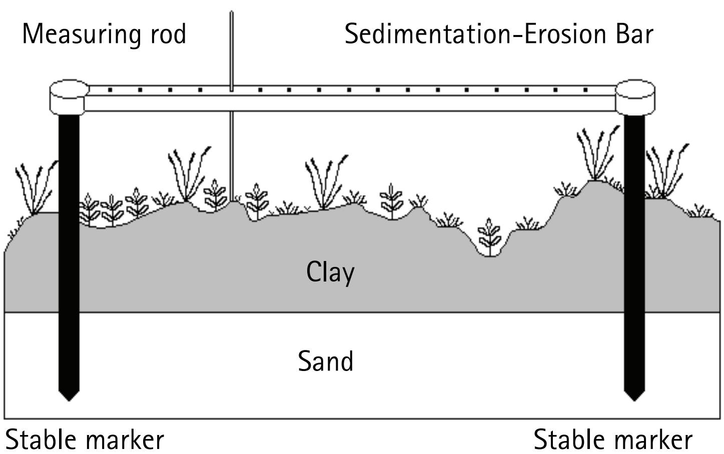


Figure 1: 17 pins Sedimentation Erosion Bar (SEB).

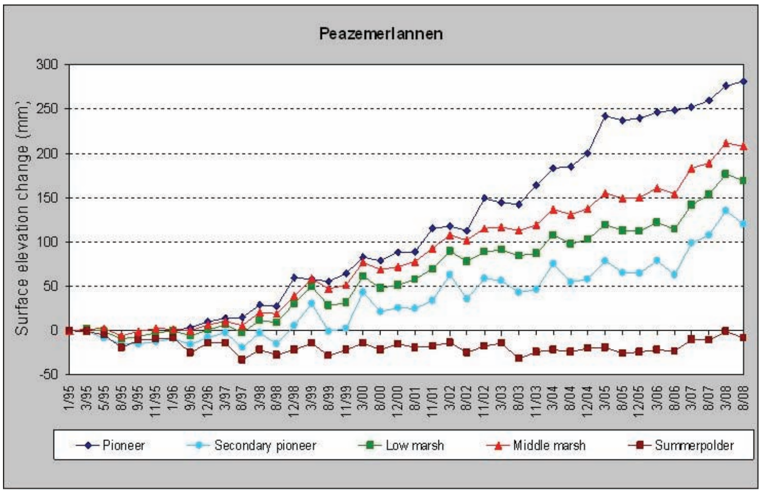


Figure 2: Peazemerlannen de-embanked summer-polder, showing effects of zone-elevation on sedimentation (SEB means). Salt marsh sedimentation is 10-22 mm/yr, summerpolder < 0 mm/yr. A winter with lower tides due to easterly wind (1995-1996) shows no sedimentation and 2 winters with stormfloods (2006-2008) show the positive effect of such events.

