Estuaries:
interface between land and sea
a complex interaction between morphology, hydrodynamics and ecology

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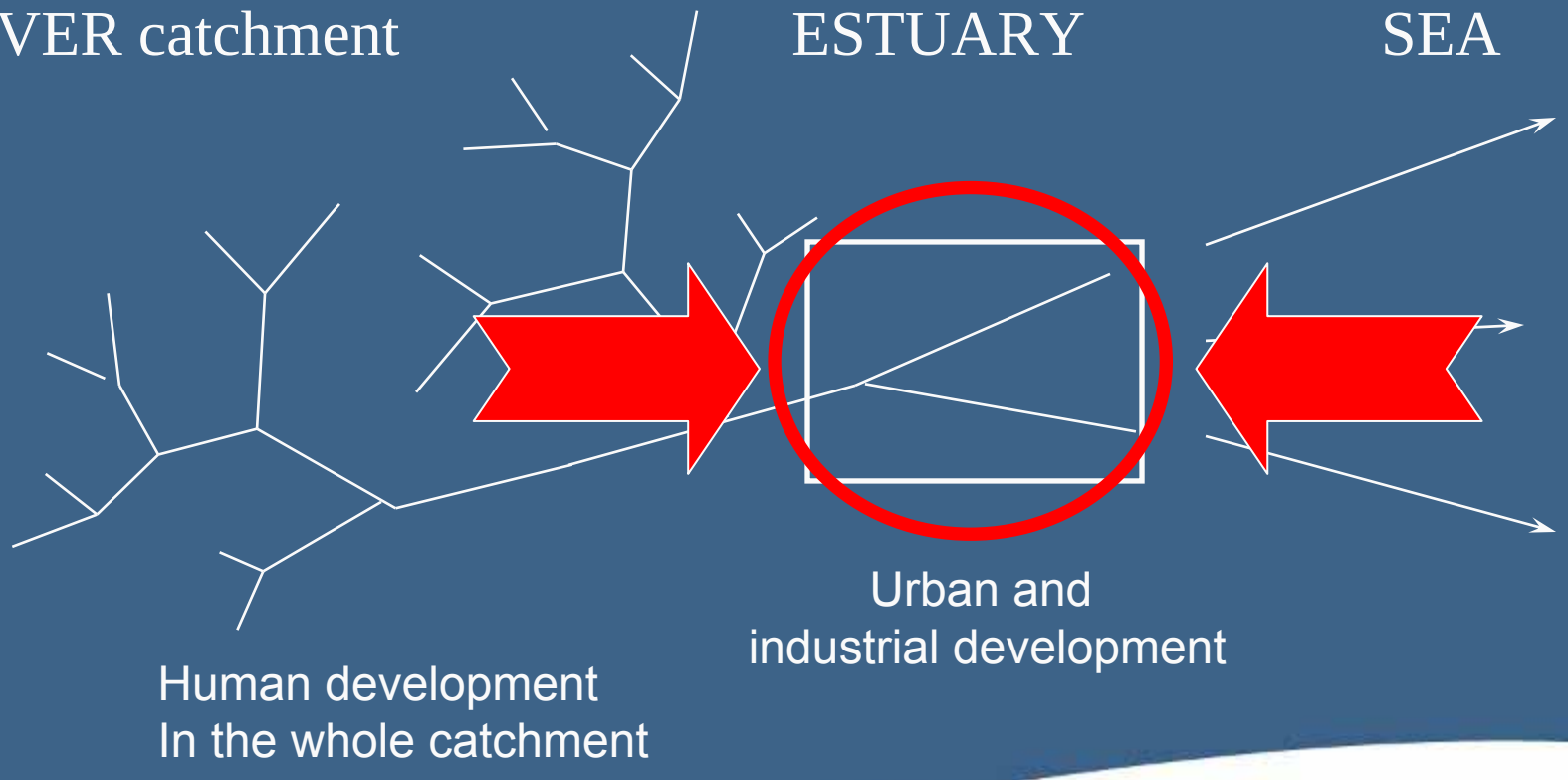
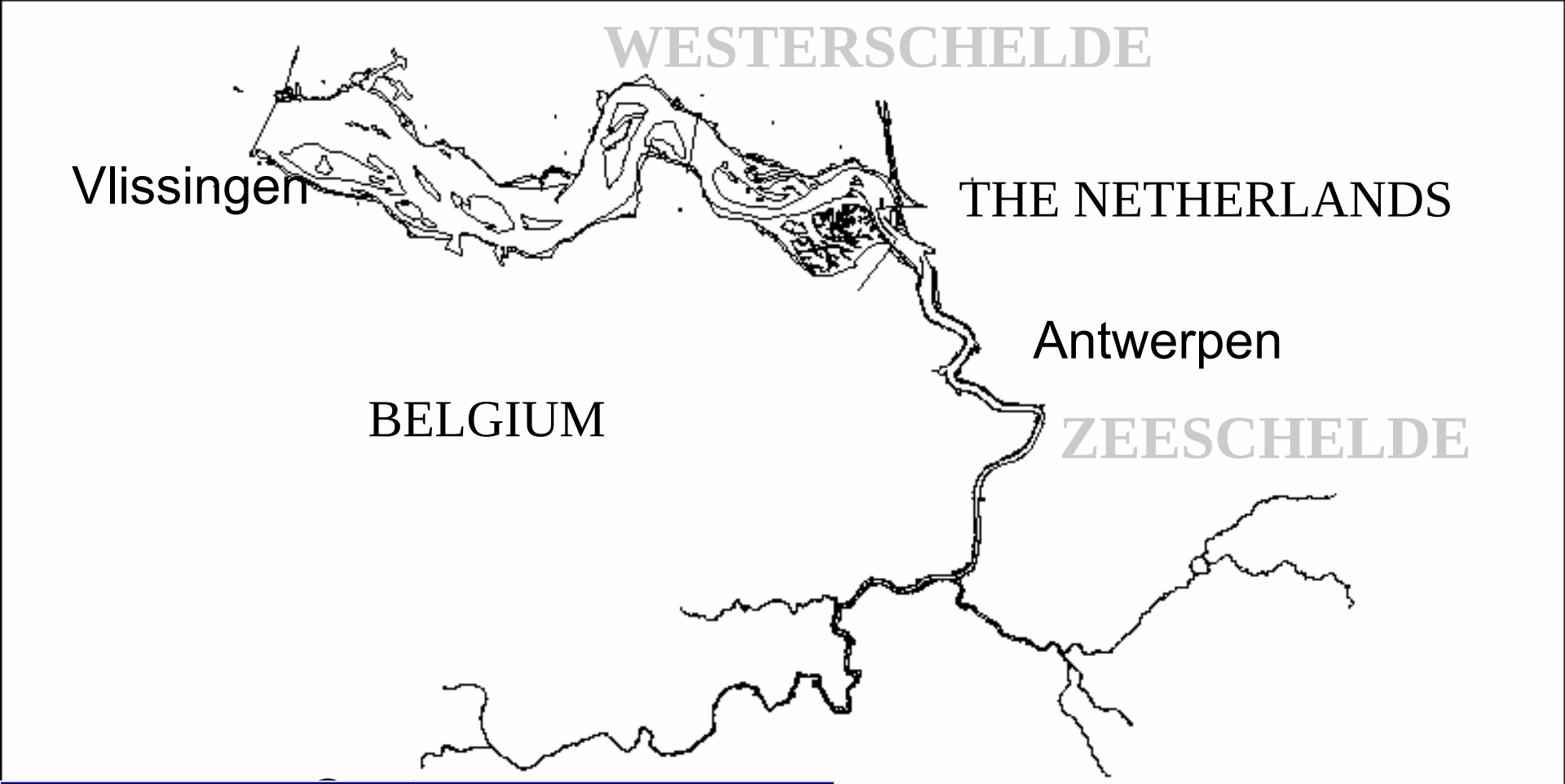
Content

- Introduction
- The Schelde estuary
- Impact of present and past management
- Conclusions

1) Introduction

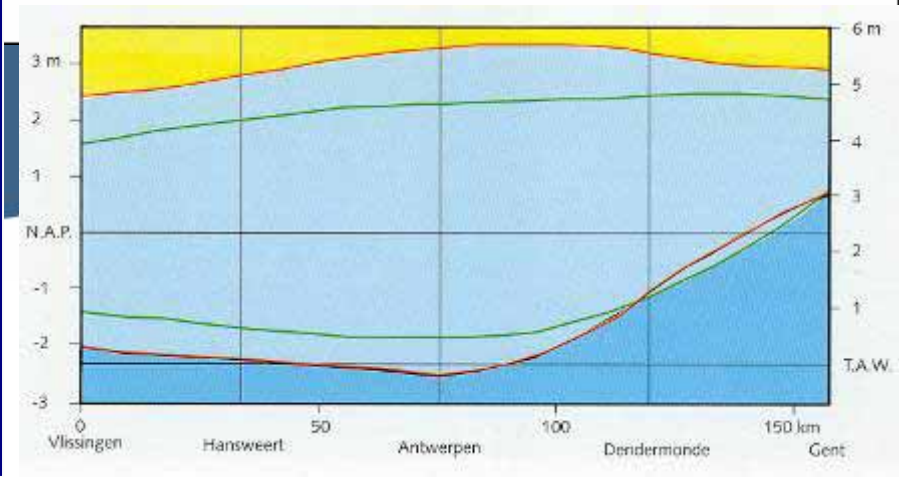


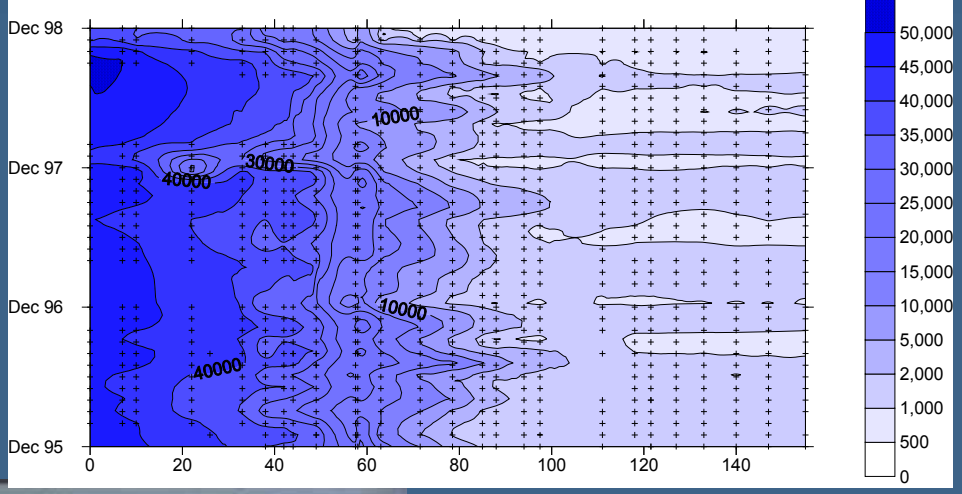
2) The Schelde estuary



The Schelde estuary:

- 160 km long and macro-mesotidal
- Entire salinty gradient from fresh to salt





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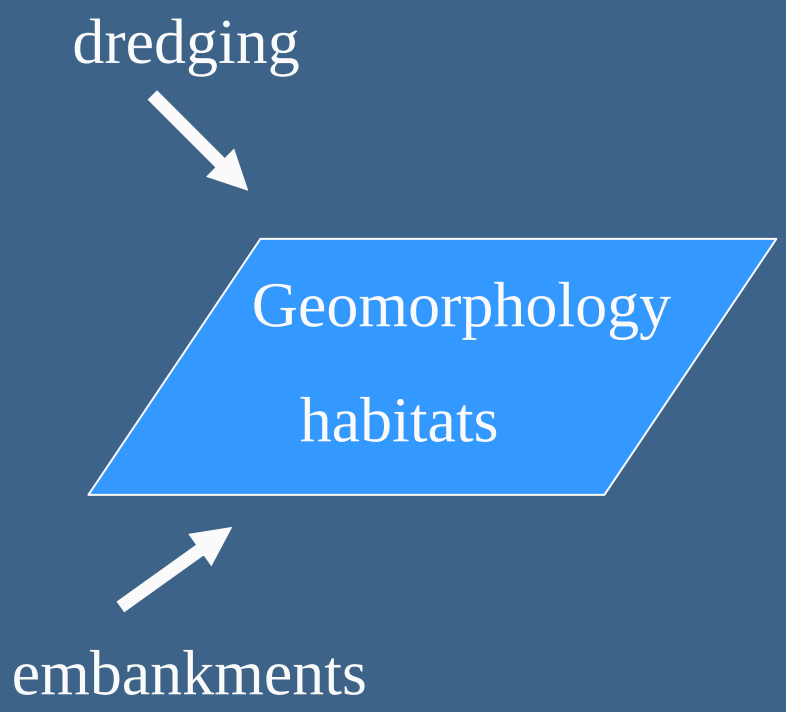
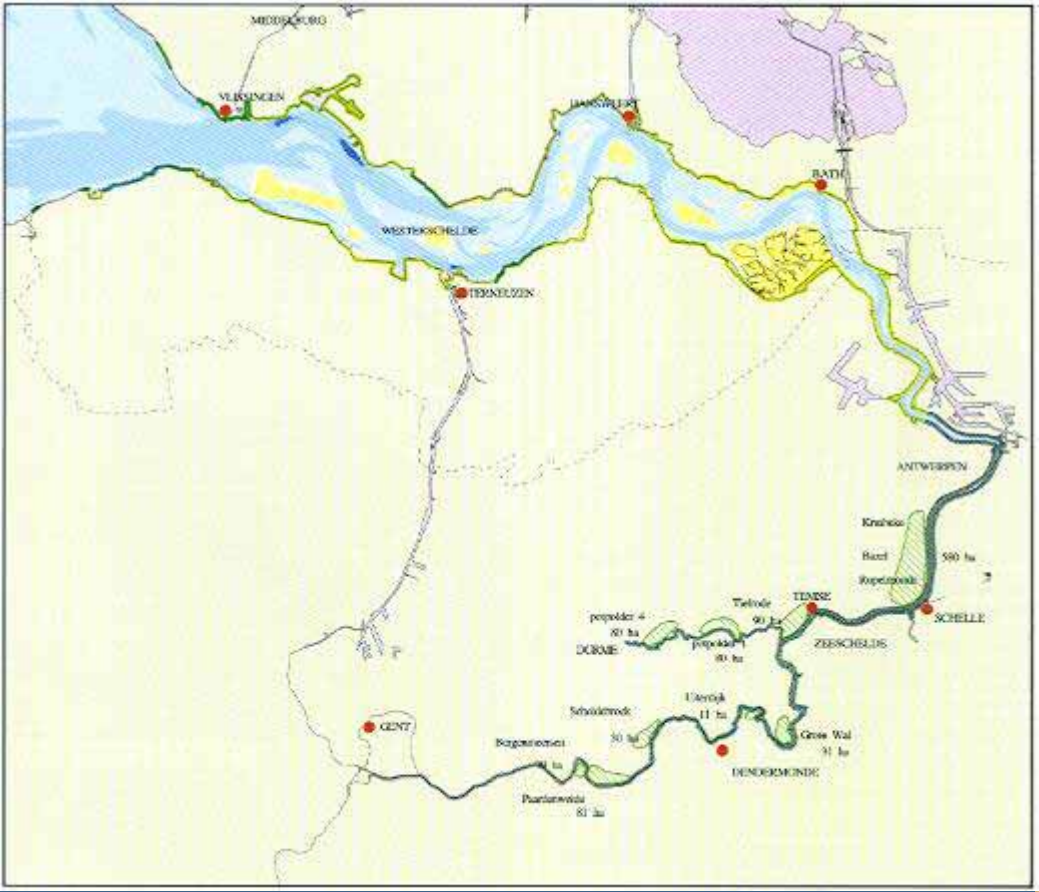
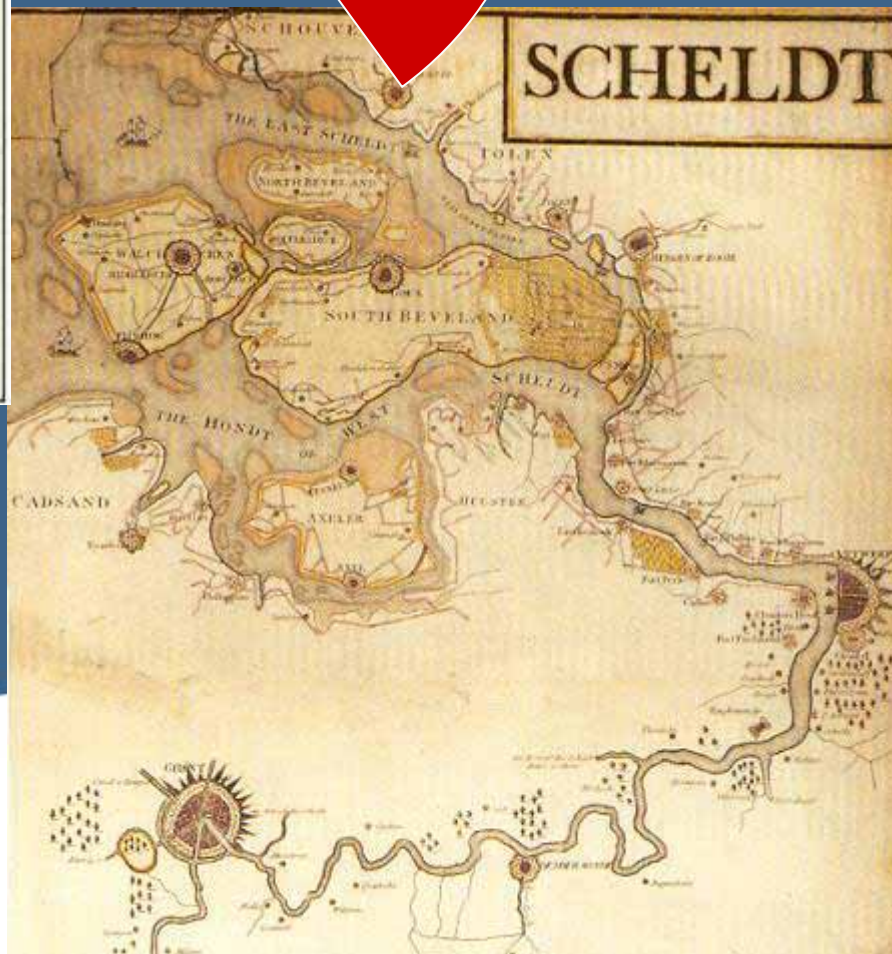
3) Impact of past and present management

Physical structure







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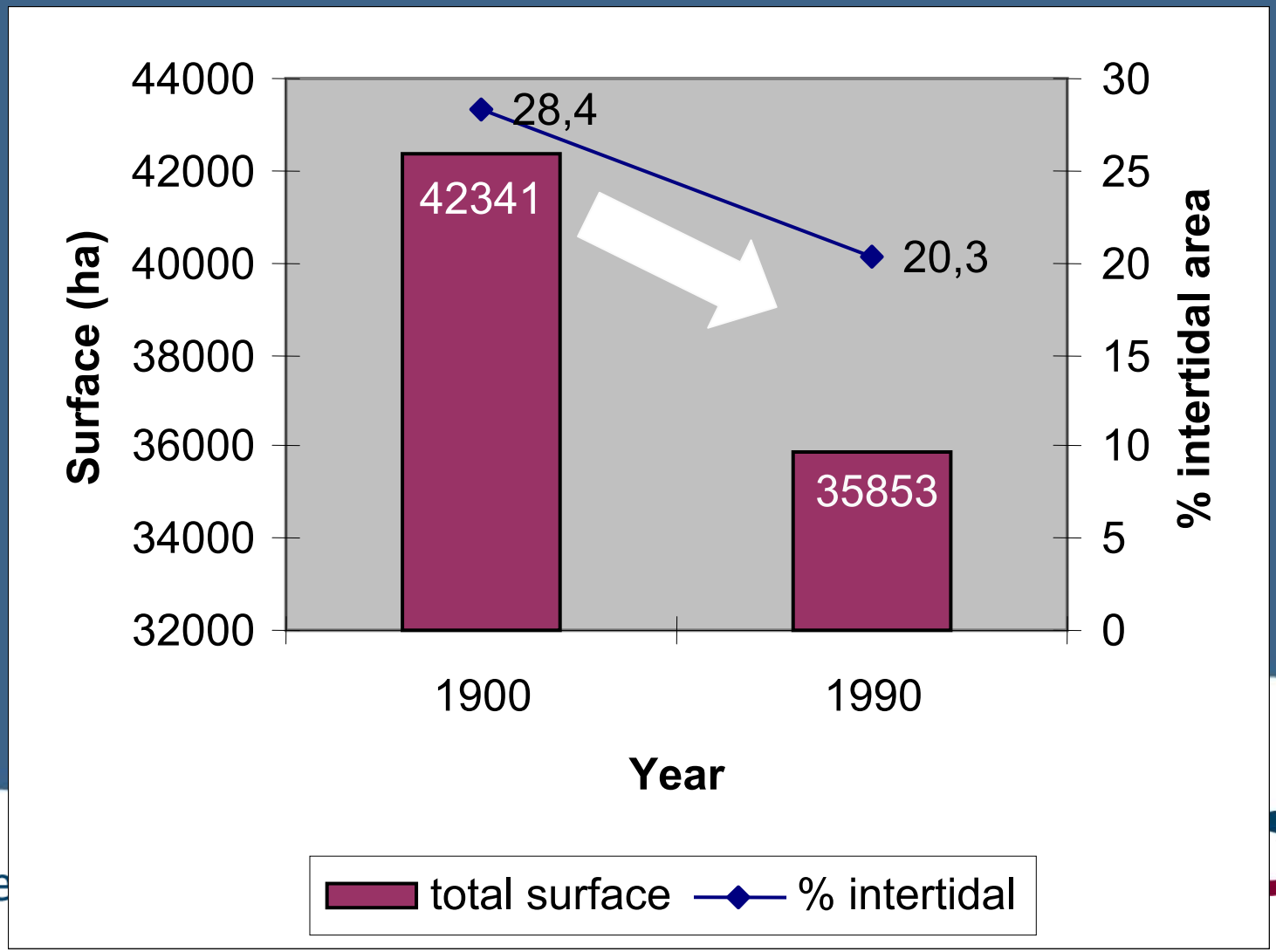
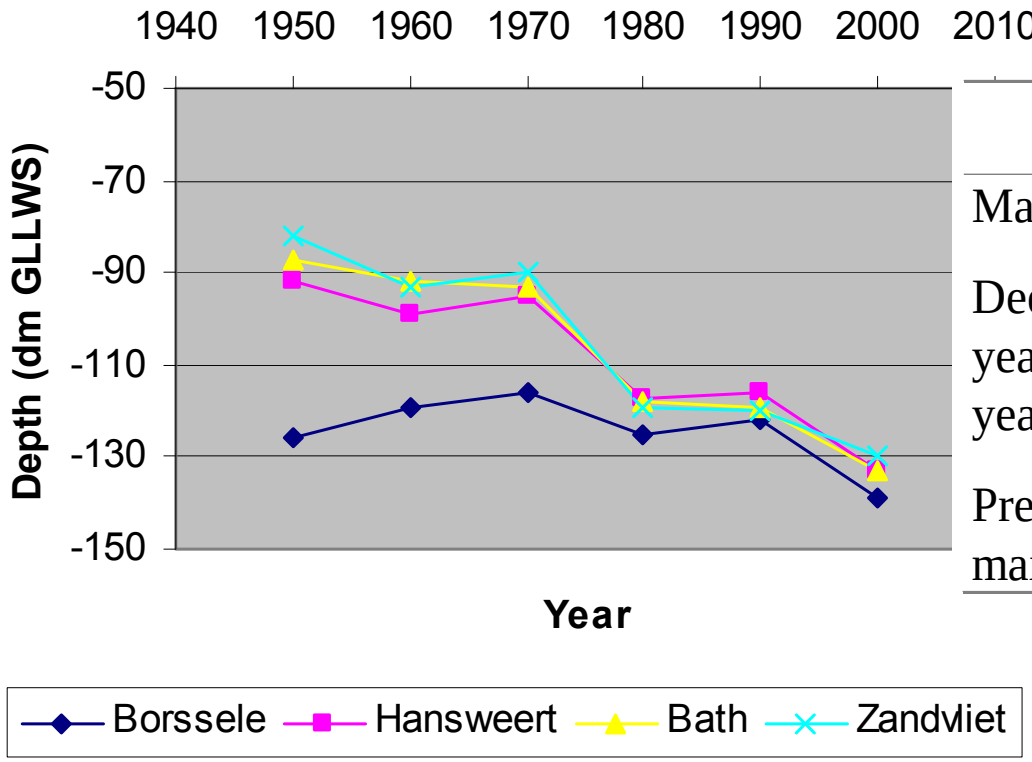
Habitat loss embankment of silted up areas





