BIO-PHYSICAL INTERACTIONS IN TIDAL MARSHES & THEIR ROLE IN NATURE-BASED COASTAL DEFENSE

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Natural ecosystems reduce waves, storm surges, erosion, build up land with rising sea & additional benefits.

Towards more sustainable coastal defense by Nature-based risk reduction & Engineering

E.g. Temmerman & Kirwan (2015) Science
1) How effective is WAVE ATTENUATION by marshes?
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WAVES

How plants affect waves?... much studies
How waves affect where plants can grow? ... much less known

MUTUAL FEEDBACKS ??

Dike
1) How effective is WAVE ATTENUATION by marshes?

How plants affect waves? ... much studies
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MUTUAL FEEDBACKS ??

PhD work of:

Alexandra Silinski
Maike Heuner
Ken Schoutens
1) How effective is WAVE ATTENUATION by marshes?

Study on 2 species dominant at marsh front in NW European brackish estuaries (Elbe, Weser)
Showing typical species zonation

Heuner et al. (2015) PlosOne

- Scirpus maritimus
- Scirpus tabernaemontani
1) How effective is WAVE ATTENUATION by marshes?

Clear species zonation in main channels of Elbe & Weser (wave-exposed, fetch lengths ~several km)

PhD Maike Heuner
1) How effective is WAVE ATTENUATION by marshes?

Species zones overlap in anabranches of Elbe & Weser (wave-sheltered, fetch lengths ~few 100s of m)

PhD Maike Heuner
1) How effective is WAVE ATTENUATION by marshes? 

Questions: 
(1) to which extent is species zonation a result of species-dependent plant tolerance to waves? 
(2) What is feedback on species-dependent wave attenuation?
1) How effective is WAVE ATTENUATION by marshes?

Effects of different plant traits?

PLANTS  

WAVES  

Plant surface area
- +

Plant stiffness
- +

Scirpus tabernaemontani

Scirpus maritimus
1) How effective is WAVE ATTENUATION by marshes?

Effects of different plant traits?

PLANTS ➔ WAVES

Differences in plant stiffness

Heuner et al. (2015) PlosOne
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PLANTS  

WAVES
1) How effective is WAVE ATTENUATION by marshes?

Effects of different plant traits?

Plants \[\rightarrow\] Waves

Flume experiments: exposing plants to waves & erosion

1) How effective is WAVE ATTENUATION by marshes?

Effects of different plant traits?

The **MORE STIFF** species provides **MORE WAVE ATTENUATION**

In the lab

Measured over 1.6 m distance

Heuner et al. (2015)  
PlosOne
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Effects of different plant traits?

PLANTS ➔ WAVES
1) How effective is WAVE ATTENUATION by marshes?

Effects of different plant traits?

PLANTS → WAVES

Flume experiments: measuring drag forces (pulling on plants)

1) How effective is WAVE ATTENUATION by marshes?

Effects of different plant traits?

The MORE FLEXIBLE species feels LESS DRAG from waves.

Heuner et al. (2015) PlosOne
1) How effective is WAVE ATTENUATION by marshes?

Effects of different plant traits?

Plants → Waves

Flume experiments: measuring stem bending before & after 200 waves

1) How effective is WAVE ATTENUATION by marshes?

Effects of different plant traits?

The MORE FLEXIBLE species is LESS BENDED after waves.
1) How effective is WAVE ATTENUATION by marshes?

The MORE FLEXIBLE species COPES BETTER with waves & therefore can grow in MORE WAVE-EXPOSED locations??
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Transplantation experiments with manipulation of wave regime
Elbe estuary, winter 2018 – winter 2020
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Elbe estuary, winter 2018 – winter 2020

3 species
X 20 replicas
X 3 elevations
X 2 wave regimes
2-yr monitoring of waves, currents, sedimentation-erosion, sediment & plant properties…
1) How effective is WAVE ATTENUATION by marshes?

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Transplantation experiments with manipulation of wave regime
Elbe estuary, winter 2018 – winter 2020

![Graph showing plant survival rate in wave exposed and sheltered conditions](image)

- **Very preliminary results**
- **Kaplan-Meyer survival analysis**
1) How effective is WAVE ATTENUATION by marshes?

Summarizing....

Intensity of interaction depends on

DRAG

Plant stiffness, surface area, density, biomass...

\[ \downarrow \]

\[ \downarrow \]

e.g. MORE STIFF

LESS EFFECTIVE to grow in WAVE-EXPOSED locations (?)

MORE EFFECTIVE in WAVE ATTENUATION

TRADE-OFFS
2) Predicting long-term, landscape-scale marsh dynamics?

Nature restoration in Hedwige- & Prosperpolder (HPP), Schelde

‘Verdronken Land van Saeftinghe’:
~3000 ha tidal marshes
~100 000 ha in historic times
(>1000 years ago)

‘De-poldering HPP’:
~465 ha new tidal marshes
2) Predicting long-term, landscape-scale marsh dynamics?

Nature restoration in Hedwige- & Prosperpolder (HPP), Schelde
2) Predicting long-term, landscape-scale marsh dynamics?