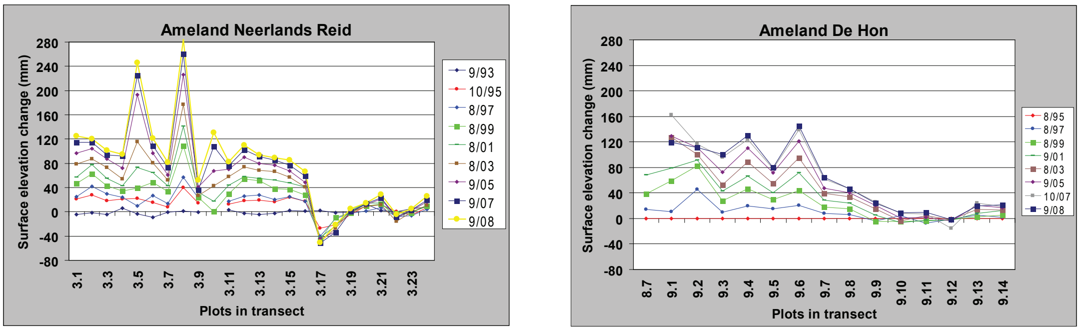


Figure 3: Ameland barrier-island sedimentation (2 SEB transects). Plots left in both graphs are close to the Wadden Sea, showing the effect of sediment source (plots right are close to sand dunes). Proximity of a tidal creek, low marsh elevation and storm-events also increase sedimentation. Soil subsidence of ca. 110 mm in the monitoring period was fully compensated in the seawards plots only. But there was hardly any effect of lowering marsh surface on the salt marsh vegetation (chapter 5).

patterns are similar important. Vertical salt-marsh zone sedimentation rates for the mainland are double those on the barrier-islands and may for most sites keep pace with a sea-level rise accelerated to 10 mm/y.

Vertical accretion in the salt-marsh zone is a natural process leading to higher salt marshes. The accretion in man-made mainland salt marshes is the highest, with 1.3-2.0 cm/y (Table 2). The vertical accretion should decrease as higher salt marshes get fewer tidal floodings, but from 2000 on, salt marsh accretion increased again (Figure 4), possibly because of an increasing number of storm tides (Dijkema *et al.*, 2009). Sediment budget measurements in Peazemerlannen (Van Duin *et al.*, 1997) showed that one such storm event may import 125 times the amount of sediment compared with a normal tide.

4. Salt marsh area restoration

Mainland salt marshes in the international Wadden Sea are mainly anthropogenic in origin, stimulated by a system of drainage ditches, and since the 1930s by a lay-out of sedimentation fields surrounded by brushwood groynes. Conditions for sedimentation and plant establishment were both improved, forming a man-made landscape of high value. The Netherlands sedimentation fields originally measured 400 x 400 m, arranged in three rows from the salt marsh onto the intertidal flat. Vertical sedimentation in the pioneer zone is critical, hampering in periods with insufficient maintenance of the brushwood groynes (Figure 4). The 50-year monitoring series of mainland salt marshes taught us how to restore the pioneer zones to a successful defence zone against erosion for the benefit of both the salt marsh and the coastal zones (Dijkema *et al.*, 2001, 2009).

Table 2: Vertical accretion Friesland and Groningen mainland, average of 25 experimental fields.

	3rd fields Bare mud	2nd fields Bare mud	2nd fields Pioneer zone	1st fields Salt marsh zone
Friesland mainland 1992-2007	0.3 cm/y	1.1 cm/y	2.4 cm/y	2.0 cm/y
Groningen mainland 1992-2007	0.1 cm/y	0.7 cm/y	0.7 cm/y	1.3 cm/y