	Westerschelde	Mouth
Maintenance	8 à 9 mio	5 à 6 mio
Deepening		
year 1	17 mio	16 mio
year 2	19 mio	16 mio
Present maintenance	15 mio	10 mio

DREDGING

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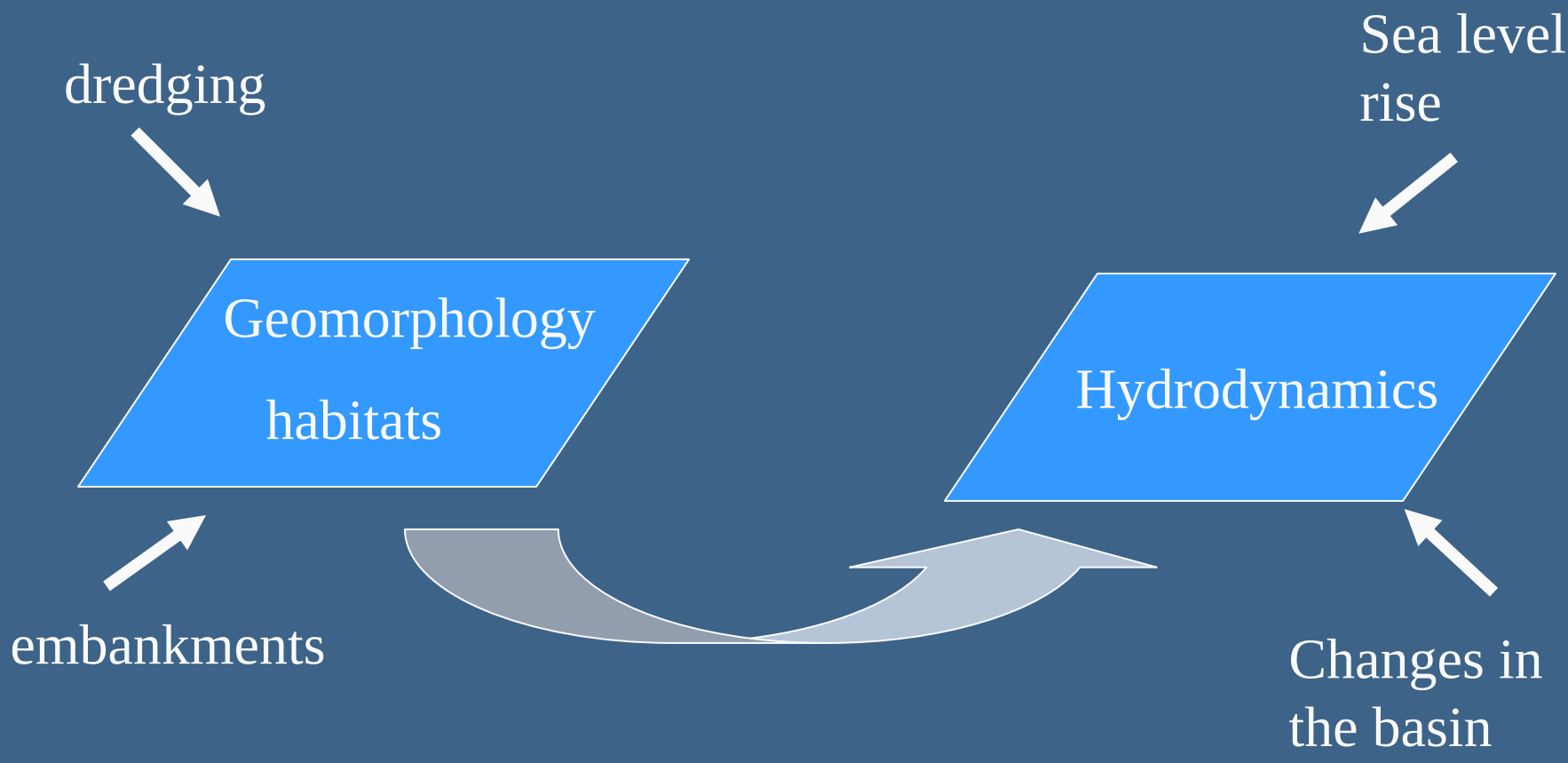
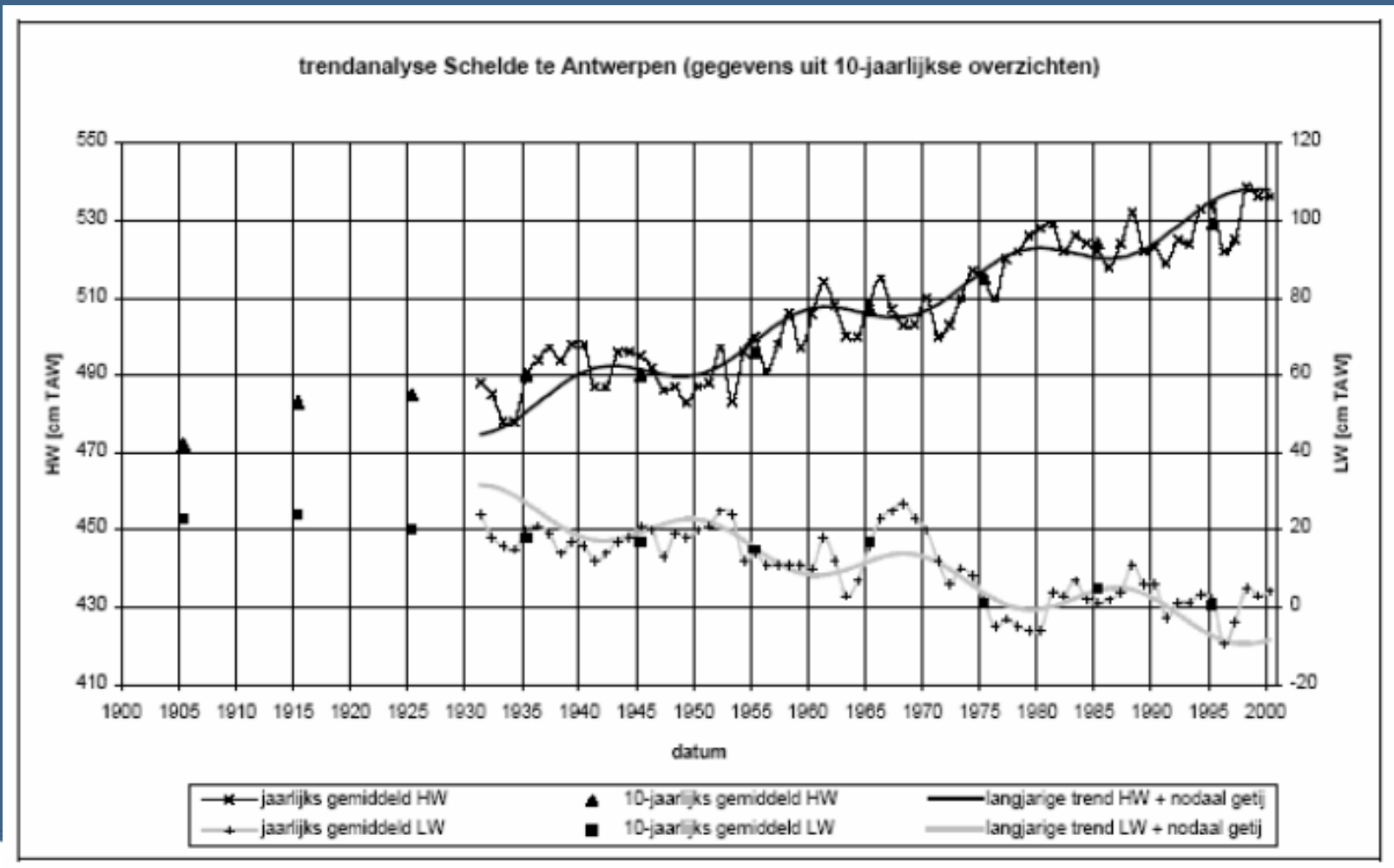
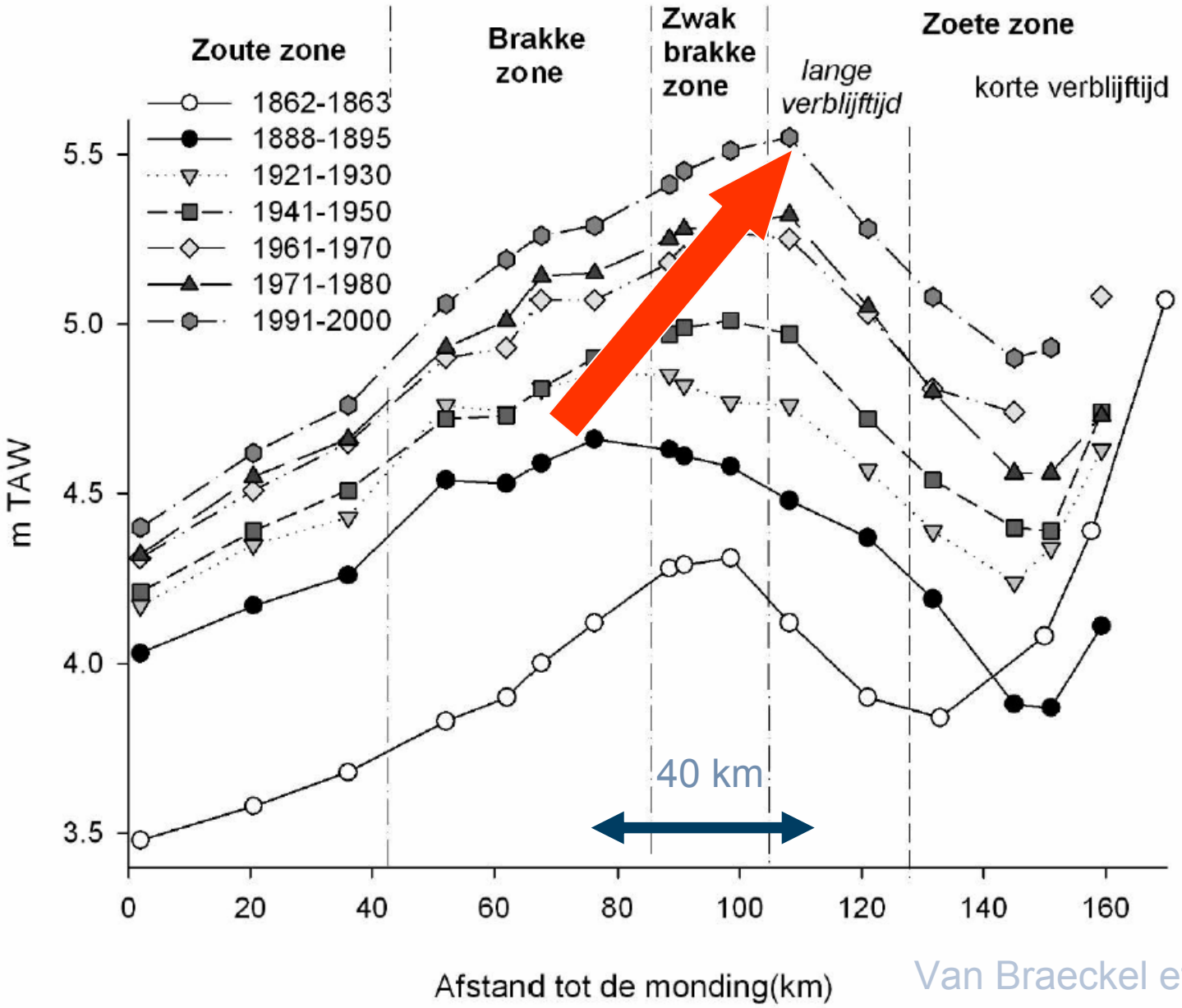

dredging
Sea level rise
Geomorphology habitats
Hydrodynamics
embankments
Changes in the basin

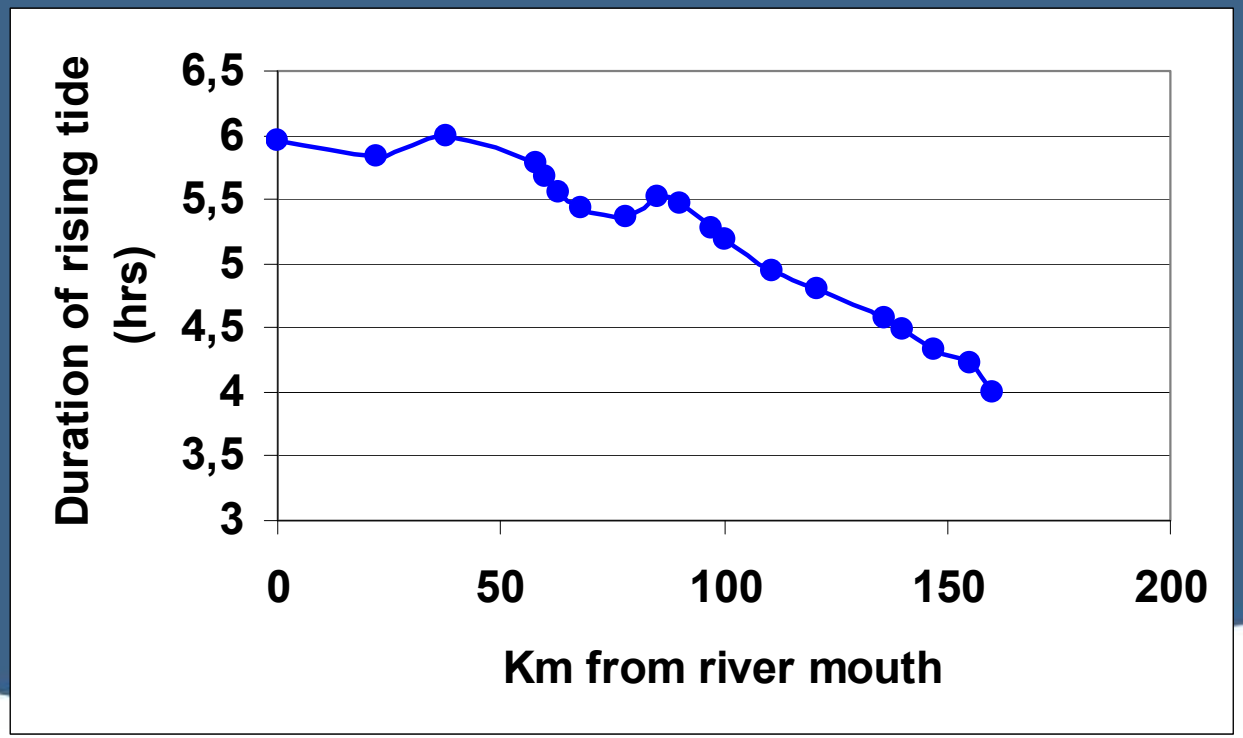

trendanalyse Schelde te Antwerpen (gegevens uit 10-jaarlijkse overzichten)
HW [cm TAW]
LW [cm TAW]
550
530
510
490
470
450
430
410
120
100
80
60
40
20
0
-20
1900 1905 1910 1915 1920 1925 1930 1935 1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000
datum
jaarlijks gemiddeld HW
jaarlijks gemiddeld LW
10-jaarlijks gemiddeld HW
10-jaarlijks gemiddeld LW
langjarige trend HW + nodaal getij
langjarige trend LW + nodaal getij

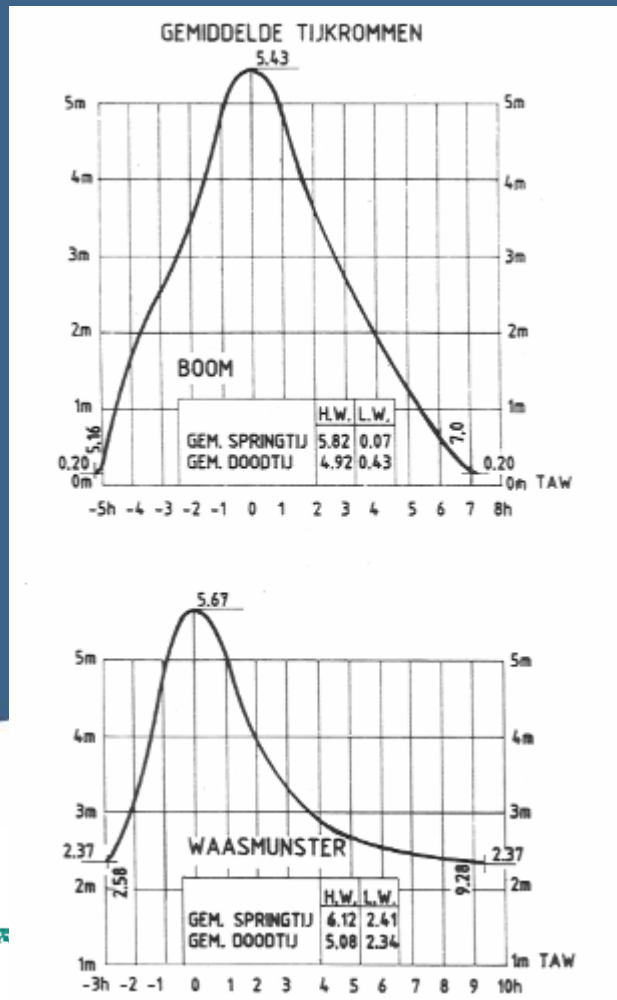
Verloop van hoogwater in de Schelde tussen 1850 en heden



Van Braeckel et al. 2006

Tidal asymmetry increases





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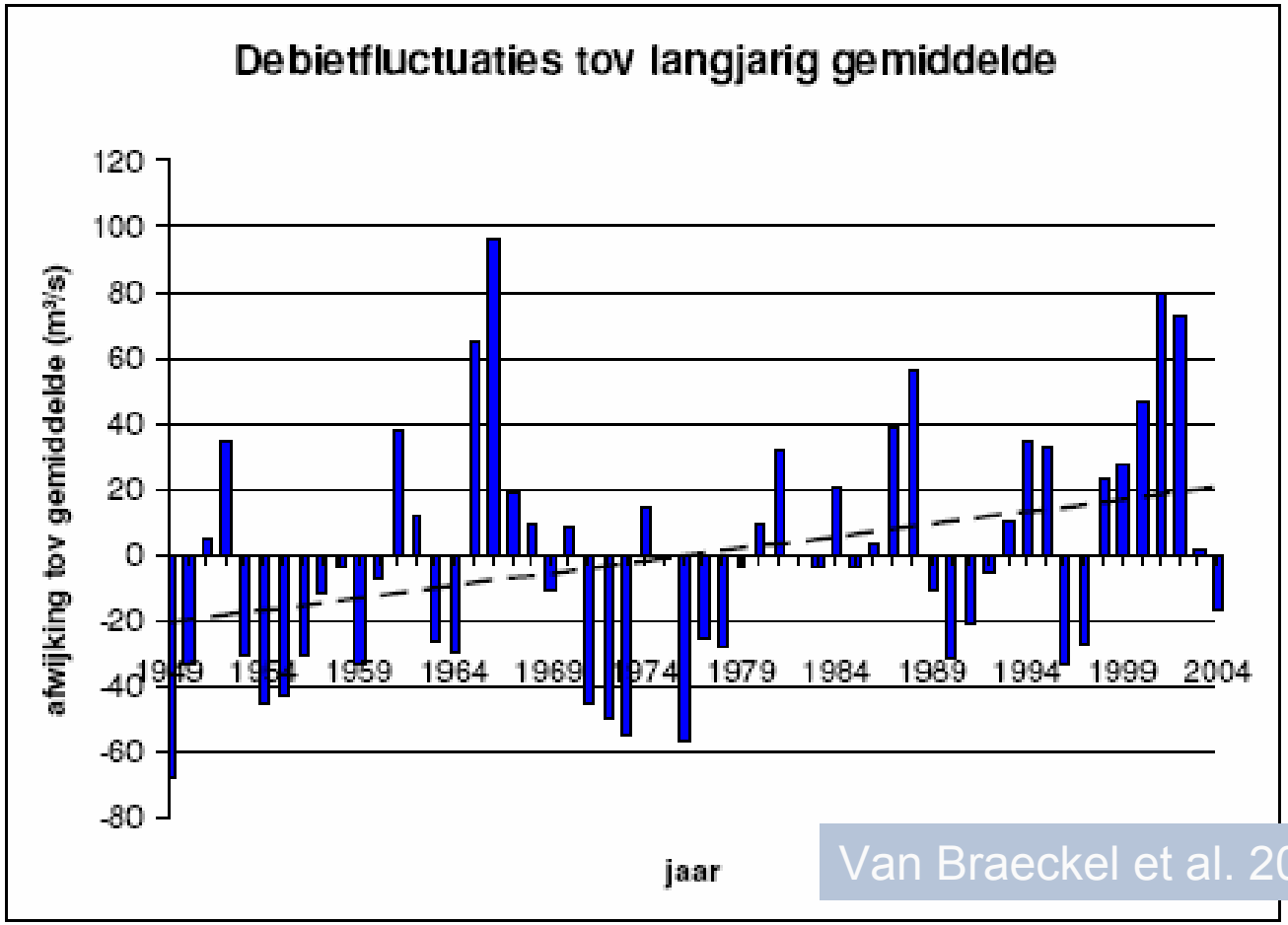
	1895	1925	1955	1985
Vlissingen - Hansweert	71	70	63	56
Vlissingen - Antwerpen	144	133	120	104