Nature restoration in Hedwige- & Prosperpolder (HPP), Schelde

+4,65 km² new marsh under construction & realized by ~2022
2) Predicting long-term, landscape-scale marsh dynamics?

Nature restoration in Hedwige- & Prosperpolder (HPP), Schelde

+4,65 km² new marsh under construction & realized by ~2022

Reasons:
- Dutch-Flemish agreement “Schelde-verdrag 2005”
- Restoration of historically lost mudflats & marshes; to meet EU Natura 2000
- Water storage to mitigate storm surges & flood risks (Flemish Sigmaplan + 40 km² new floodplains)
- Not compensation for dredging & port access
2) Predicting long-term, landscape-scale marsh dynamics?

How successful is marsh restoration in a former polder area?

Will it stay ‘a big box of mud’ for ever?
Will it evolve quickly to a ‘boring’ climax vegetation of reeds?

Can you steer the development?
(options: breach width & number, digging channels,...)
2) Predicting long-term, landscape-scale marsh dynamics?

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2) Predicting long-term, landscape-scale marsh dynamics?

A new bio-geomorphic model

- Hydrodynamics
- Morphodynamics
- Vegetation dynamics
2) Predicting long-term, landscape-scale marsh dynamics?

A new bio-geomorphic model
Based on extensive new field & flume data
2) Predicting long-term, landscape-scale marsh dynamics?

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A new bio-geomorphic model
New techniques for coupling of multi-scale interactions

Vegetation model
0.25 m resolution
2) Predicting long-term, landscape-scale marsh dynamics?

A new bio-geomorphic model
New techniques for coupling of multi-scale interactions

Vegetation model
0.25 m resolution

Hydro- & morphodynamic model
coarser resolution & TIN
2) Predicting long-term, landscape-scale marsh dynamics?
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- Schelde
- Hedwigepolder
- Prosperpolder
- Digging channels
- Bird breeding islands
- Dike breaches

Diagram showing the marsh dynamics with a color gradient and markers for specific locations and actions.
2) Predicting long-term, landscape-scale marsh dynamics?
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Topographical development
2) Predicting long-term, landscape-scale marsh dynamics?

Development of main vegetation types
2) Predicting long-term, landscape-scale marsh dynamics?

Slow development; uncertainty due to stochasticity etc....
2) Predicting long-term, landscape-scale marsh dynamics?

Slow development; uncertainty due to stochasticity etc....

Equilibrium level of marshes

Area-averaged soil elevation [m TAW]

Time [year]
2) Predicting long-term, landscape-scale marsh dynamics?

Calculation of delivery of ecosystem services: sediment removal

~100,000 tons/year
2) Predicting long-term, landscape-scale marsh dynamics?

Calculation of delivery of ecosystem services: **sediment removal**

![Graph showing sedimentation rate over time](image)

**Total sedimentation rate**

- **$10^3$ tons/year**

**Time [year]**

In comparison:

- **Yearly local sediment flux**: $\sim 1 - 3$ million m$^3$/year
- **$\sim 200\ 000$ m$^3$/year**
2) Predicting long-term, landscape-scale marsh dynamics?

Calculation of delivery of ecosystem services: carbon removal

~6 000 ton C/year
~Yearly emission of ~9000 cars

x 9000 / year
2) Predicting long-term, landscape-scale marsh dynamics?

Temporal ‘de-poldering’ as a measure to build up land elevation with sea level rise.
2) Predicting long-term, landscape-scale marsh dynamics?

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Temporal ‘de-poldering’ as a measure to build up land elevation with sea level rise
2) Predicting long-term, landscape-scale marsh dynamics?

Rate of sedimentation & vegetation development: can be steered by dike breach design

**Prosperpolder**
**Small dike breach** (50 m)
2) Predicting long-term, landscape-scale marsh dynamics?

Rate of sedimentation & vegetation development: can be steered by dike breach design
2) Predicting long-term, landscape-scale marsh dynamics?

Rate of sedimentation & vegetation development: can be steered by dike breach design

Hedwige-polder
Wide dike breach (600 m)
Slower sedimentation

Prosper-polder
Small dike breach (50 m)
Faster sedimentation
2) Predicting long-term, landscape-scale marsh dynamics?

Summarizing…

• HPP does not develop into ‘mud box’ or ‘boring reed marsh’
  • Instead slow development, diversity of habitat types
2) Predicting long-term, landscape-scale marsh dynamics?

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- HPP does not develop into ‘mud box’ or ‘boring reed marsh’
  - Instead slow development, diversity of habitat types
- Uncertainties due to stochasticity, sea level rise, sediment supply, biotic top-down controls,…
2) Predicting long-term, landscape-scale marsh dynamics?

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- Estimation of ecosystem service delivery: multi-benefits
2) Predicting long-term, landscape-scale marsh dynamics?

Summarizing…

- HPP does not develop into ‘mud box’ or ‘boring reed marsh’
  - Instead slow development, diversity of habitat types

- Uncertainties due to stochasticity, sea level rise, sediment supply, biotic top-down controls,…

- Estimation of ecosystem service delivery: multi-benefits

- Rate of land rise & vegetation development can be steered by landscape design (breach dimensions, channels…)}