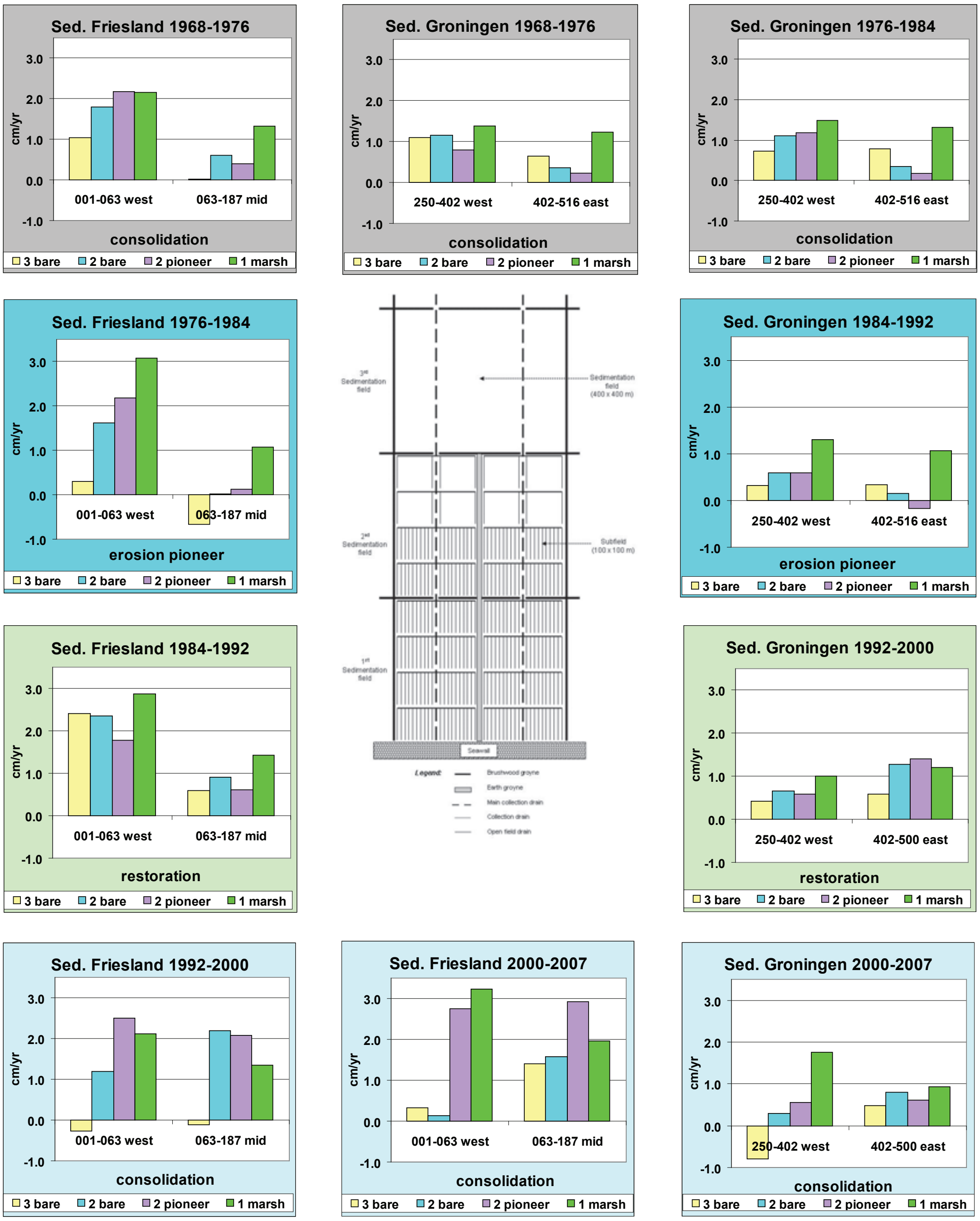


Figure 4: Vertical accretion in both Friesland and Groningen mainland salt marsh zones is at an all time high. However, the pioneer zone needs artificial protection against waves and currents. All sedimentation fields renovated since 1989 (W-E fetch reduced to 200 m and building new brushwood groynes at the original 0.30 cm + MHT) show a positive accretional balance today. Compare Friesland-mid before and after 1984 and Groningen-east before and after 1992.

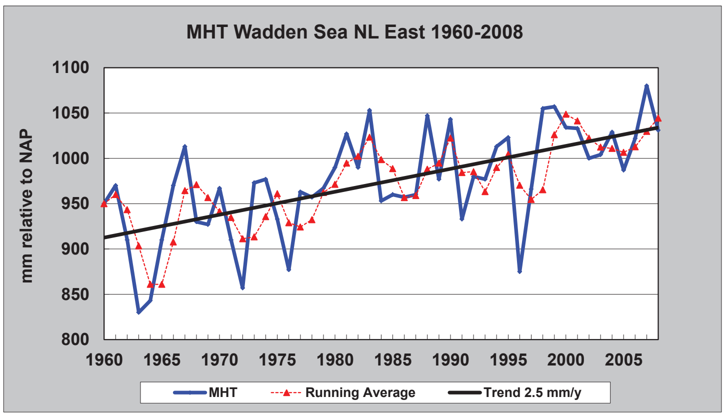


Figure 5: Yearly average MHT-levels in the eastern Wadden Sea, The Netherlands (mean value of the tidal stations Nes, Lauwersoog and Schiermonnikoog). Note the trend in MHT-rise of 2.5 mm/y. The large year-to-year difference is explained by wind force, wind direction and air pressure (Bossinade *et al.*, 1993).