Time of flood wave (min)



- Increased discharges from the catchment
- Less buffering of peak discharges upstream

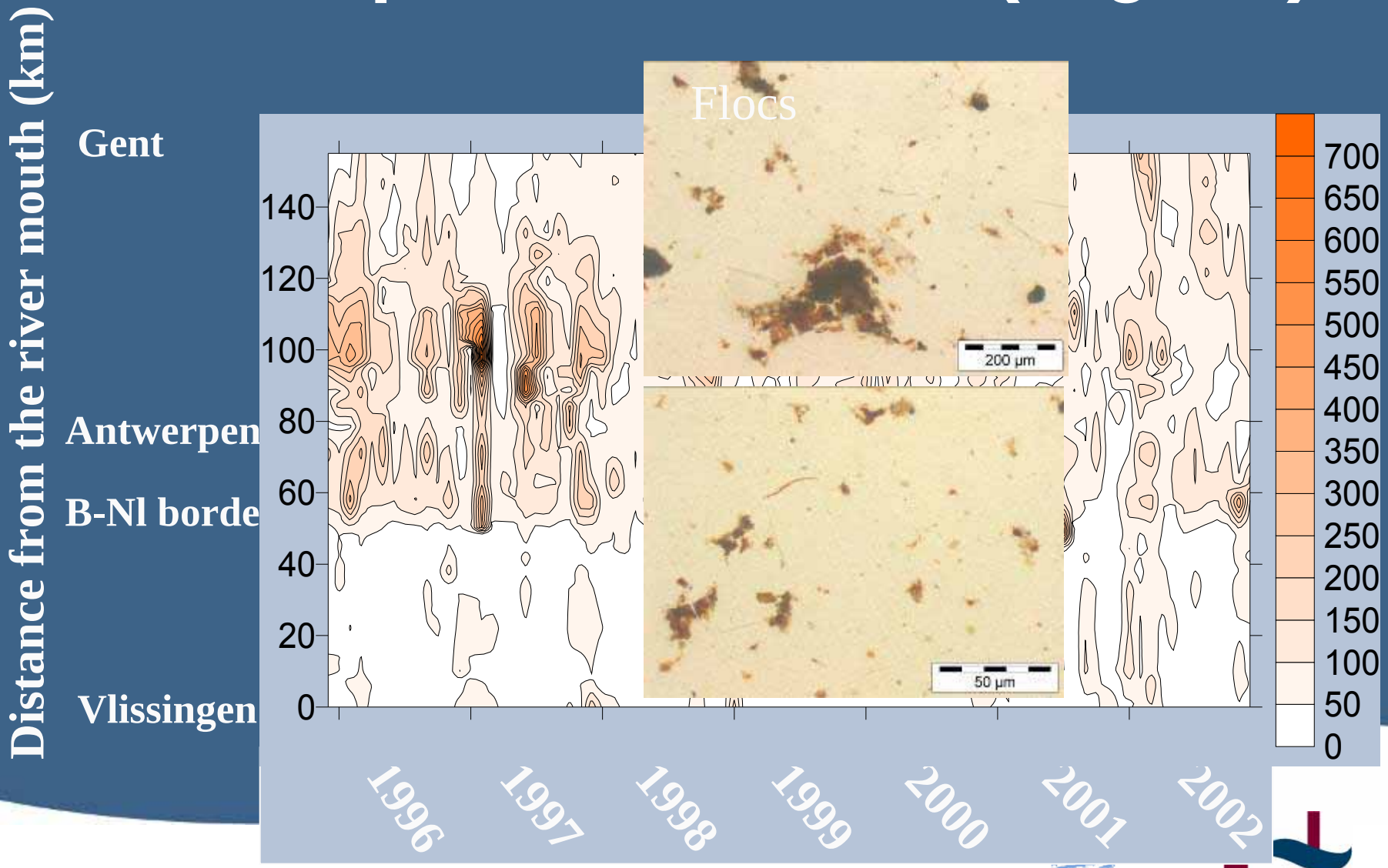
Van Braeckel et al. 2006

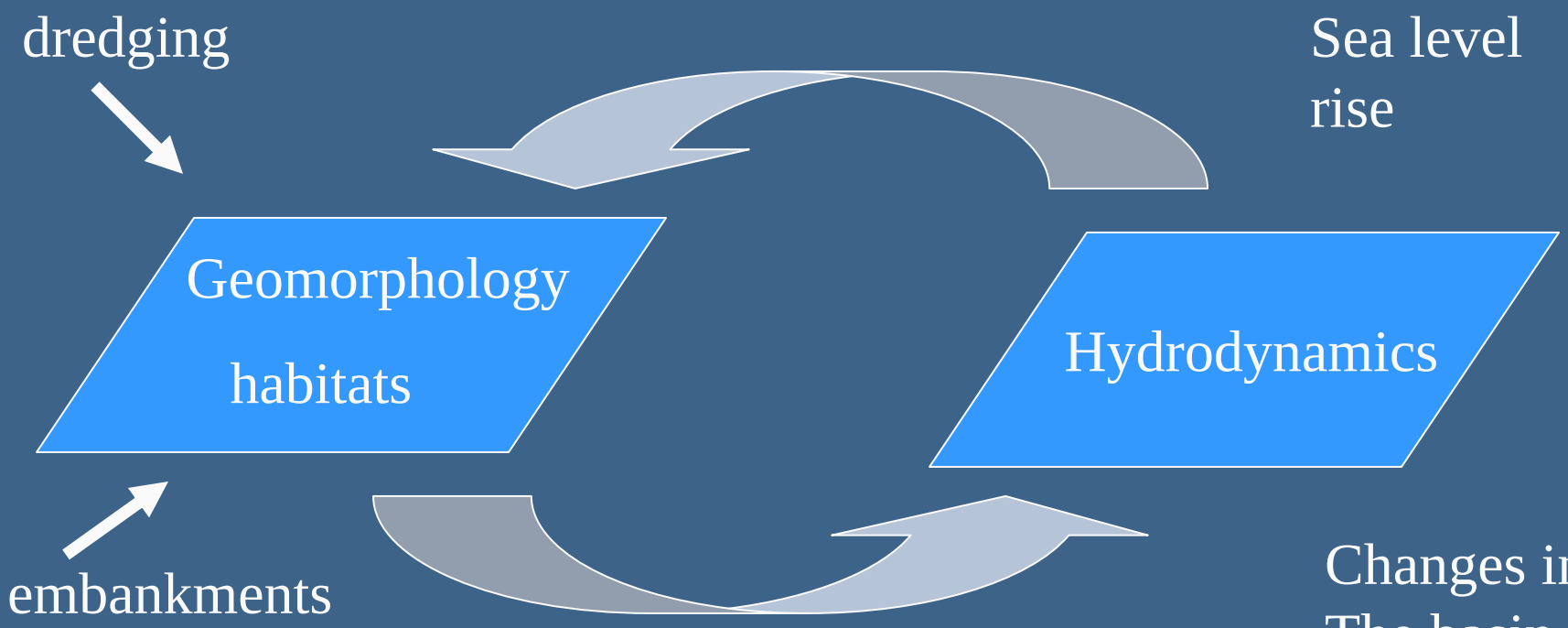
Import from the catchment: erosion

Erosion factor:
Forest: 0.001
Meadow: 0.01
Field: 0.37
(Govers, KUL)

Sediment input in the estuary, average 670.000 ton dry matter, is largely anthropogenic

Suspended matter ($mg.L^{-1}$)

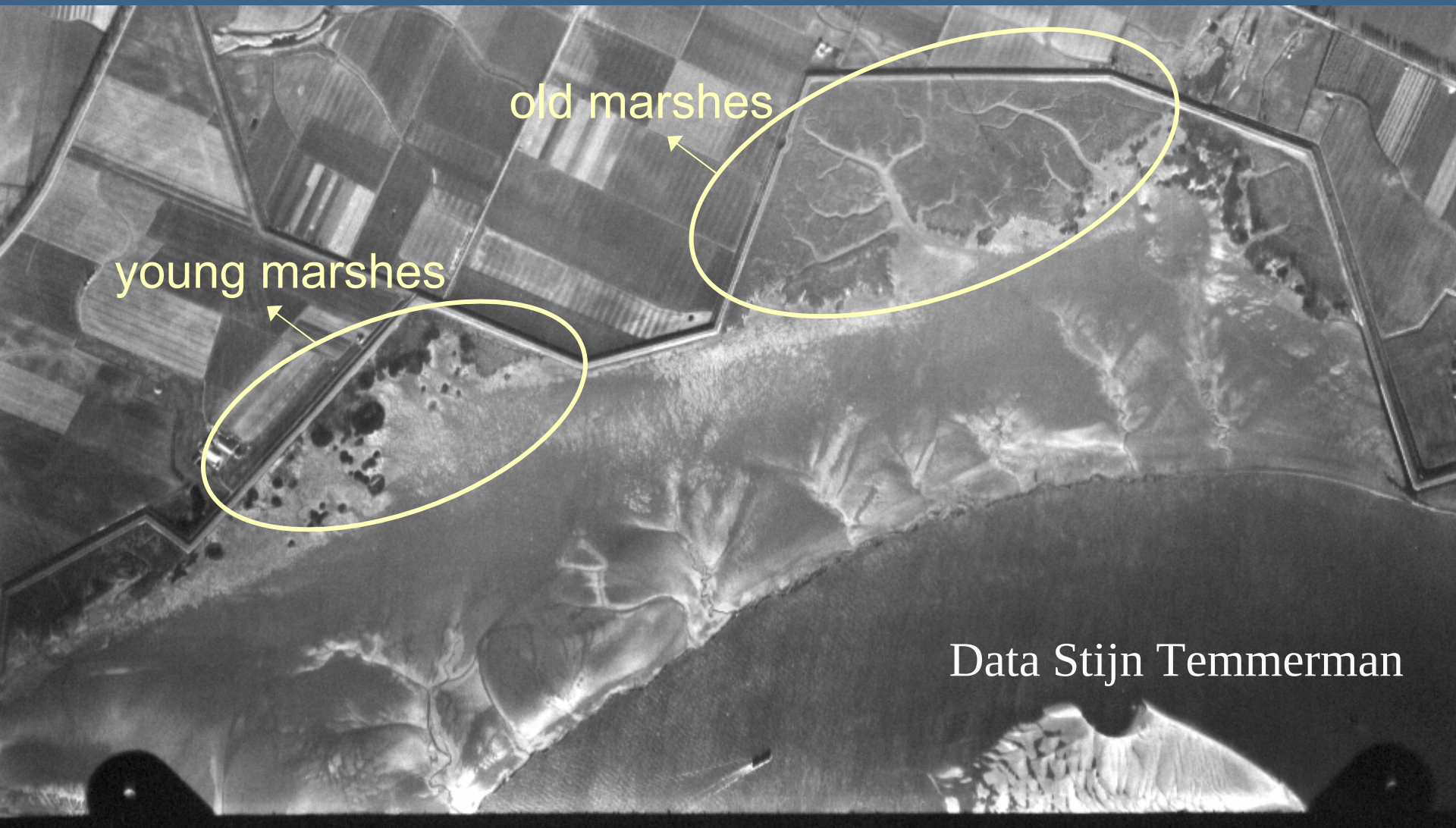



dredging
Sea level rise
Geomorphology habitats
Hydrodynamics
embankments
Changes in The basin

- Can habitats cope with this changing hydrdynamic conditions?

Tidal asymmetry ➔ Tidal pumping

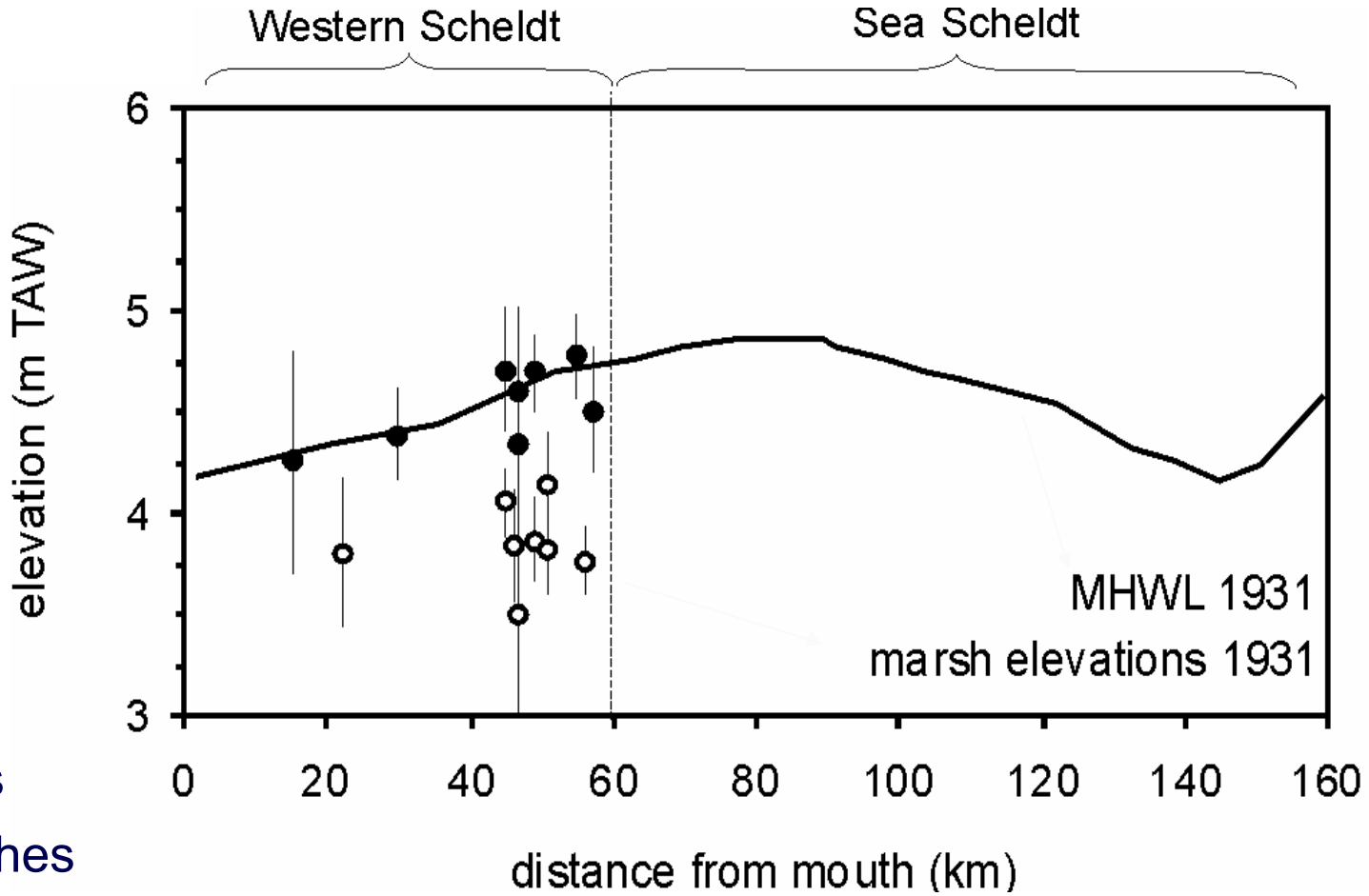
Can habitats cope with the changing tidal amplitude?



Data from aerial photgraphs and topographic maps

Temmerman et al., 2003; 2004, *Marine Geology*

1931

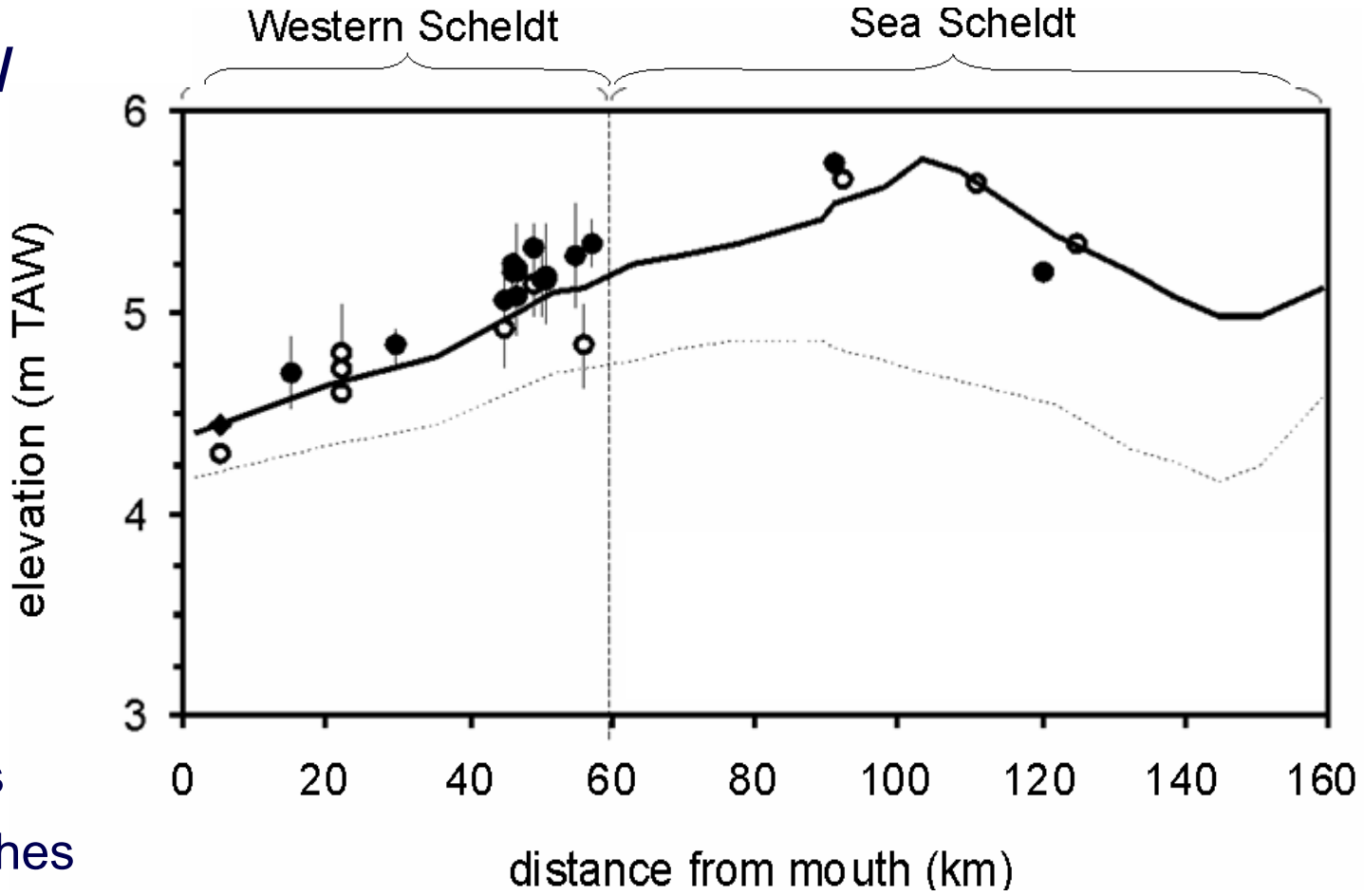


- old marshes
- young marshes

Temmerman et al., 2003; 2004, *Marine Geology*

Field data

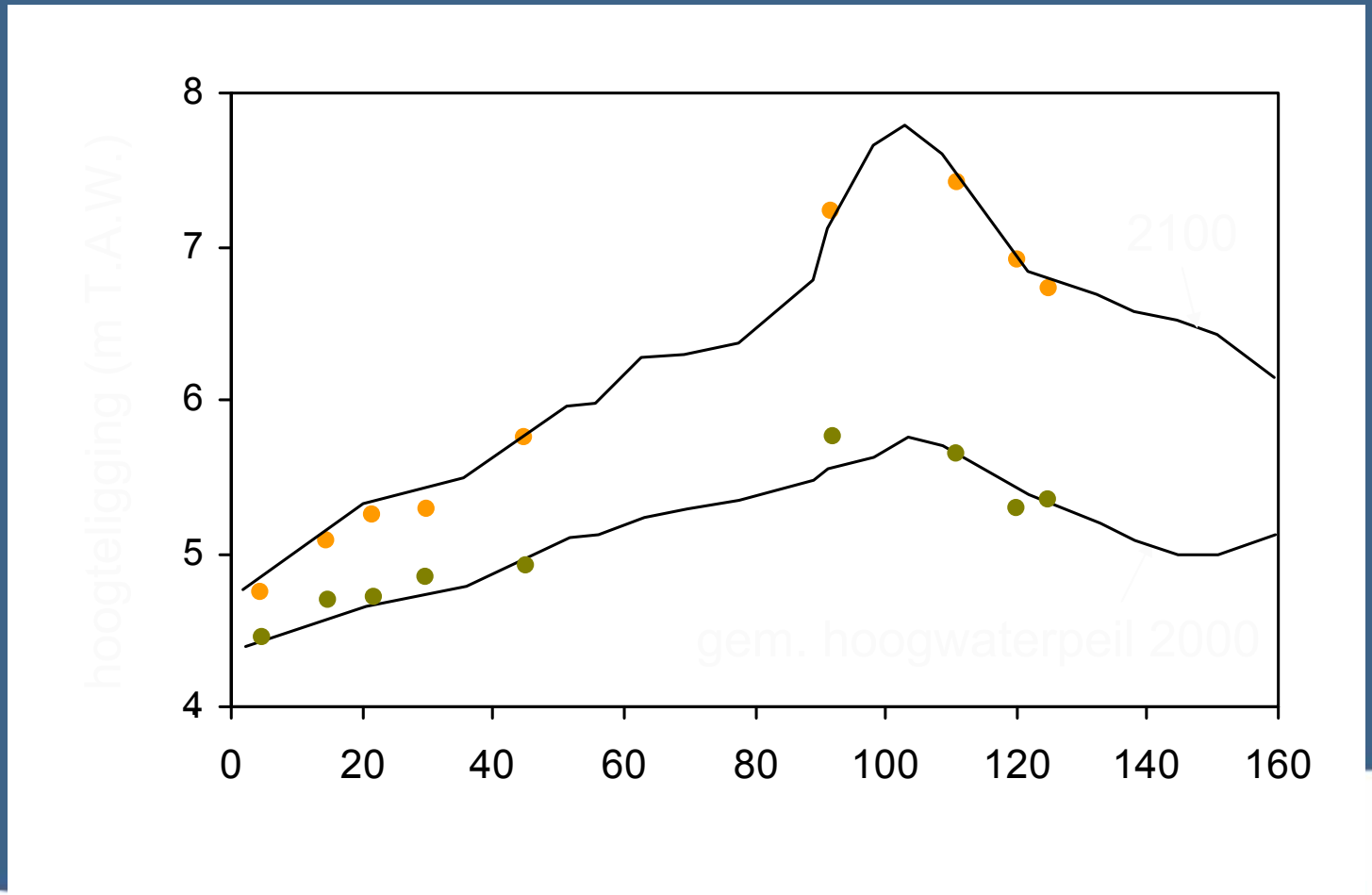
1999/2001/ 2002



- old marshes
- young marshes

Modeling future developments

Gepubliceerd in:
Temmerman et al., 2003;
2004, *Marine Geology*



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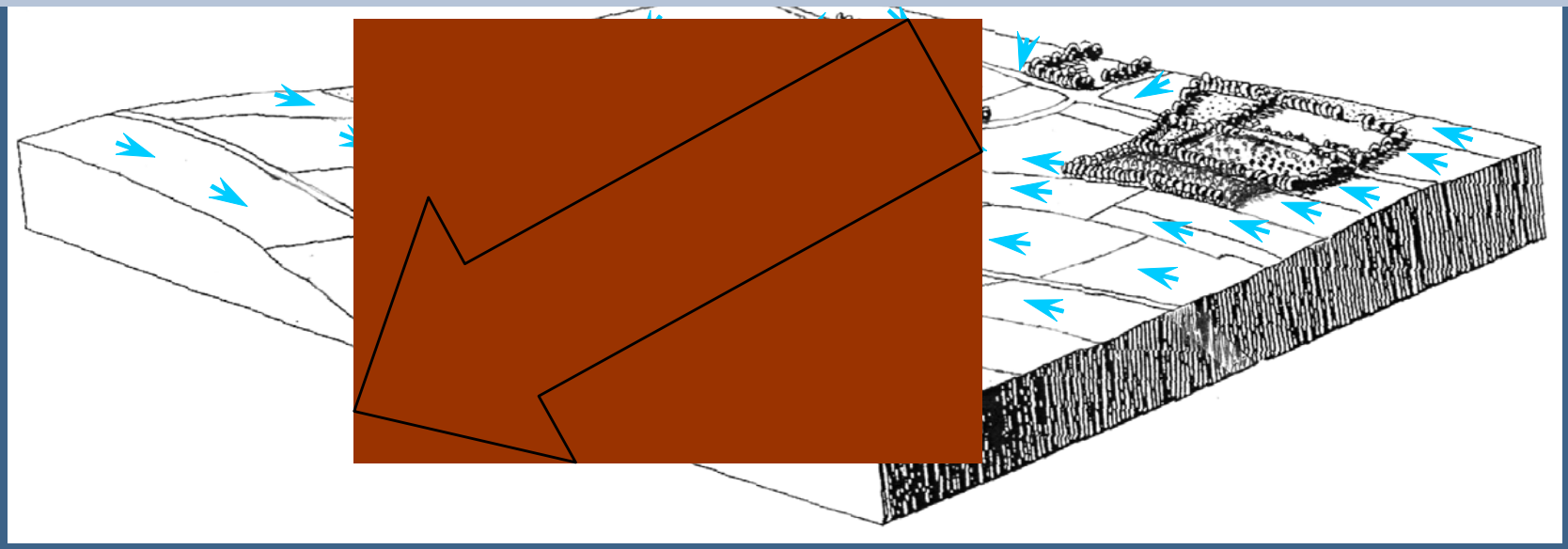
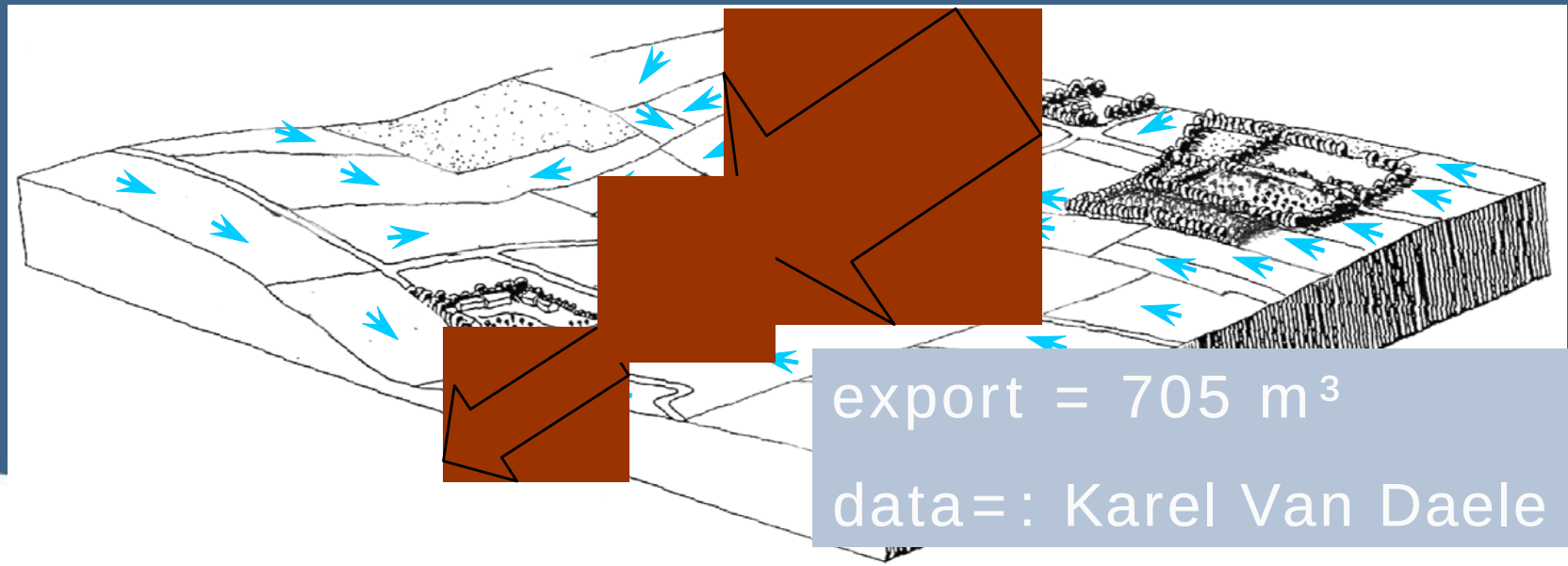
Sediment management in catchment

Total sedimentexport = +/- **1385 m³**





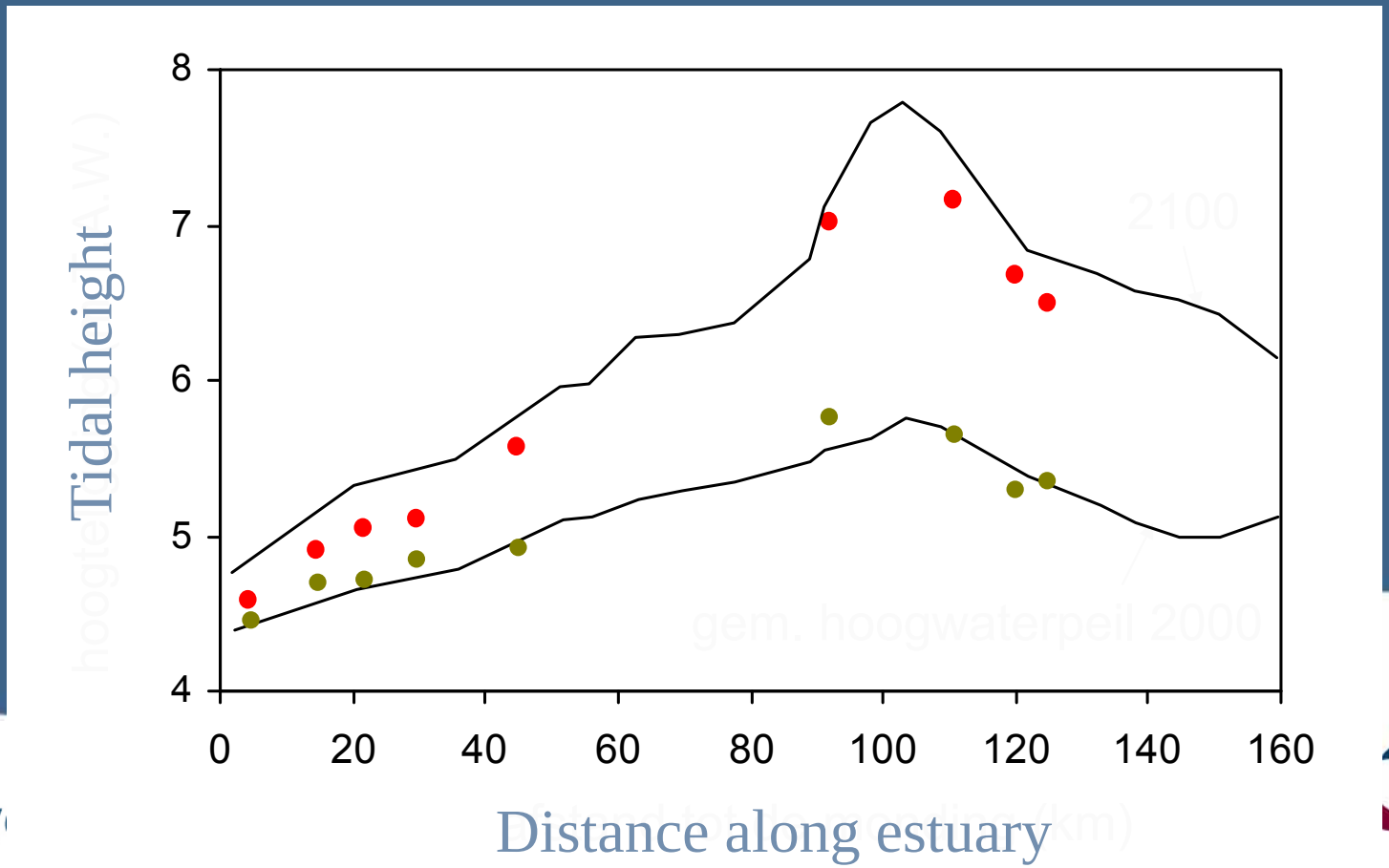
export = 705 m³

data=: Karel Van Daele

Temmerman et al., 2003; 2004, *Marine Geology*

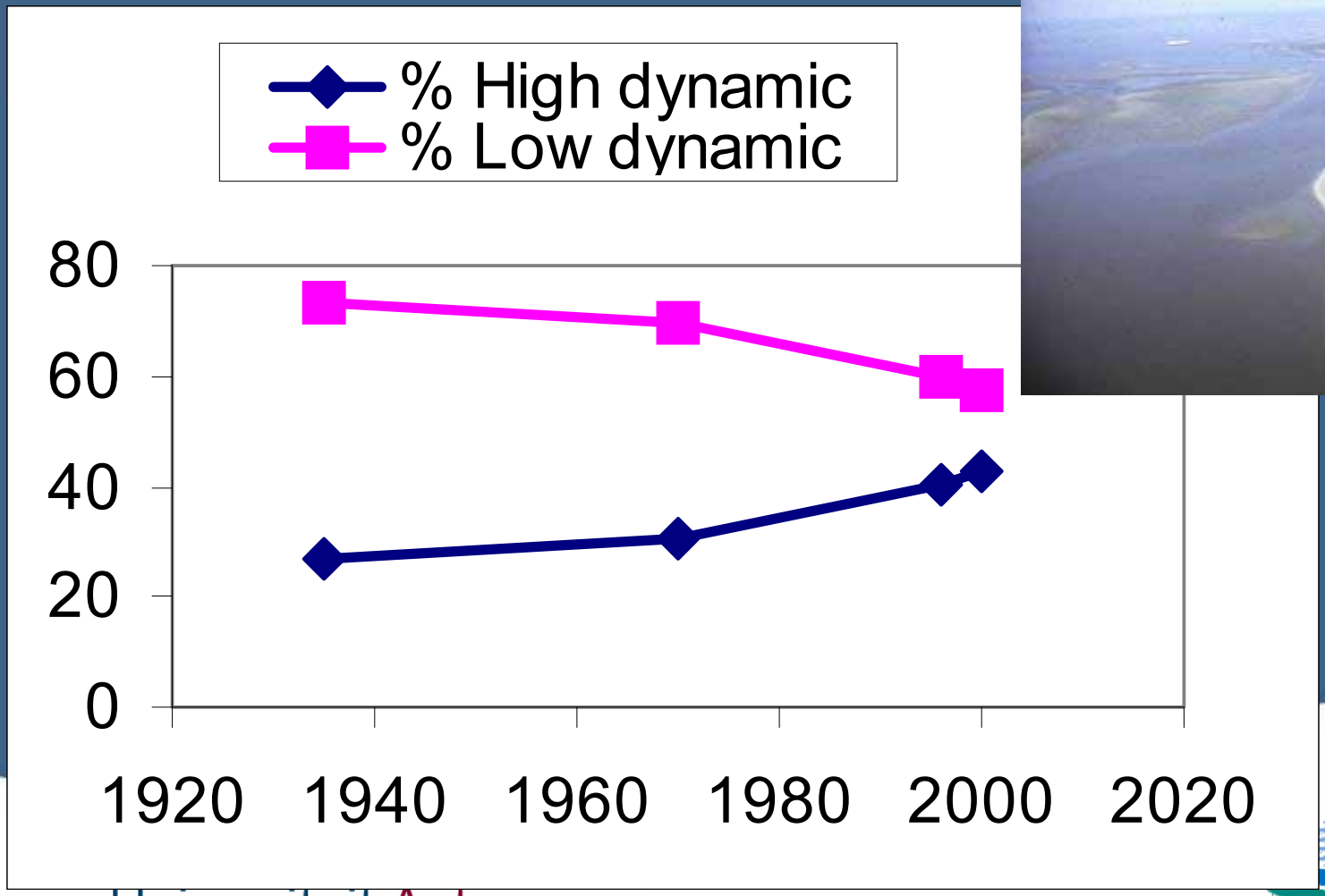
Modellering

→ If SS Conc decreases: marshes disappear ?

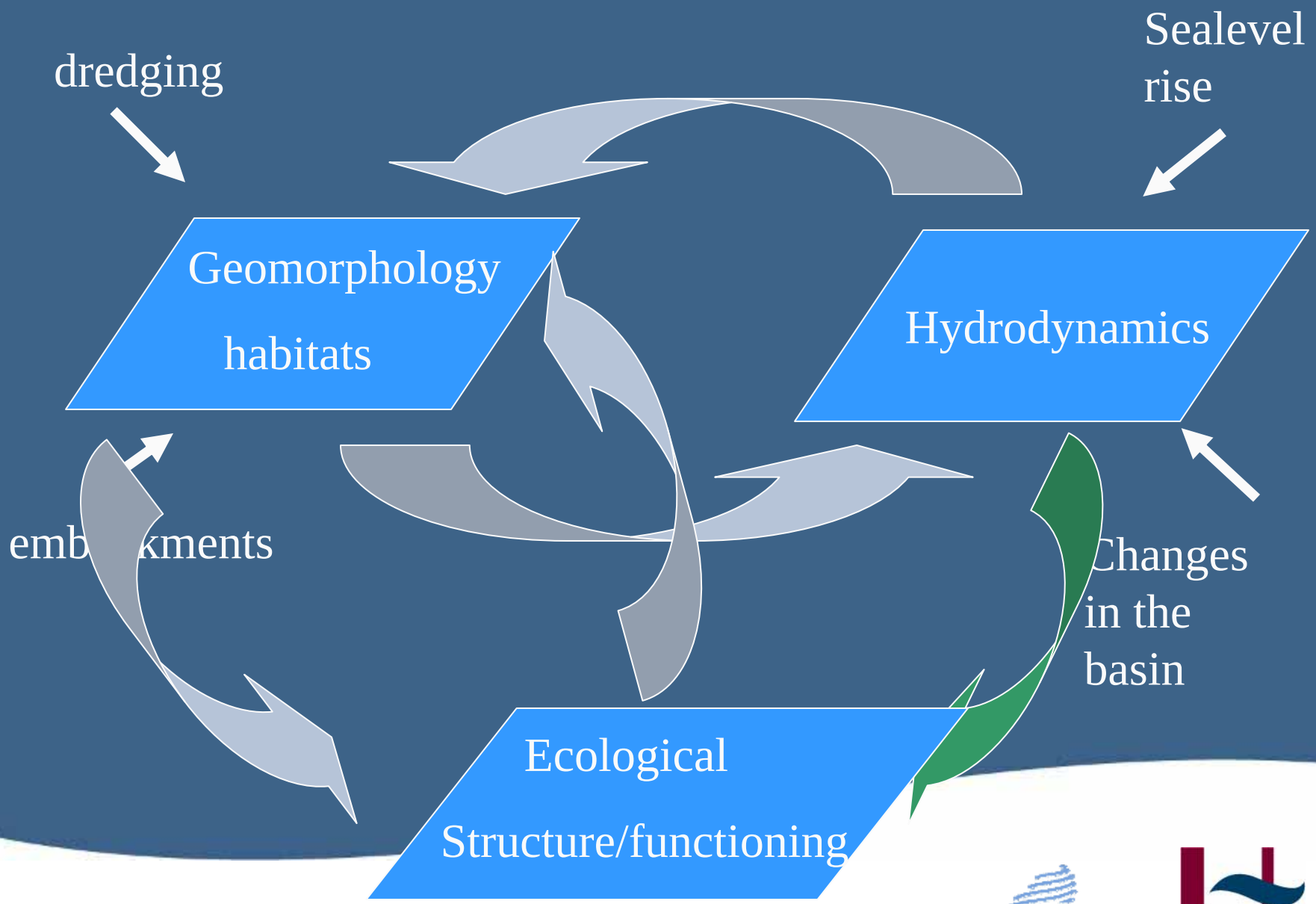



Slope ↑, current speed ↑ ➔ marsh erosion ↑

Increase high dynamic flats

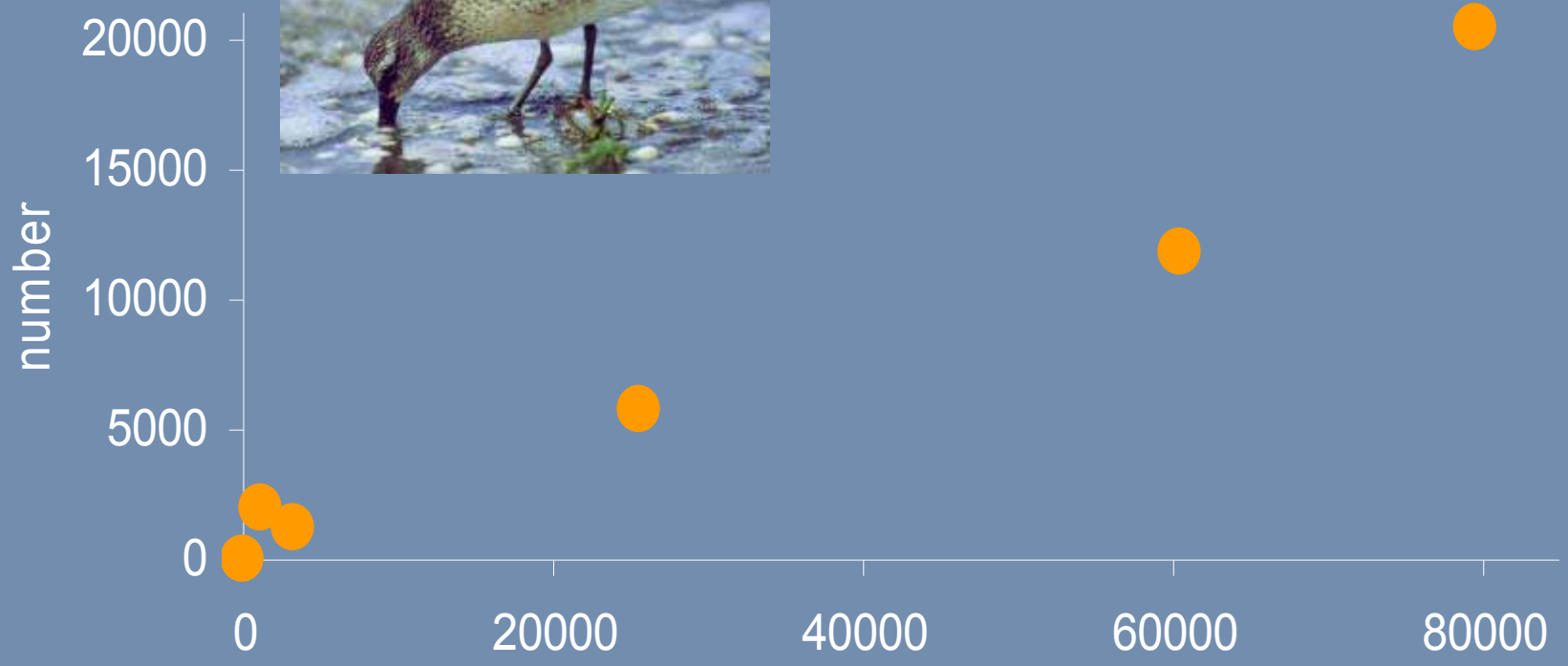


Courtesy Dick de Jong, RIKZ


dredging
Sealevel rise
Geomorphology habitats
Hydrodynamics
emb kments
Changes in the basin
Ecological Structure/functioning