- Sedimentation fields should be constructed only under certain prerequisites. The elevation in the upper tidal zone is from about 0.5 m below MHT onwards. The third, most seaward row of sedimentation fields, which did not contribute to protection, was abandoned.
- Sufficient sediment availability is an important condition. The currents in the area must be low enough to allow sedimentation in the fields. Engineering measures, on sites where either the accretion rate was very high or where elevations stayed too low to allow salt marshes to develop, were finished.
- The establishing of sedimentation fields has ensured the presence of an extensive pioneer zone. The pioneer zone itself protects the salt marsh higher up. There is no other need for additional protection measures in the salt marsh zone. A reduction in size of sedimentation fields in the pioneer zone to 400 x 200 m or to even 200 x 200 m to lower the wave fetch at sites where elevation development of the pioneer zone did not keep pace with the MHT-rise and where the low salt marsh deteriorated.
- All remaining groynes were restored to the original construction height of 0.30 m above MHT, with an extra margin for future sea-level rise (Figure 5). Use of durable brushwood filling (*Picea abies*, *Pseudotsuga menziesii*, *Picea sitchensis*) allowed a lower filling frequency, and meant a cut in maintenance costs.
- To allow natural creek systems to form, no groundwork should be carried out within sedimentation fields. This is a prerequisite for a natural salt marsh development even within man-made salt marshes. Groundwork does not enhance the sedimentation rates within sedimentation fields (Dijkema *et al.*, 1991, Michaelis *et al.*, 2008). All groundwork on the drainage system was finished after 1997, without impact on vertical accretion. As a consequence, constant monitoring and maintenance of a solid connection between brushwood groyne and salt marsh is necessary to prevent erosive water currents forcing their way through.
- Cliff erosion of salt marshes is a natural process, both in naturally establishes marshes as and man-made salt marshes. In an extended salt marsh, sedimentation fields should not be constructed because natural processes should be allowed to work. If cliff erosion has to be stopped, only two courses of action are recommended. The most nature-friendly one is the construction of a new sedimentation field in front of the cliff. Only under very extreme conditions should stone revetments established *e.g.* around the Halligen.
- There is no need and no intention to restore an entire border of salt marshes along the entire Wadden Sea coast, nor should sedimentation fields be constructed at the edge of natural salt marshes to extent the marsh. The construction of sedimentation fields would transform one highly valued natural feature – the tidal flats – into another one. For the same reason we advised against hydraulic filling for „salt marsh building" or as a