- Pelagic and benthic habitats

Birds and their food

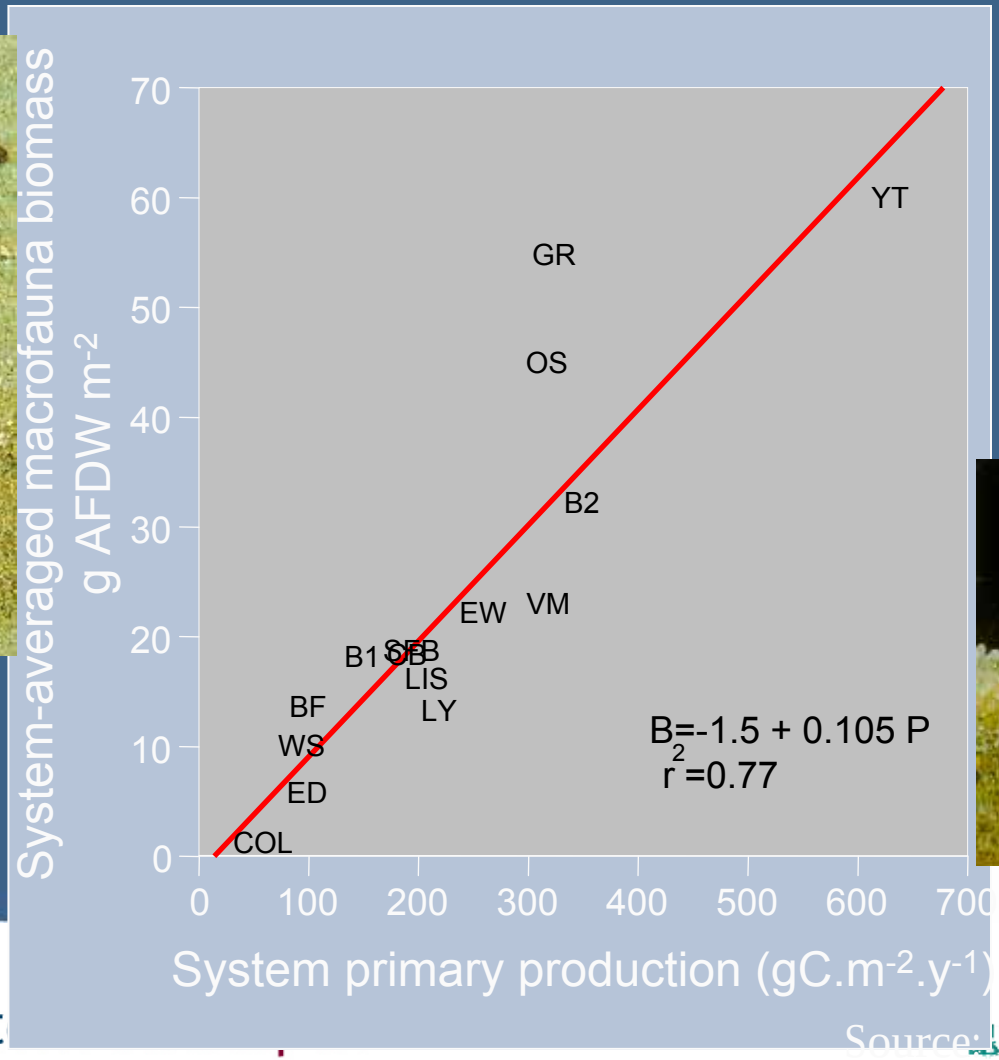


Data Tom Ysebaert NIOO- CEMO

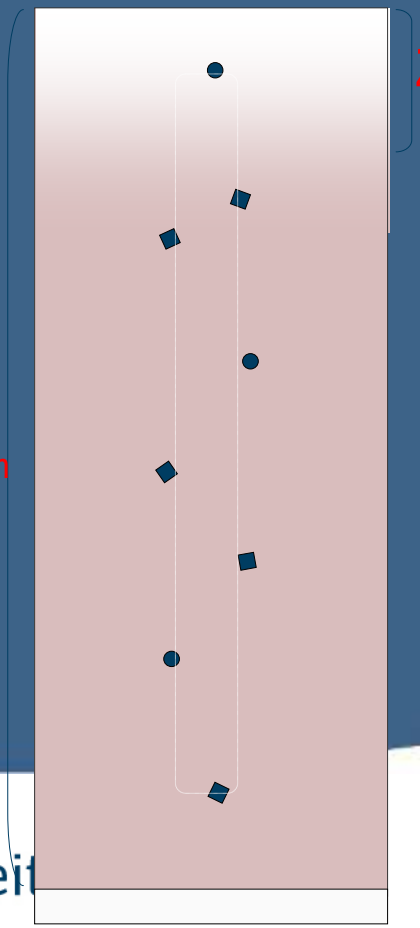
Benthos biomass depends on sediment characteristics

Data Tom Ysebaert NIOO- CEMO

Benthos and its food



Light climate phytoplankton



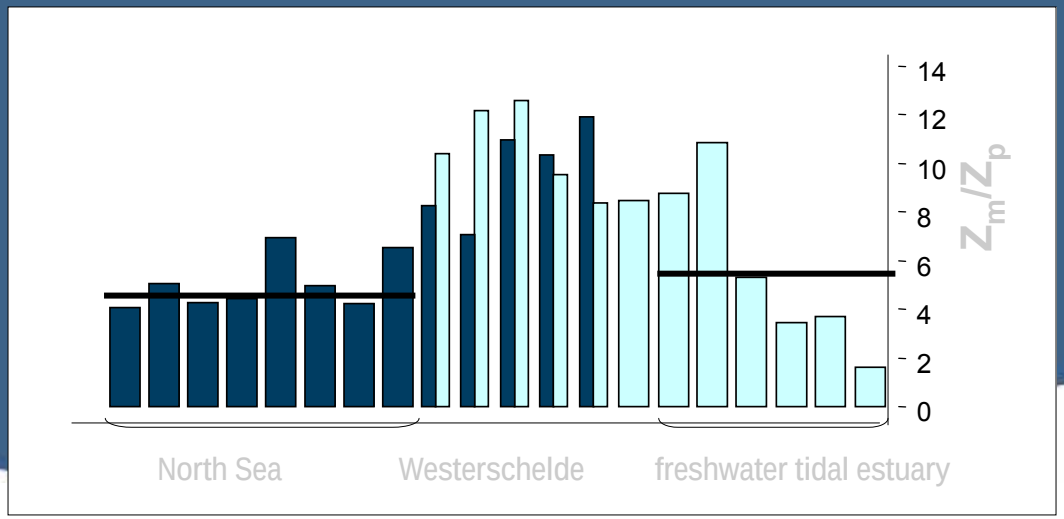
Z_p **Photic depth**

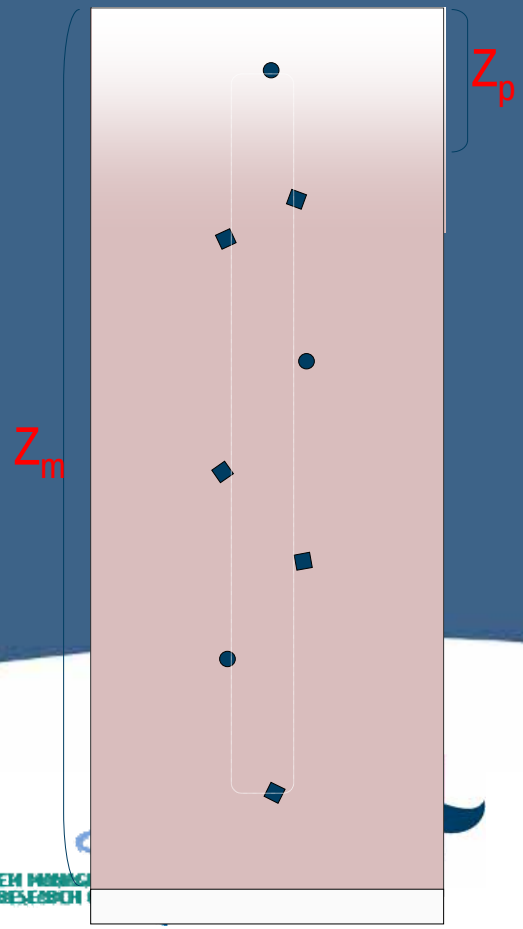
Mixing depth Z_m

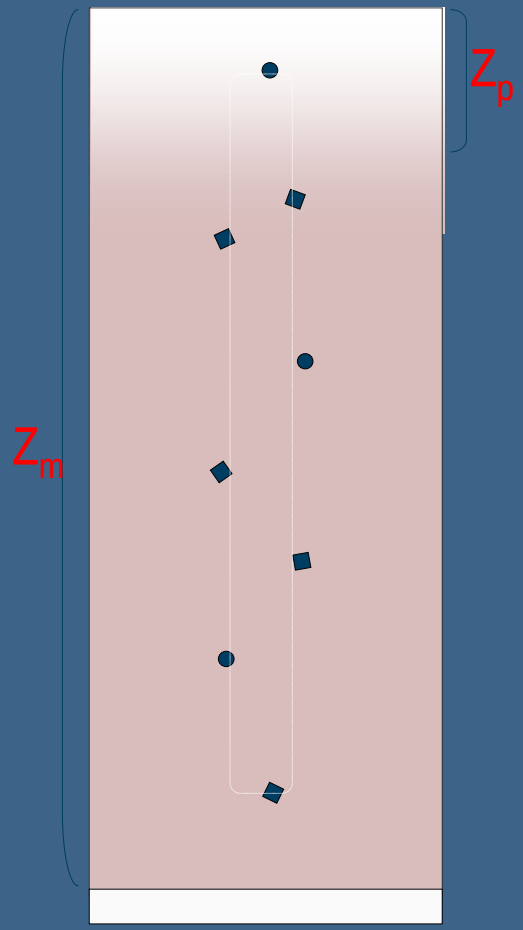
Survival chance
~ Zp / Zm

Benthos is dependent on primary production in pelagic

North Sea	Schelde estuary	
	Westerschelde	freshwater tidal estuary
(Reid *et al*. 1990)	(Soetaert *et al*. 1994)	(this study)
200 g C m^{-2} $year^{-1}$	41 g C m^{-2} $year^{-1}$	260 g C m^{-2} $year^{-1}$





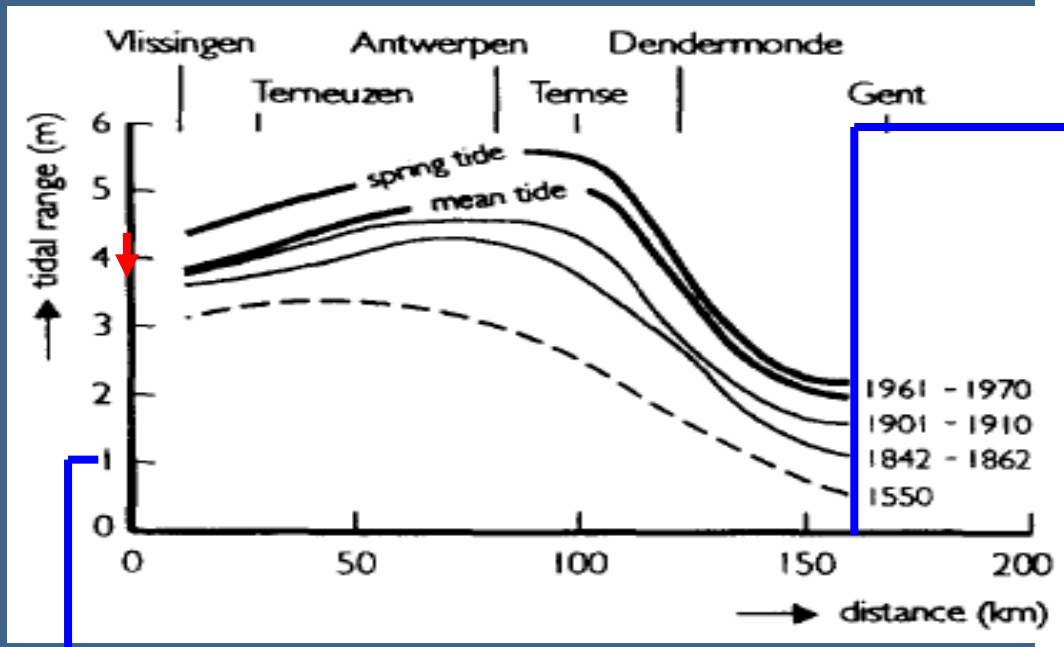


mixing depth Zm
~ embankments / deepening

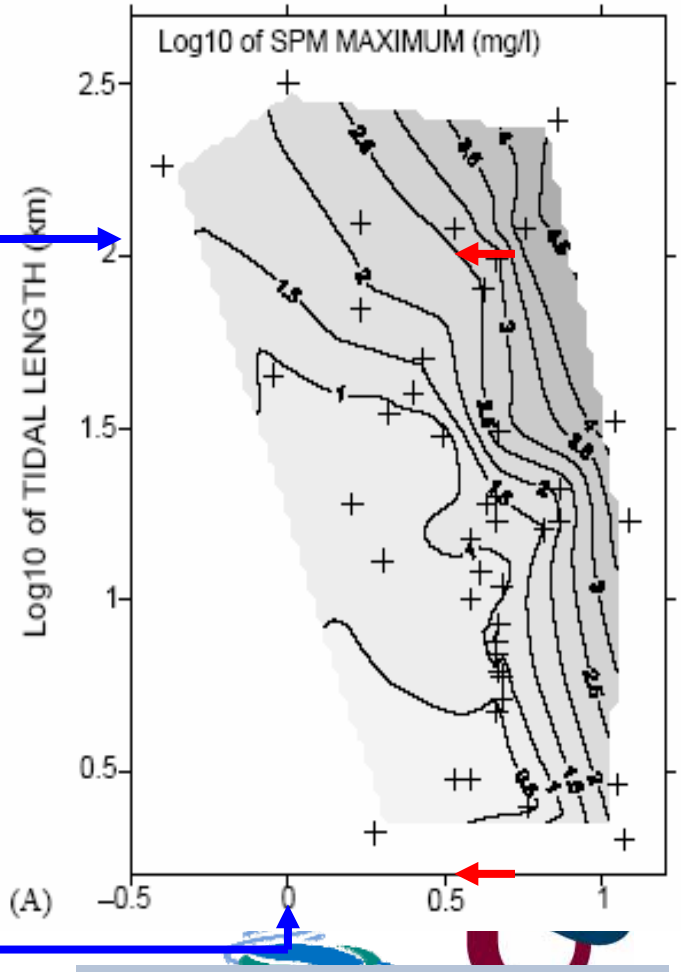
Photic depth Zp
~ suspended matter

Linking tidal range history with the relation between tidal range, tidal lenght and SPM

1 meter less mean spring tidal range <u>would</u> give for an estuary of 160 km long an **SPM concentration** of **about ten times less**



Van der Spek et al., 1997



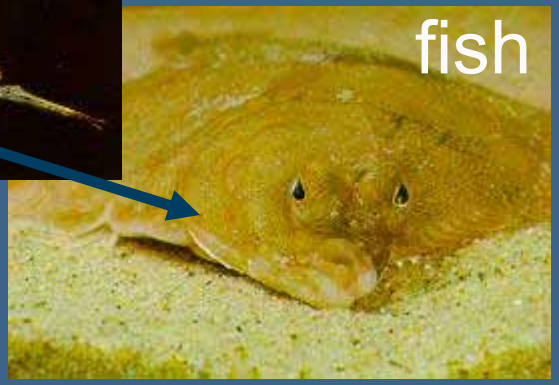
Log 10 of mean spring tidal range

Uncles et al., 2002

Major changes in foodweb

Microbes

CO_2

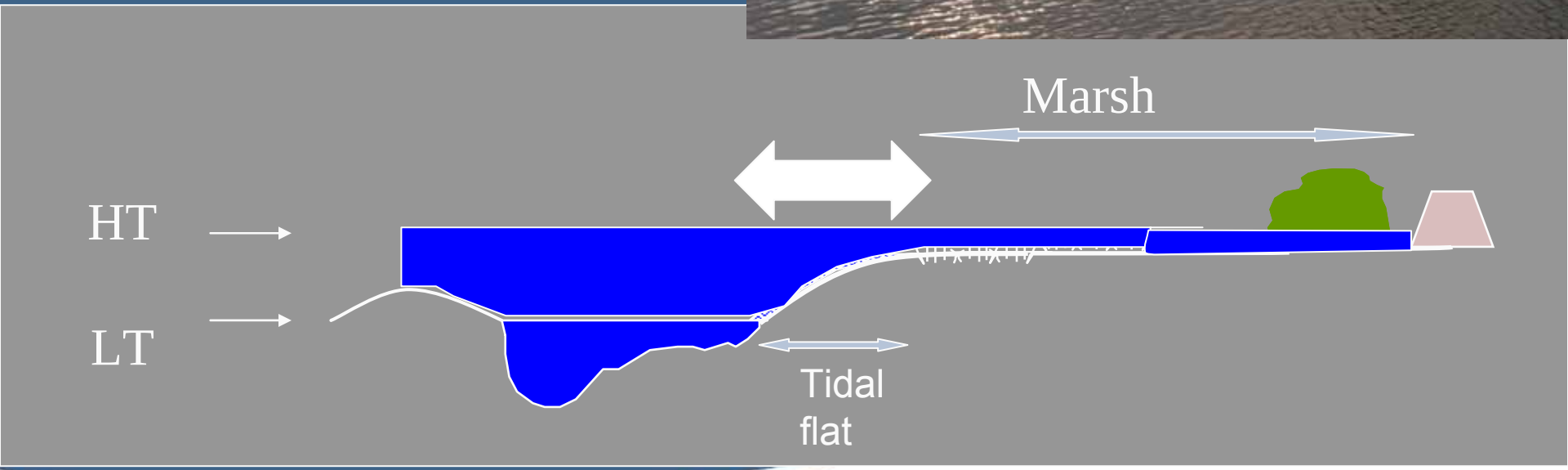


- Suspended sediments:
- ➔ decrease is benefical for primary production
- ➔ possibly a problem for survival of marshes under global change scenario's

- Are marshes important?

Role of marshes

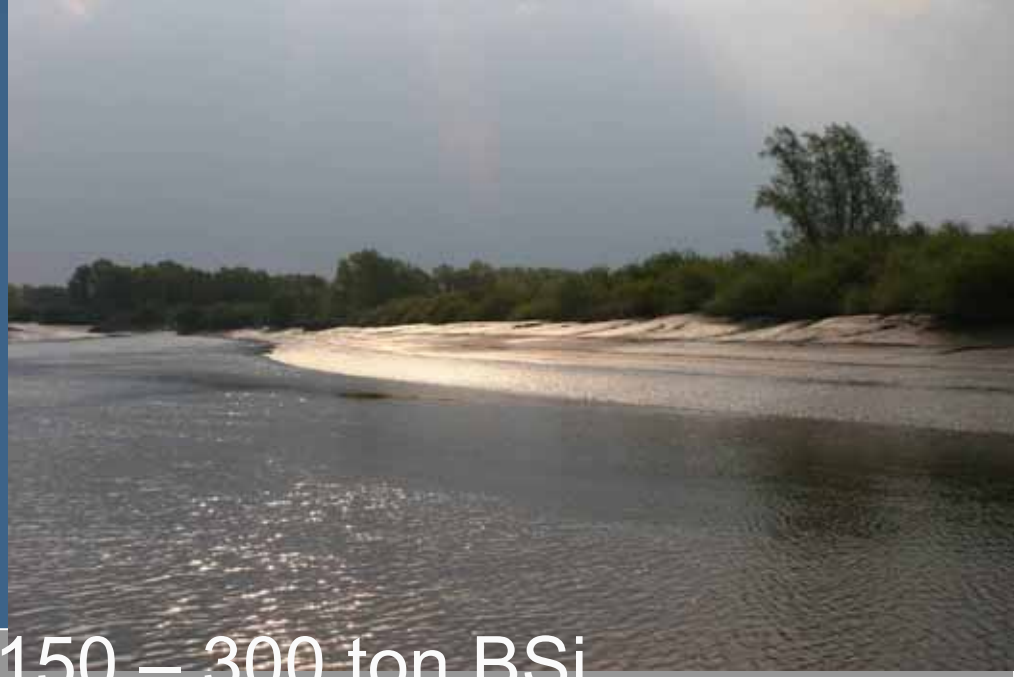
Exchange between marsh and pelagic

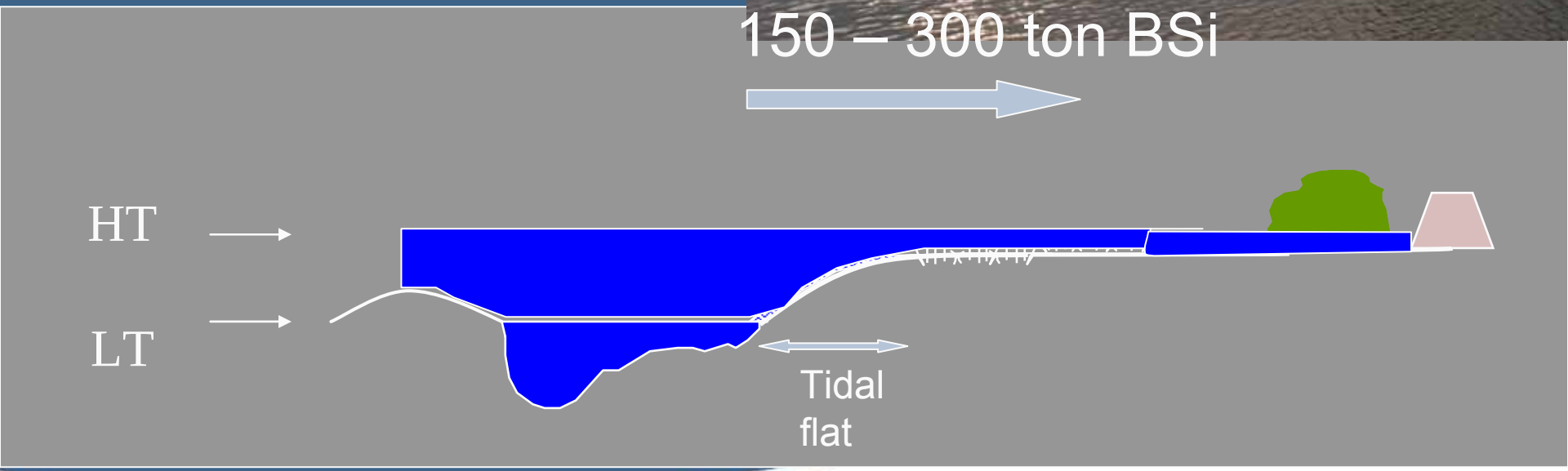


- Based on a whole ecosystem labeling experiment (N^{15}) we were able to show that about 15% of DIN is retained in the tidal marshes each tide! (Gribsholt et al. Lim & Ocean)

Role of marshes

Exchange between marsh and pelagic





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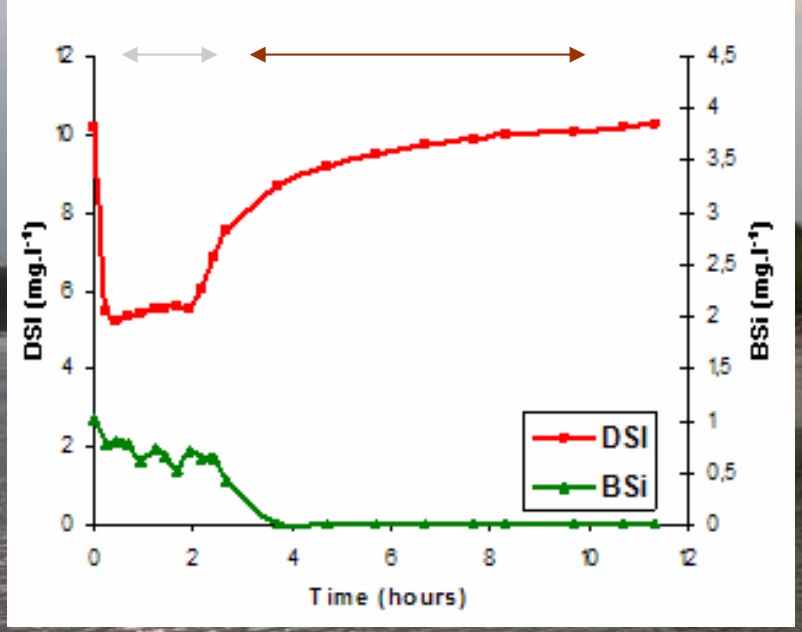
Role of marshes