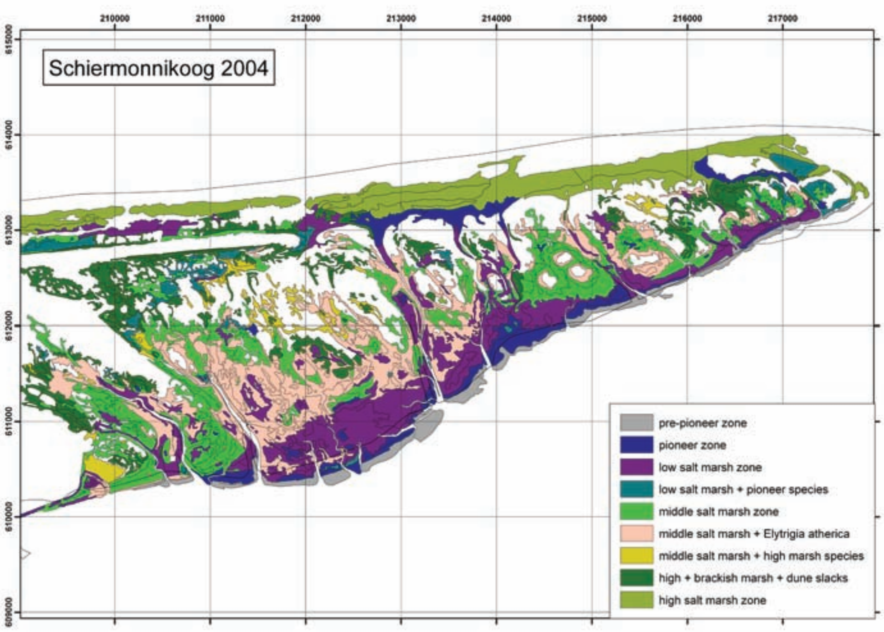


Figure 6: Vegetation map of the barrier-island Schiermonnikoog as an example of the Trilateral salt marsh aim: a vegetation biodiversity reflecting the geomorphological conditions of the habitat.

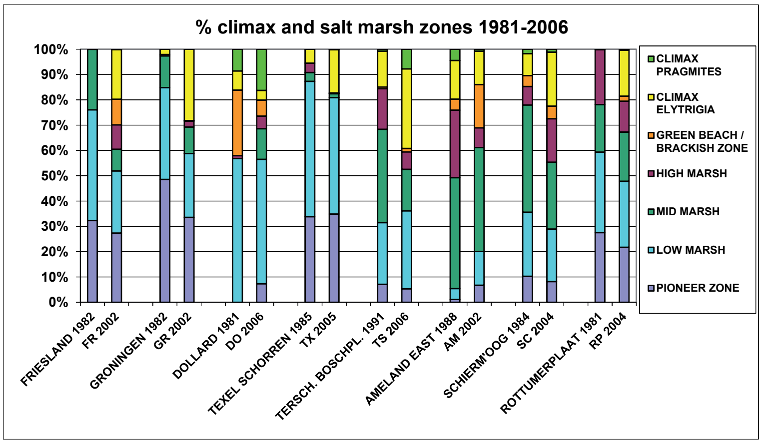


Figure 7: Comparing vegetation maps of RWS-DID (Dijkema *et al.*, 2007).

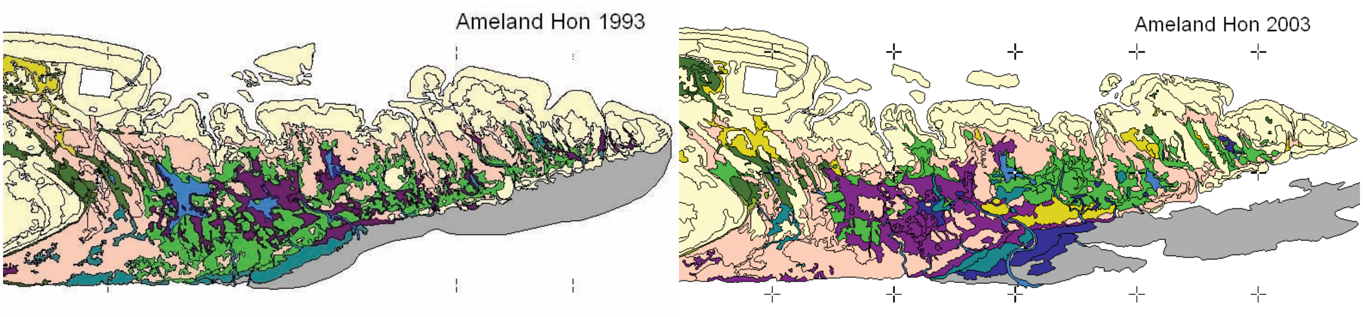
protection measure. The only exception is for dike protection in the future to counteract an increased sea level rise *e.g.* for restoration of the 30 km long Afsluitdijk with a sustainable salt marsh in front of the dike.