3) Exchange between marsh and pelagic



150 – 300 ton BSi

100 – 200 ton Si

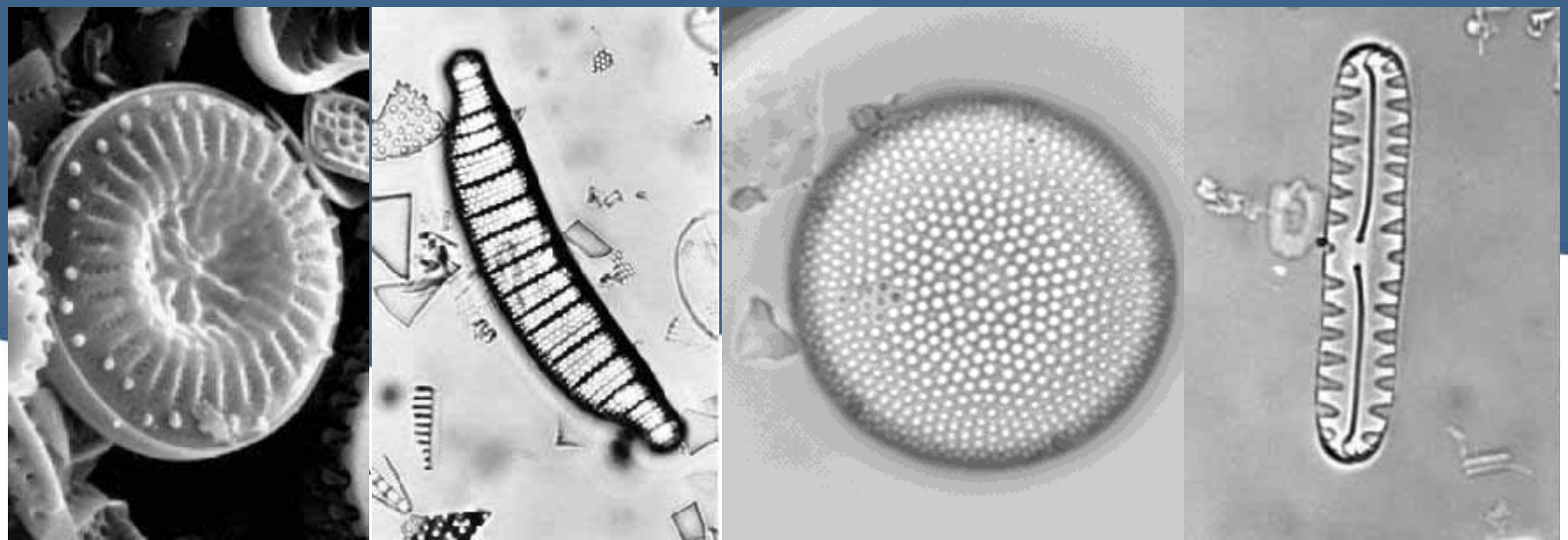
HT

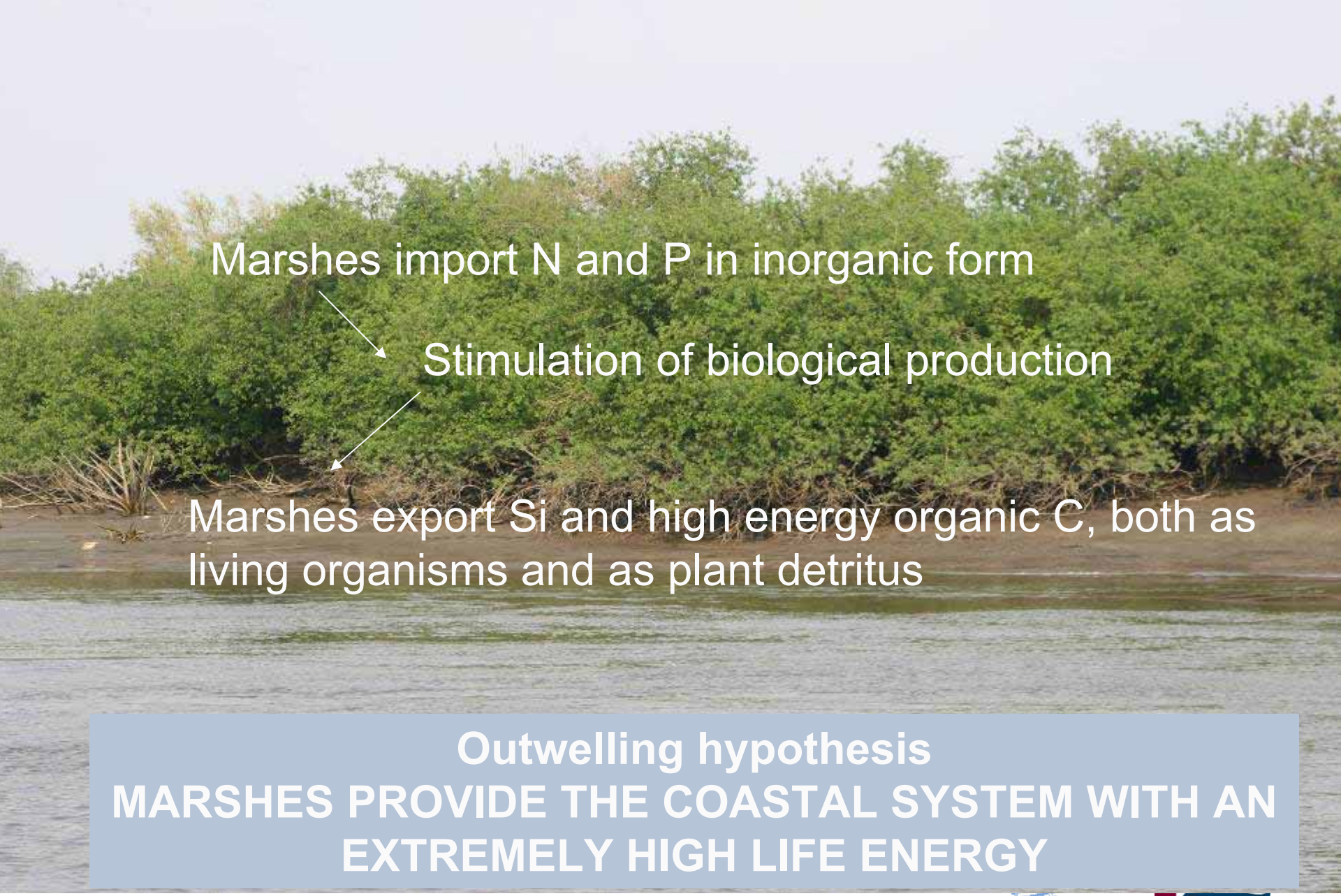
LT

Tidal flat

Does marsh Si recycling matter?

- Marshes significantly affect yearly flux of BSi and DSi to the ocean (7%)
- In summer months, **43 %** of Si load in the estuary is recycled trhough the marshes
- **In summer months, marshes are essential DSi suppliers to estuarine ecosystem**





Outwelling hypothesis

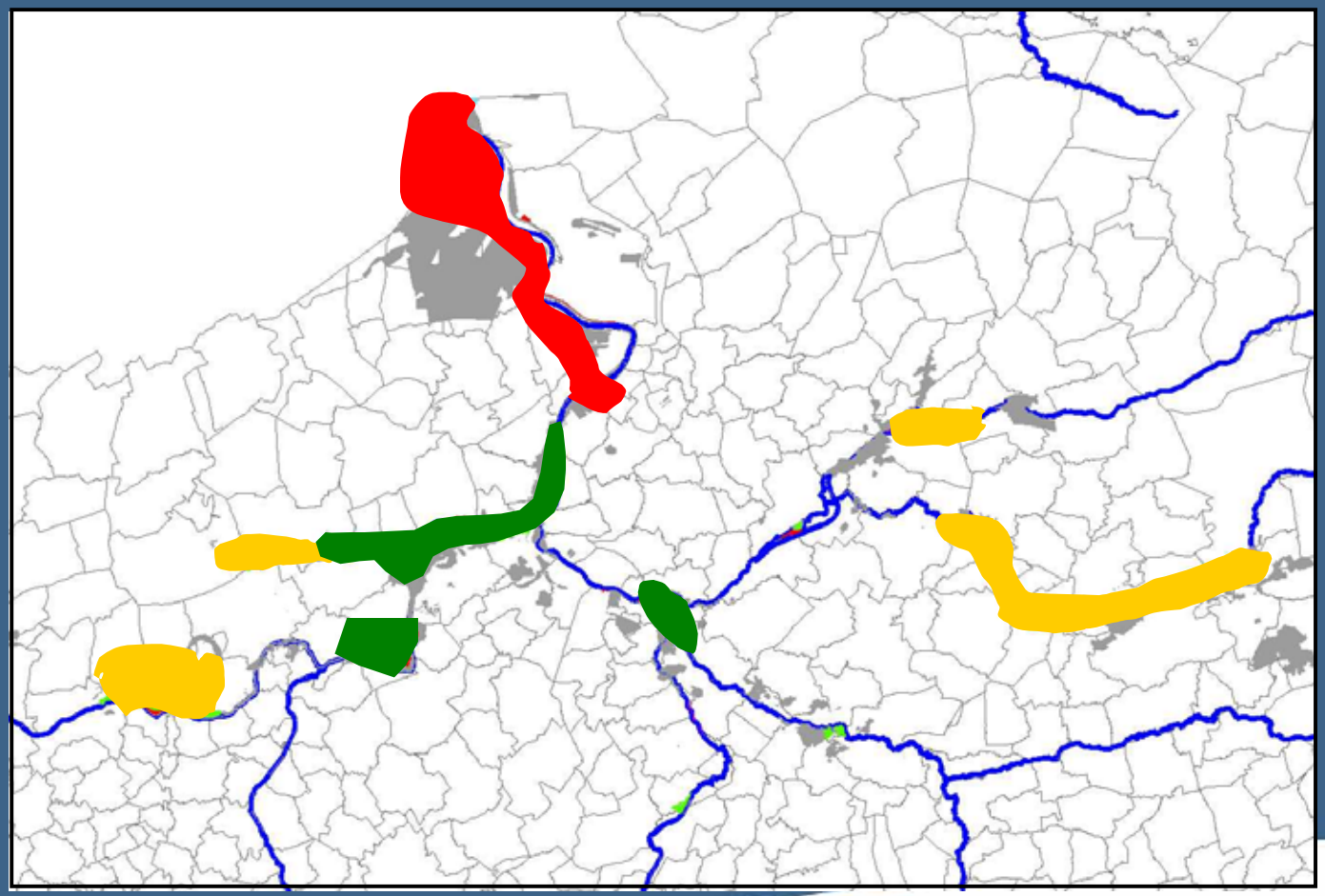
MARSHES PROVIDE THE COASTAL SYSTEM WITH AN EXTREMELY HIGH LIFE ENERGY

Conclusion 1

- Complex interaction between human activity, hydrodynamics and sediment dynamics led to a significant loss of habitats
- Loss of habitat and changing characteristics of habitats led to changes in the structure and function of the biodiversity
- This led to a decrease of ecosystem services
- Restoration is necessary

- Based on modelling ➔
  - 1500 ha of marsh extra is needed to take away Si limitation for diatoms
  - 500 ha of tidal flats extra is needed for stabilizing the estuarine food chain and water quality improvement

Spatial distribution of restoration sites



Restoring raised sites

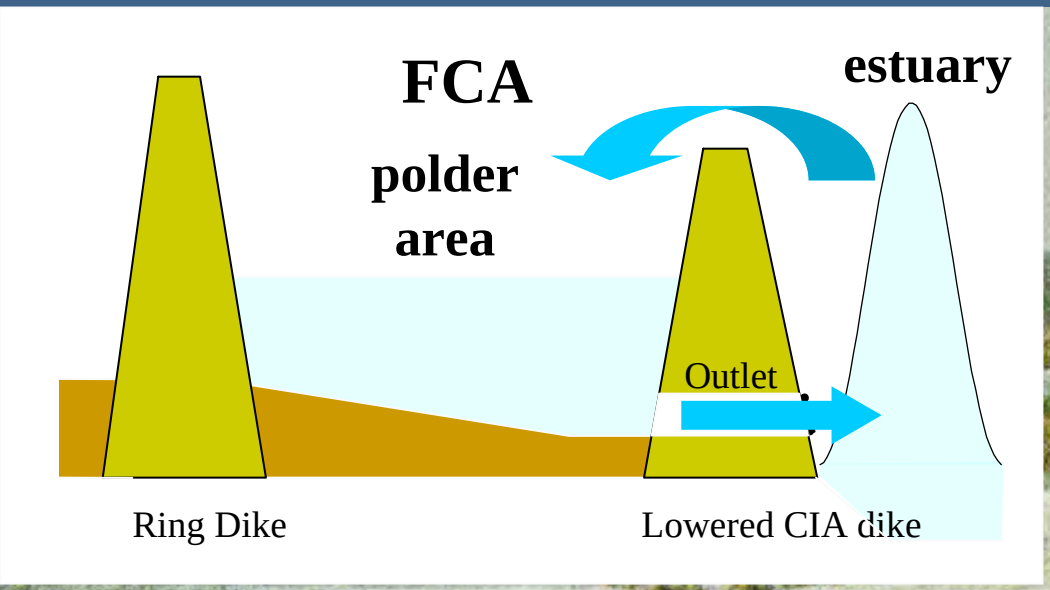
Managed realignment

1990

1998

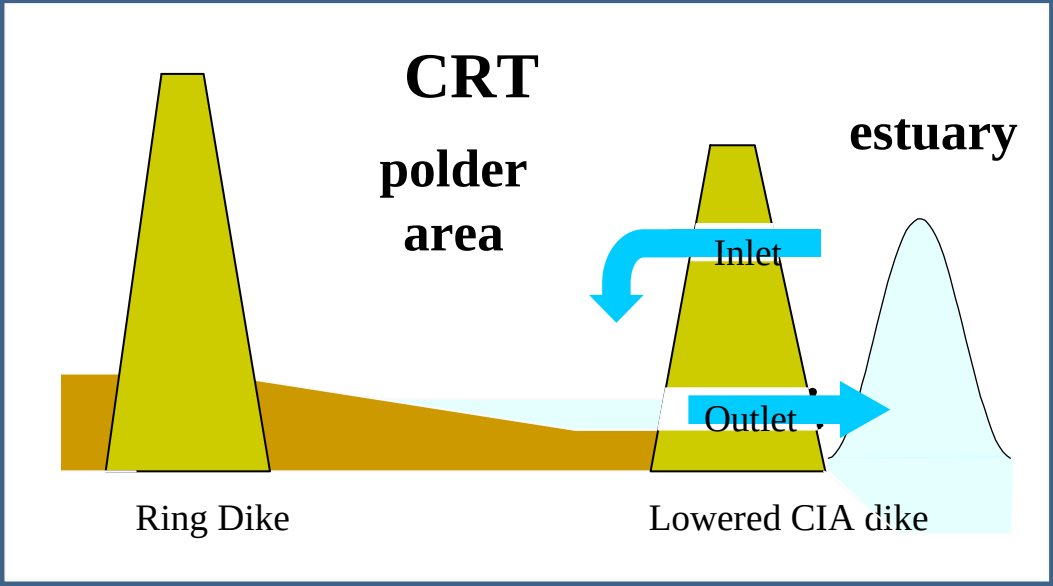
The Sigmaplan

1800 ha of Flood Control Areas (FCA) needed to reach required safety against inundations

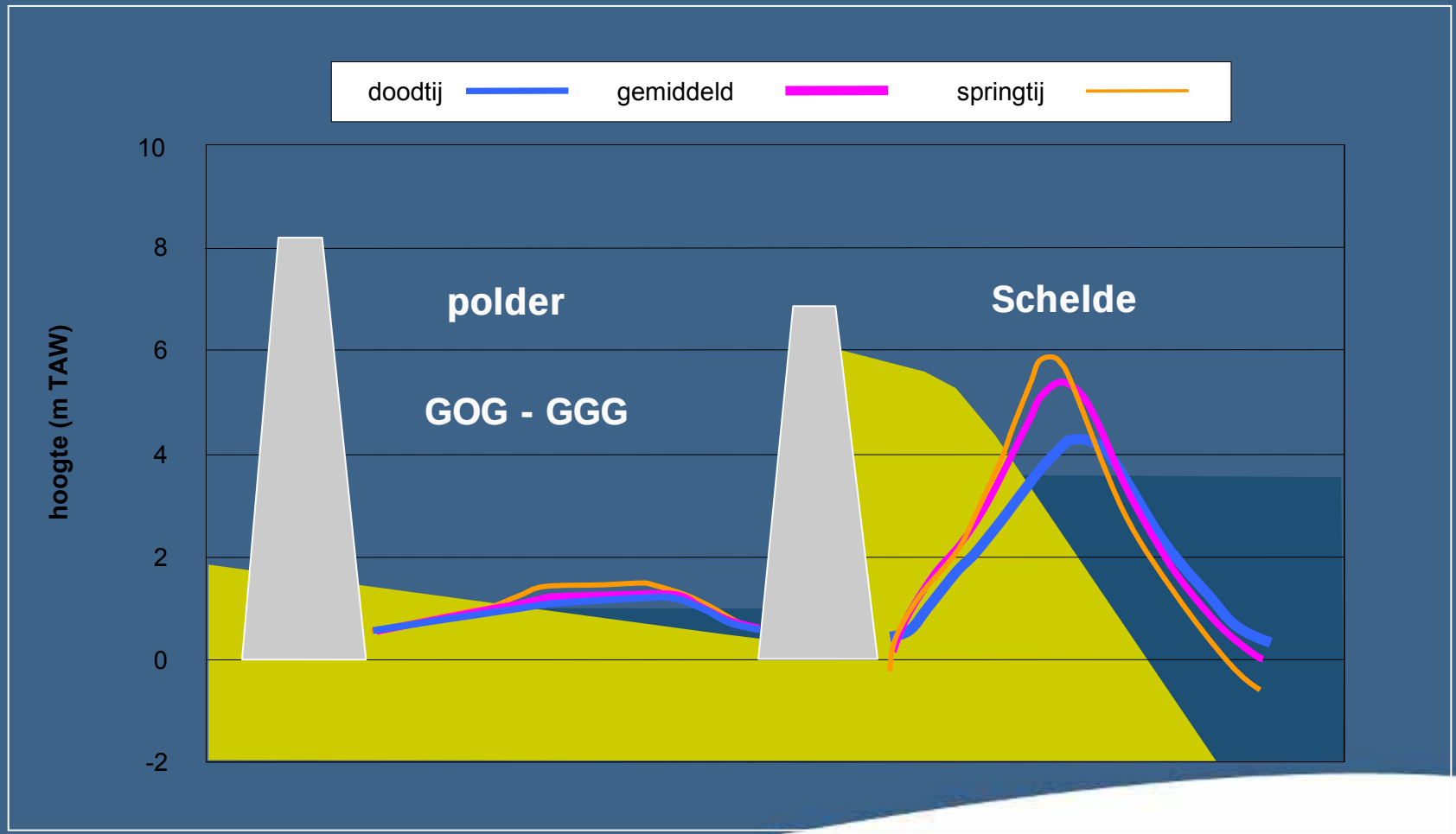


- Is there a combination possible with the area needed for safety?