5. Vegetation succession and biodiversity

Monitoring with vegetation maps is essential for scaling-up of the transect method. Sequential vegetation maps show the development of the entire marsh area and its vegetation biodiversity (Figure 6). A 30-year series of vegetation maps of all salt marshes in The Netherlands and the estuarine Dollard marshes shows that vertical sedimentation triggers vegetation succession to older stages with less biodiversity. The autonomous aging process is accelerated on creek levees, on salt marshes without cyclic processes (sand-dike or groyne protected) and on drained mainland marshes (Figure 7; Dijkema *et al.*, 2007). The distribution of vegetation zones and succession climax stages is still diverse. Due to succession, the area of climax-vegetation has increased; on the islands, the high marsh zone decreased and on the mainland coast, the low marsh zone decreased. Groningen and Friesland mainland shows the highest increase of *Elytrigia* climax due to highest figures for sedimentation (Friesland) and strongest decrease in grazing (Groningen). In the Dollard, the *Elytrigia* climax has decreased, caused by an overall grazing management and by rewetting due to ditch-blocking in the eastern segment; grazing is not enough to stop the increase of the brackish *Phragmites* climax (Esselink, 2000). On the barrier islands, *Elytrigia* climax increases on Texel, Terschelling, Schiermonnikoog and Rottumerplaat. *Elytrigia* climax has the highest share on the oldest sand-dike protected salt marsh Boschplaat, on the barrier-island Terschelling. On the barrier-island Ameland, heavy grazing and soil subsidence slow down succession. The most important sites for the pioneer zone are the Friesland and Groningen mainland salt marsh works.

A 22-year period of 1.5 mm/y soil subsidence on Ameland had ver little effect on the salt marsh vegetation (Figure 8). The maps show a 10 ha regression in salt marsh basins with a relative large distance to the sediment source (central part, from green middle marsh to purple low marsh). The other parts show 20 ha autonomous succession to *Elytrigia atherica* climax (rose) and even 5 ha new marsh growth (central south part, dark

Figure 8: Comparison of vegetation maps of 1993 and 2003 from the soil subsidence area De Hon on the barrier-island Ameland.



blue). Most remarkable is the succession from a 2.4 ha water-filled basin (left part, blue) to low marsh zone (pink) after natural connection of the basin to a creek. The hypothesis of Dijkema *et al.* (1990), that a delay in the regression of salt marsh vegetation after soil subsidence and/or sea level rise allows an increased vertical accretion to compensate for the subsidence of the marsh surface, may come true. Year-to-year fluctuations in MHT-levels, and especially years with raised average MHT-levels, may contribute to this compensation mechanism (Figure 5; Dijkema *et al.*, 2007). Aging is decreased by soil subsidence (and/or sea-level rise; Figure 7).

6. Conclusions

Vegetated salt marshes are sustainable habitats in present scenarios for sea level rise and subsidence due to gas extraction:

- Management measures should focus on (1) upkeep of mainland pioneer zone for protecting the marsh edge and (2) allowing more dynamics on the barrier island marshes.
- Recommendations for restoring pioneer zones to a successful defence zone against erosion of both salt marsh and coastal zones were based on a 50-year monitoring series.
- The present man-made marsh-renewal technique is an opportunity for coastal defence, *e.g.* for restoration of the 30 km long Afsluitdijk with a sustainable salt marsh in front of the dike.
- The trend in vegetation succession is aging from young marsh to climax vegetation, leading to a decrease in young successional stages and in biodiversity:
- Management measures should focus on rejuvenation of salt marsh vegetation.
- The TMAP trilateral salt marsh aim "Biodiversity reflecting geomorphological conditions" means that management should not be reached by "gardening".
- We recommend the development of a biodiversity measurement tool using the new TMAP-classification.

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