Flood Control Areas (FCA)
Controlled Reduced Tide (CRT)

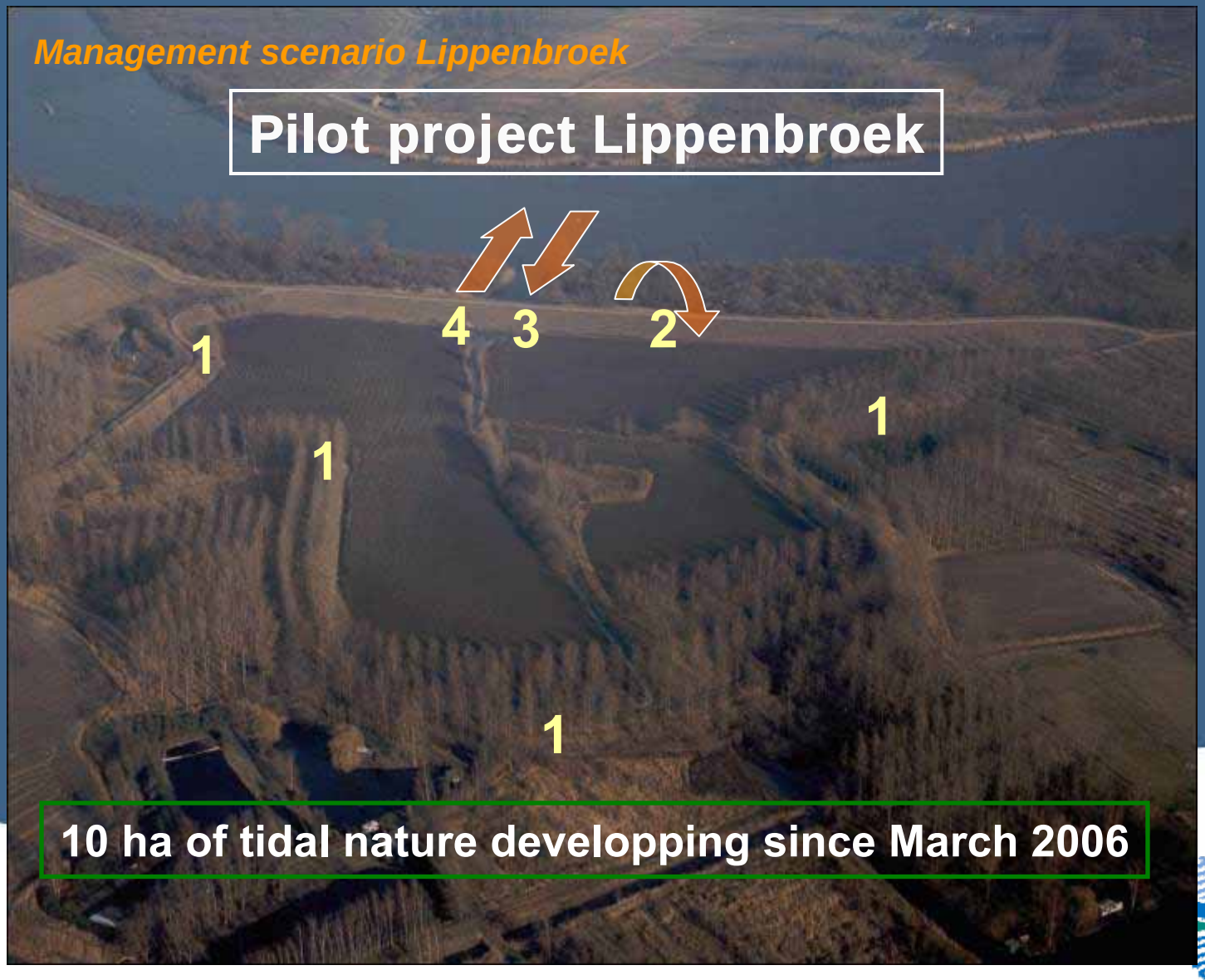


5 0 5 Kilometers


doodtij
gemiddeld
springtij
hoogte (m TAW)
10
8
6
4
2
0
-2
polder
GOG - GGG
Schelde

Management scenario Lippenbroek

Pilot project Lippenbroek



10 ha of tidal nature developping since March 2006

Lippenbroek

1: Ring Dike

2: FCA dike

3: Inlet sluice

4: Outlet sluice

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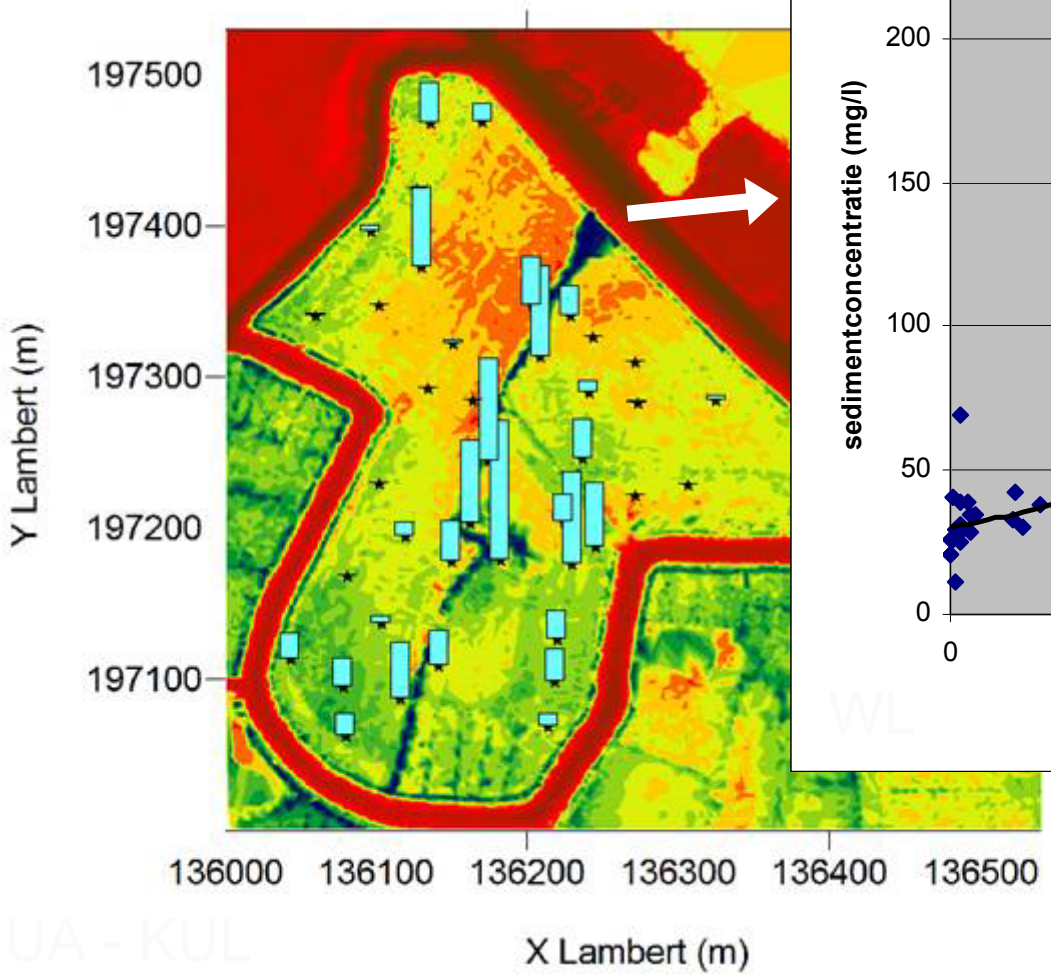
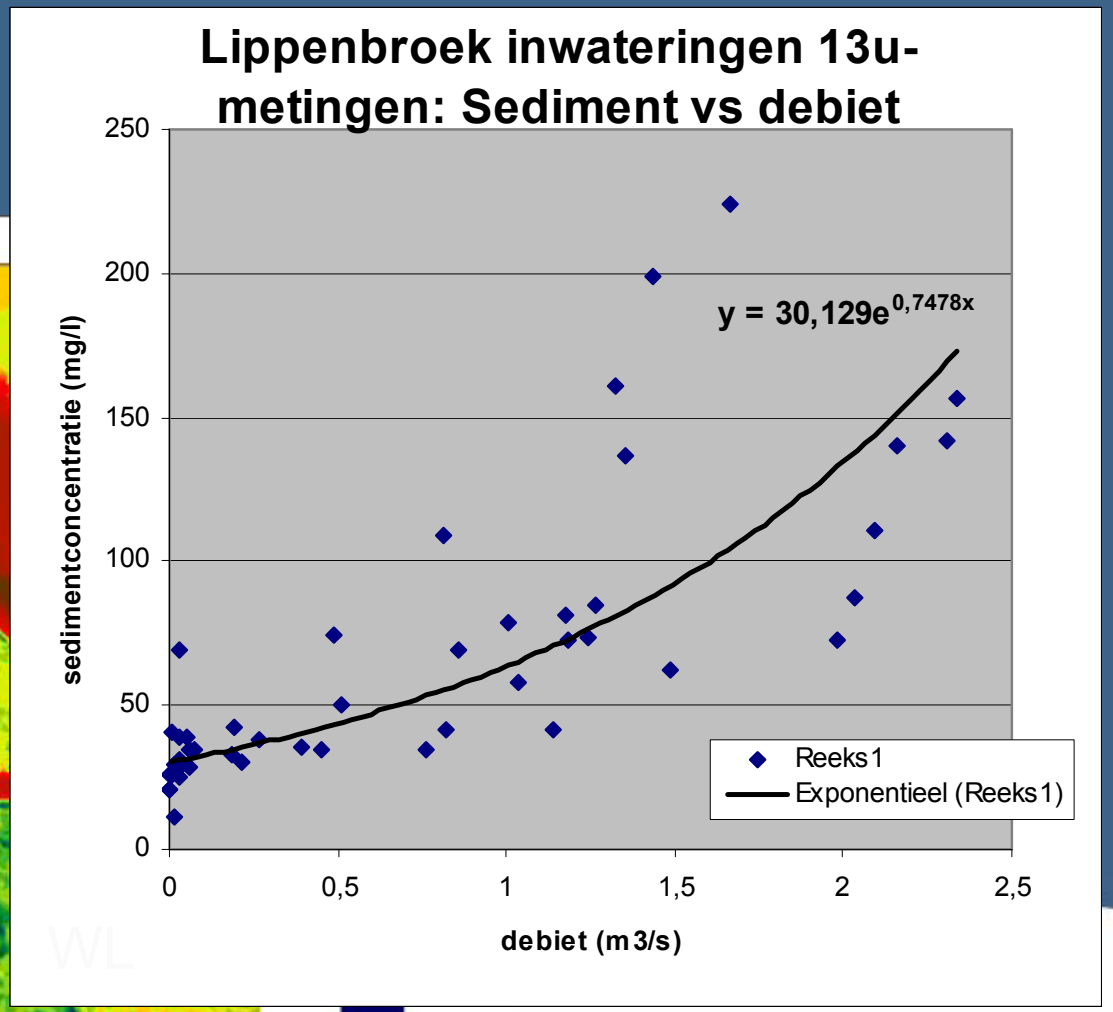
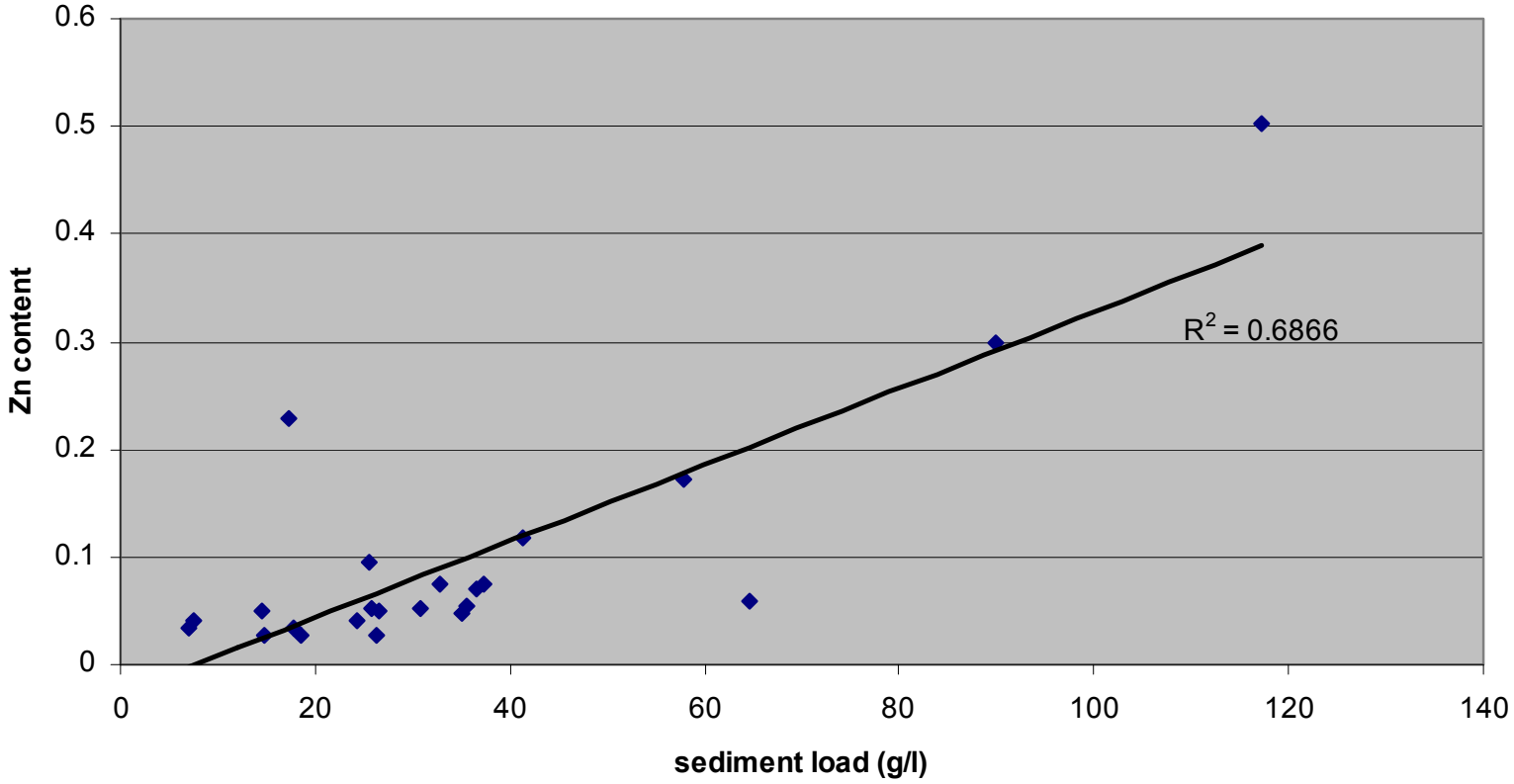
ECOSYSTEM MANAGEMENT RESEARCH GROUP

Pilootproject Lippenbroek

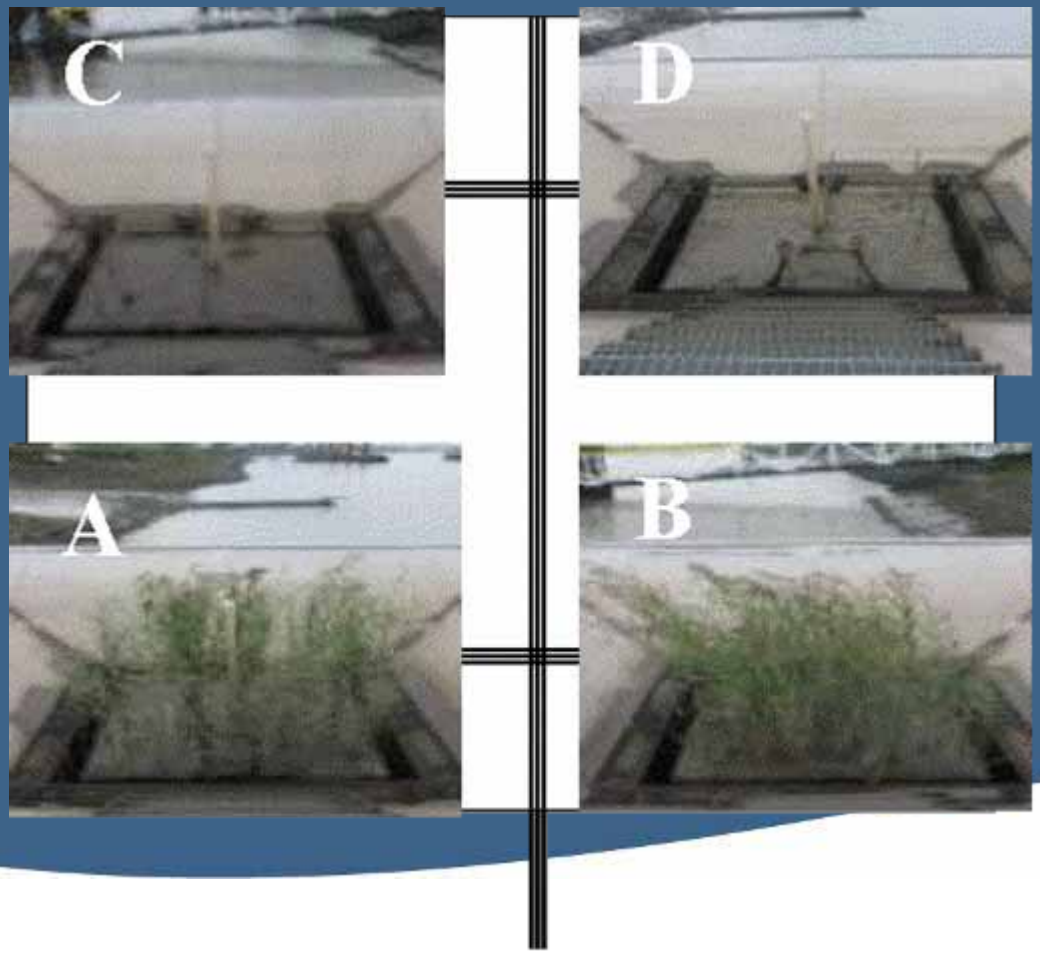





0.6
0.5
0.4
0.3
0.2
0.1
0
Zn content
0
20
40
60
80
100
120
140
sediment load (g/l)
R2 = 0.6866

Mesocosm experiment

Historical versus actual pollution



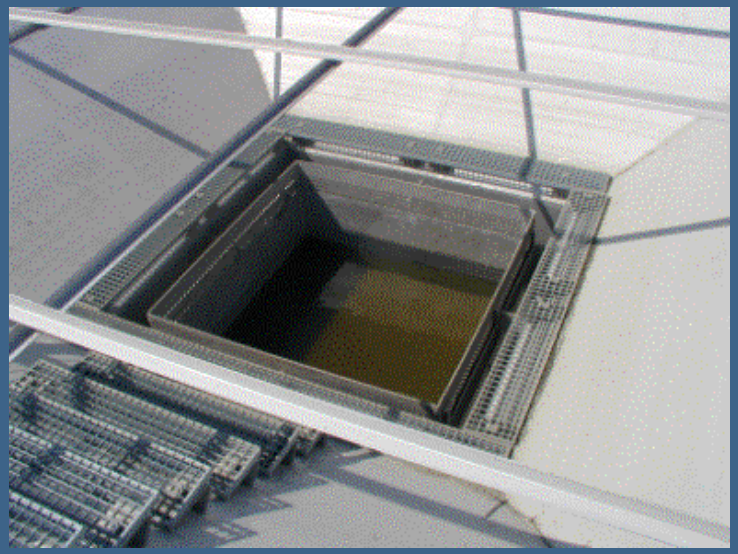
A: non contaminated + reed

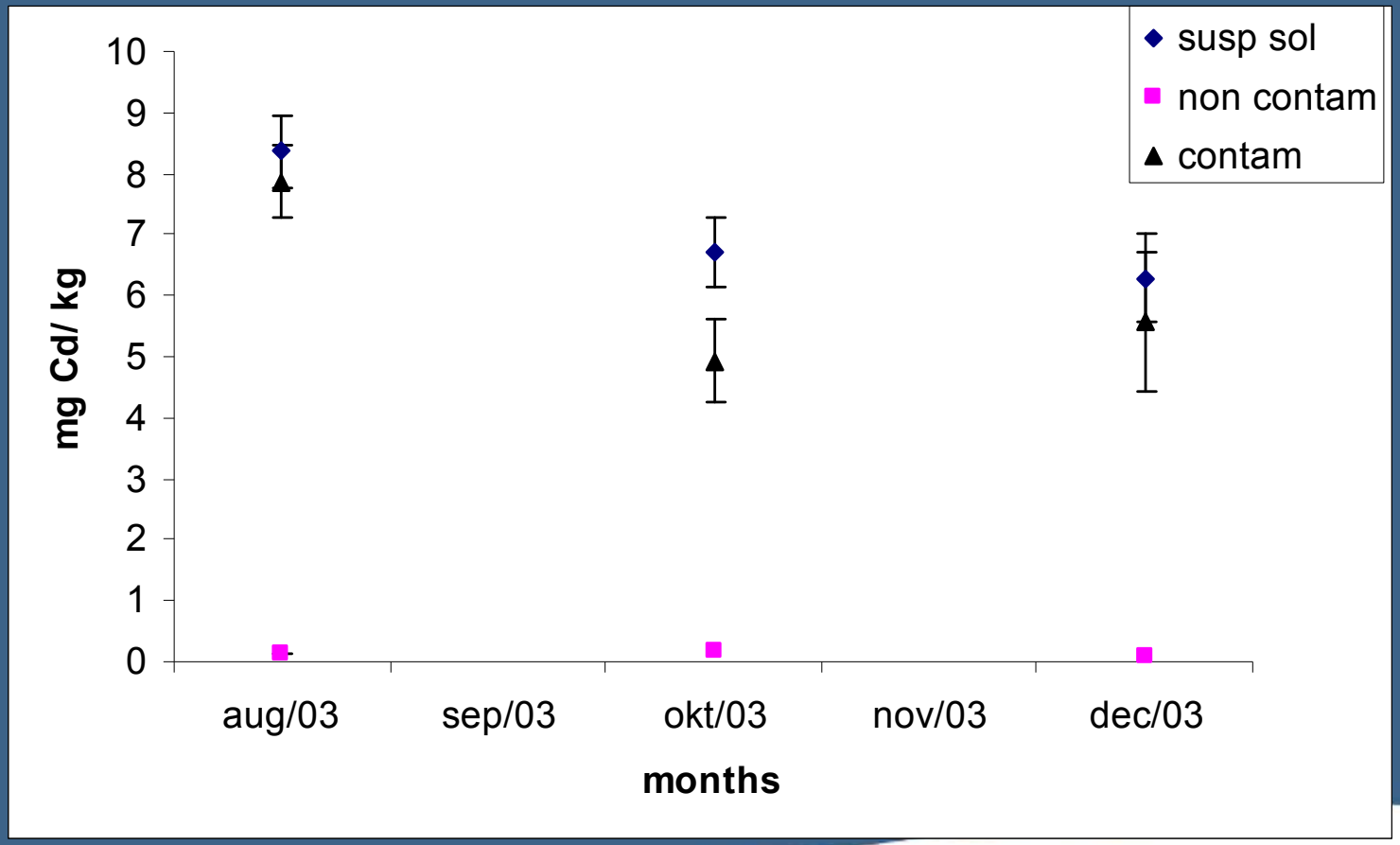
C: non contaminated blanco

B: contaminated + reed

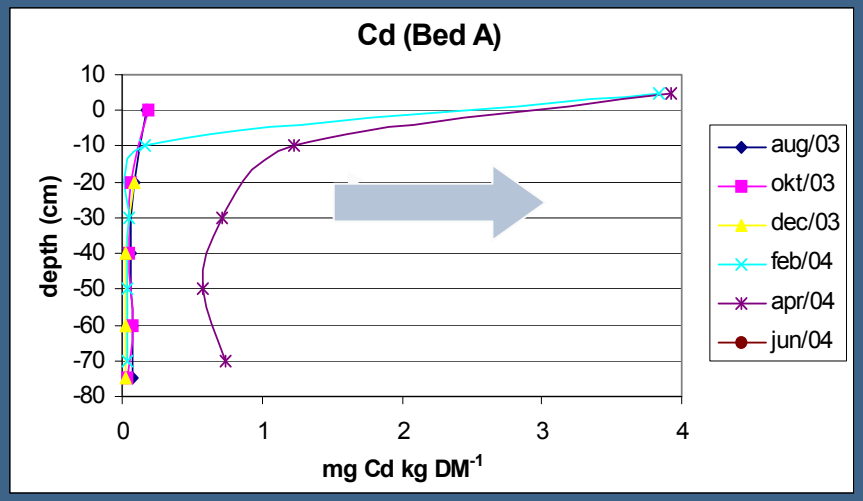
D: contaminated blanco

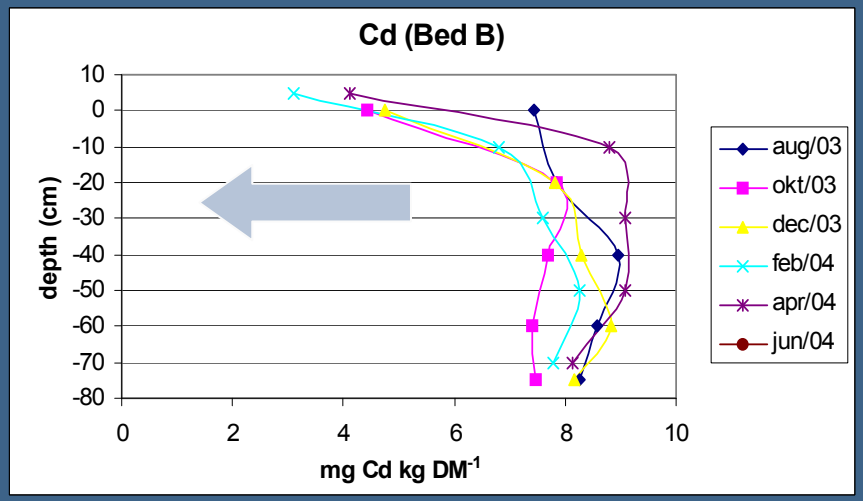
Waterregime

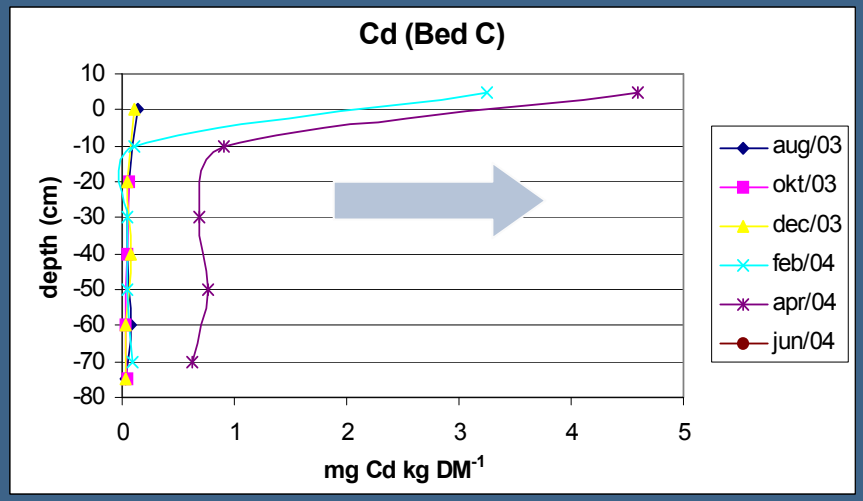


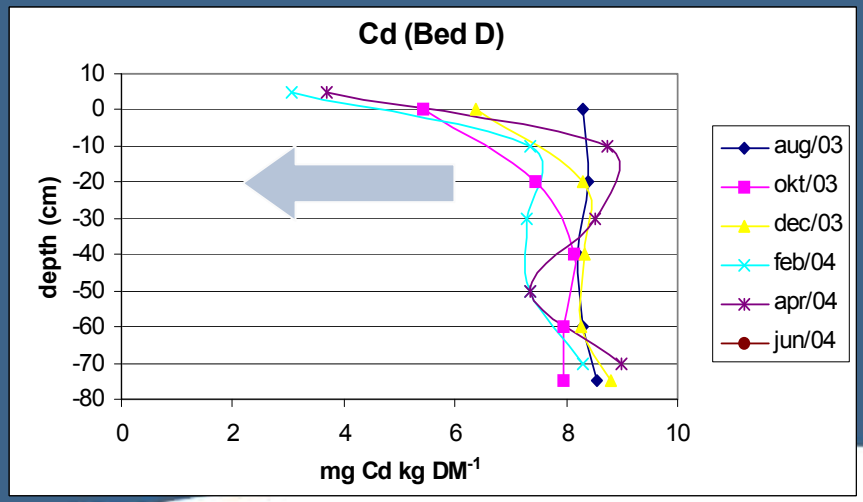

susp sol
non contam
contam
mg Cd/ kg
10
9
8
7
6
5
4
3
2
1
0
aug/03
sep/03
okt/03
nov/03
dec/03
months

Impact of heavy metal contamination on the development of controlled inundation areas along the Scheldt-estuary









A: non contam + reed **B**: contam. + reed **C**: non contam. **D**: contam.

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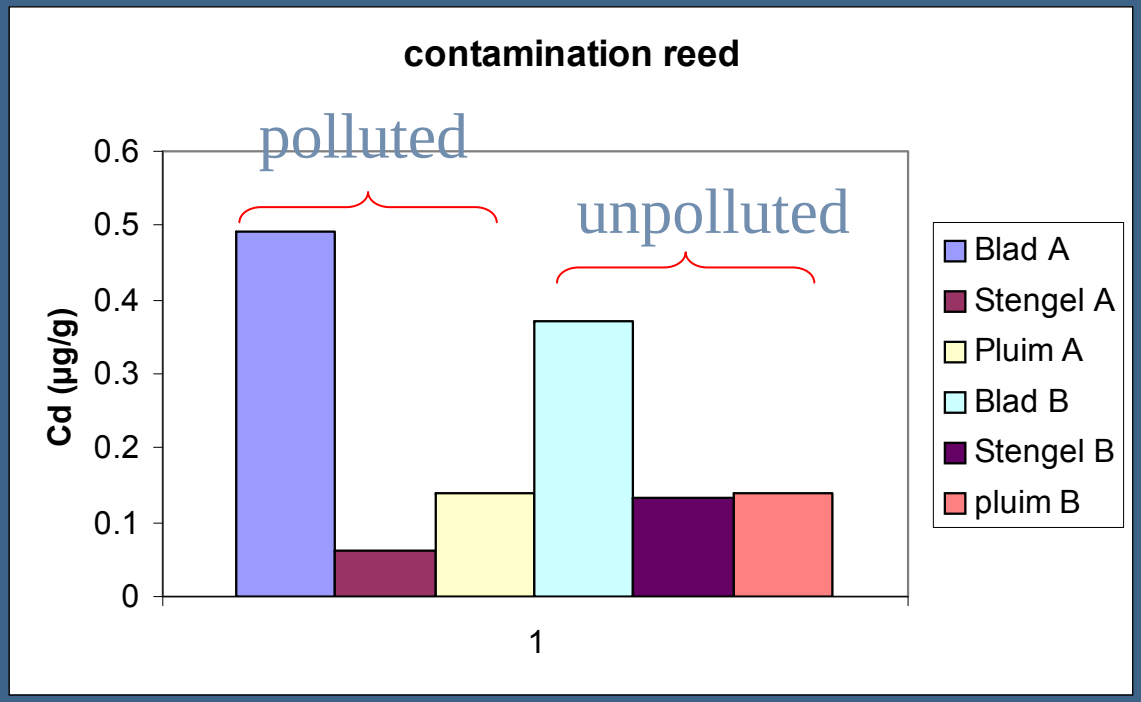
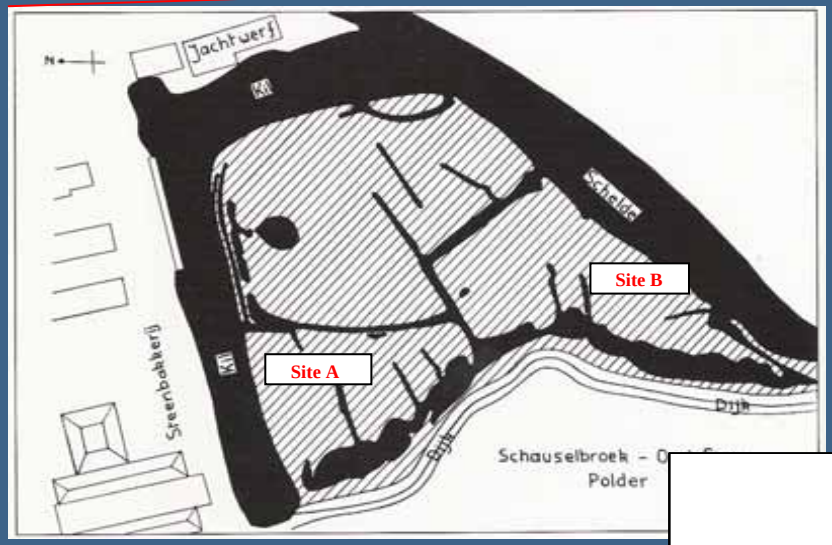
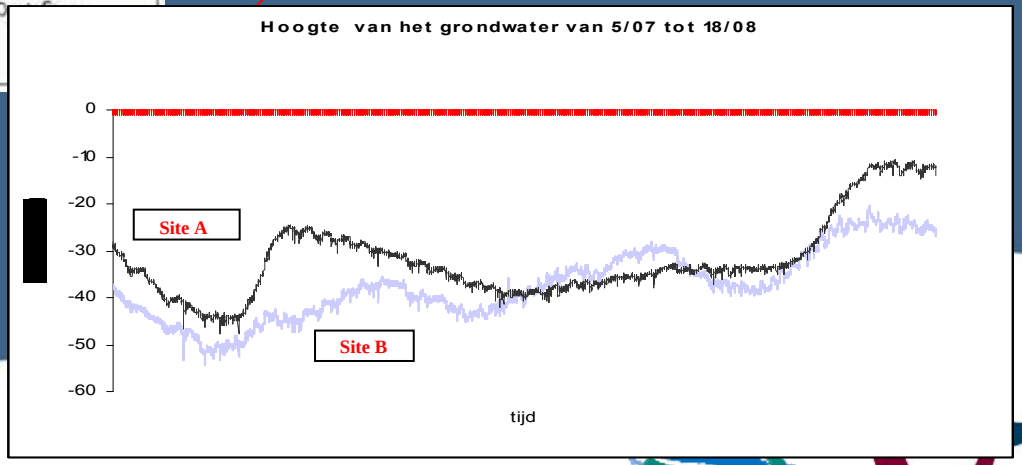
Vegetation: metal concentration 2003



No effect on pore water concentrations

No effect on performance of reed





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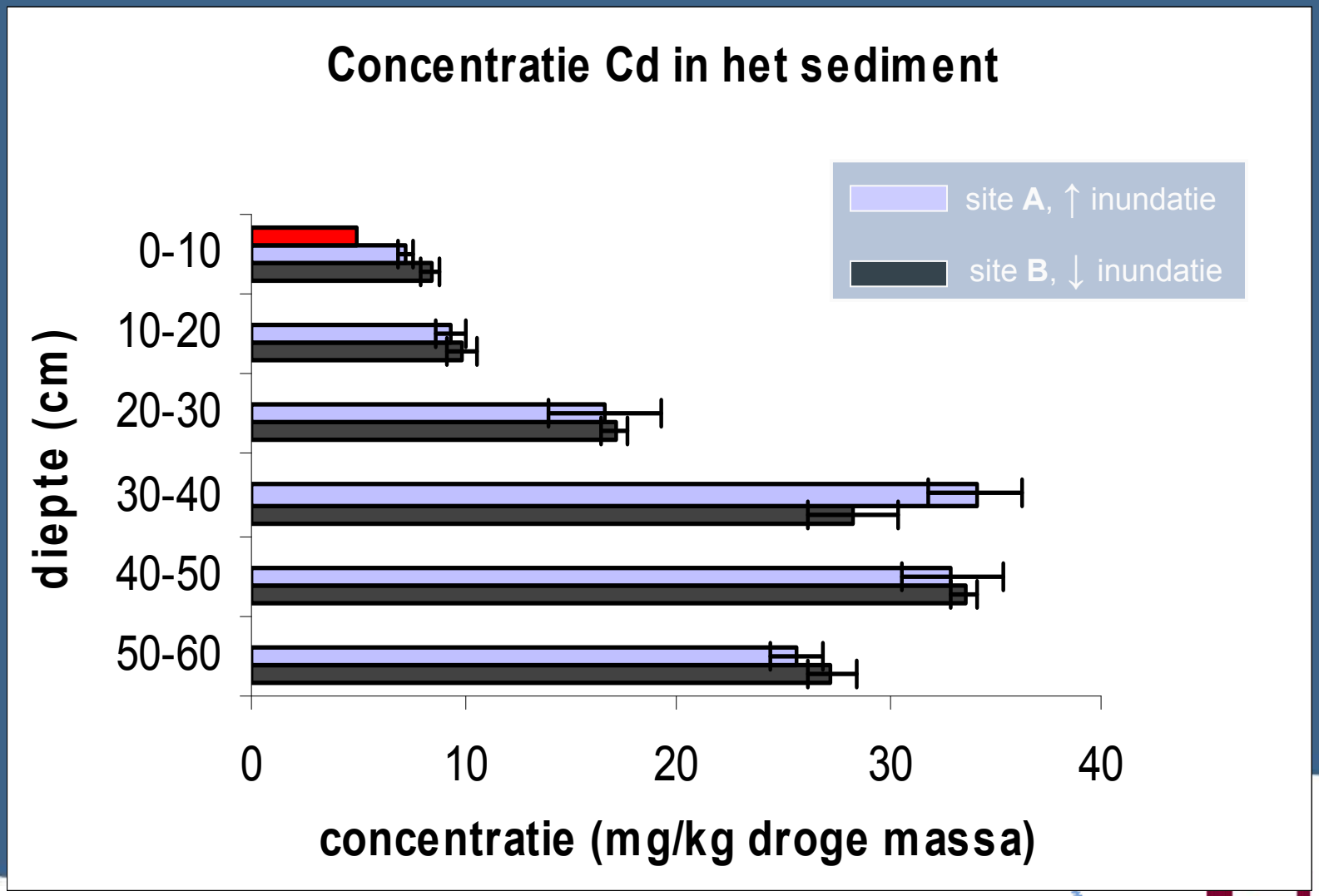
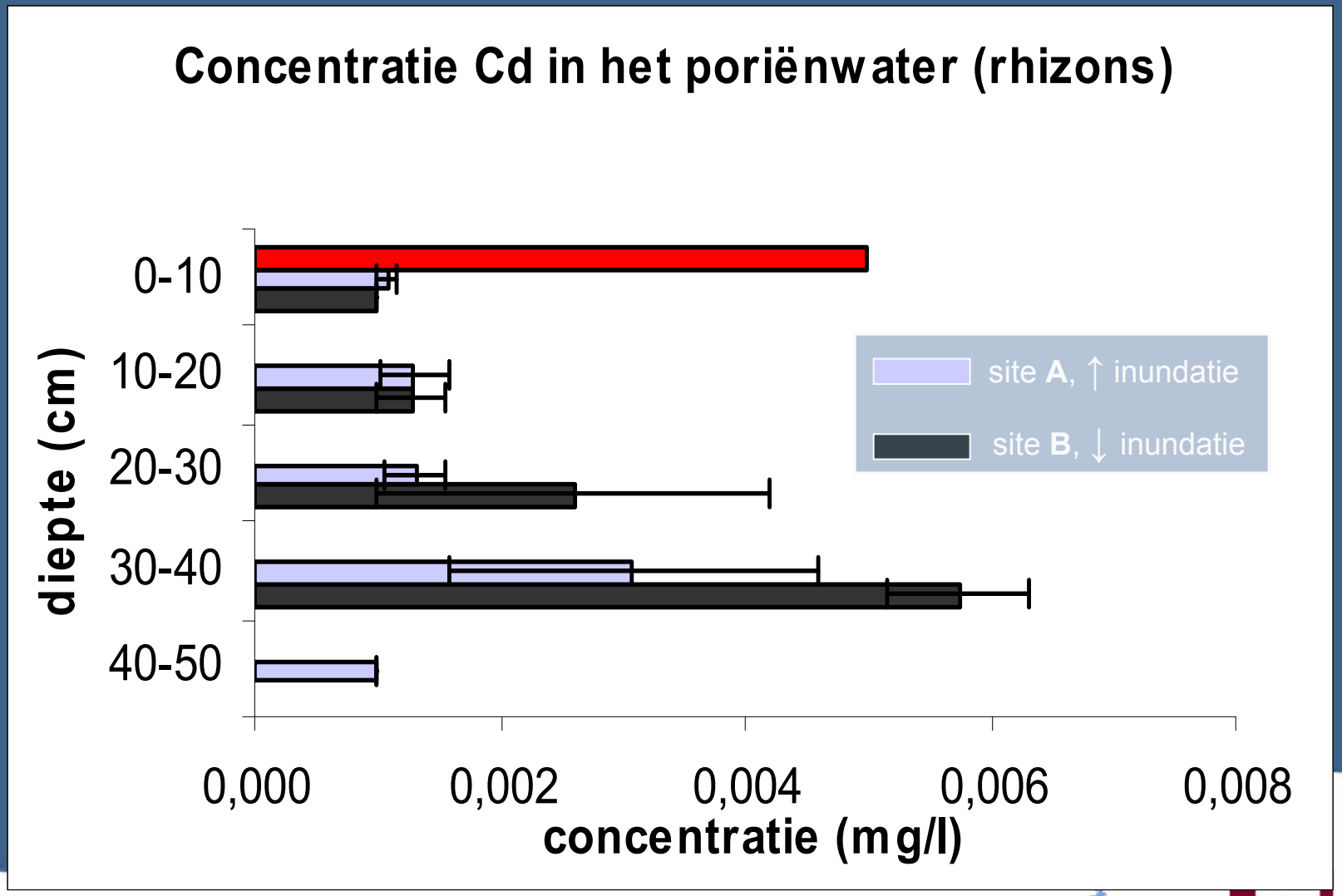
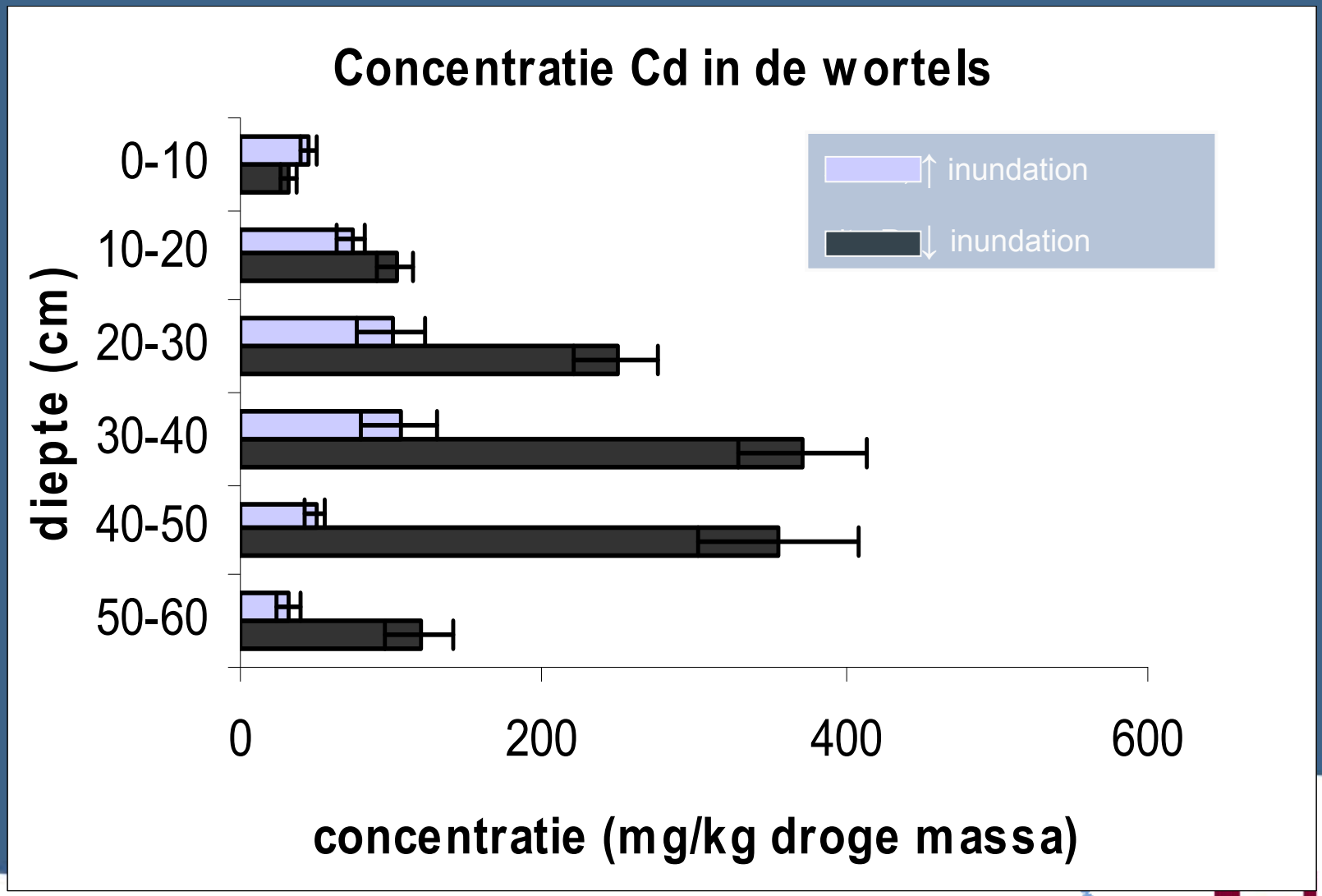
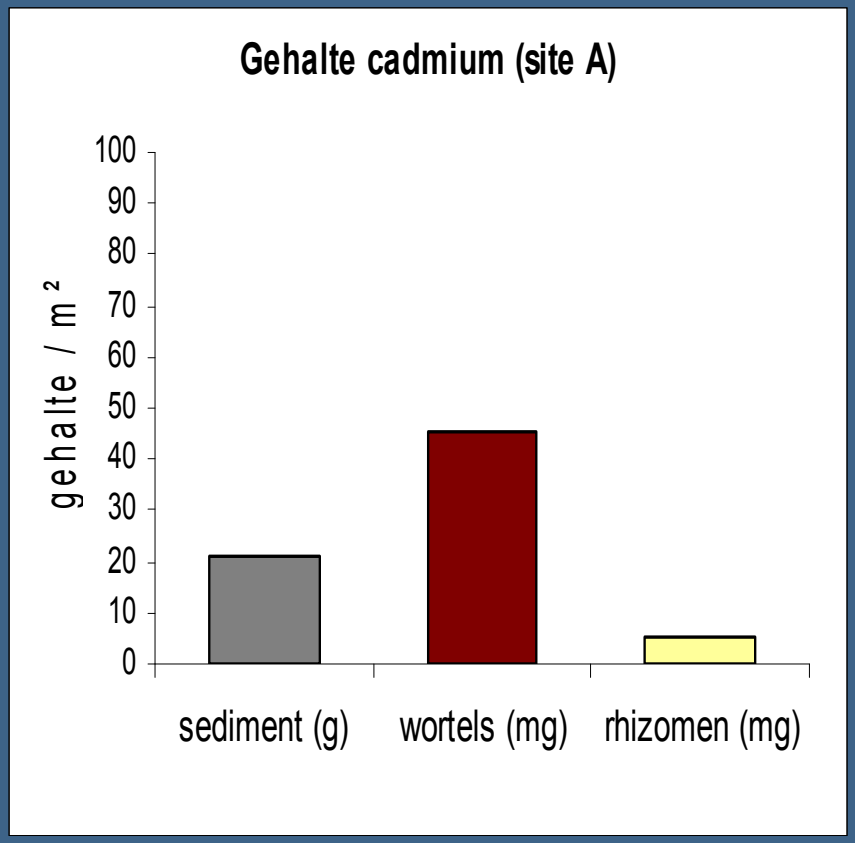
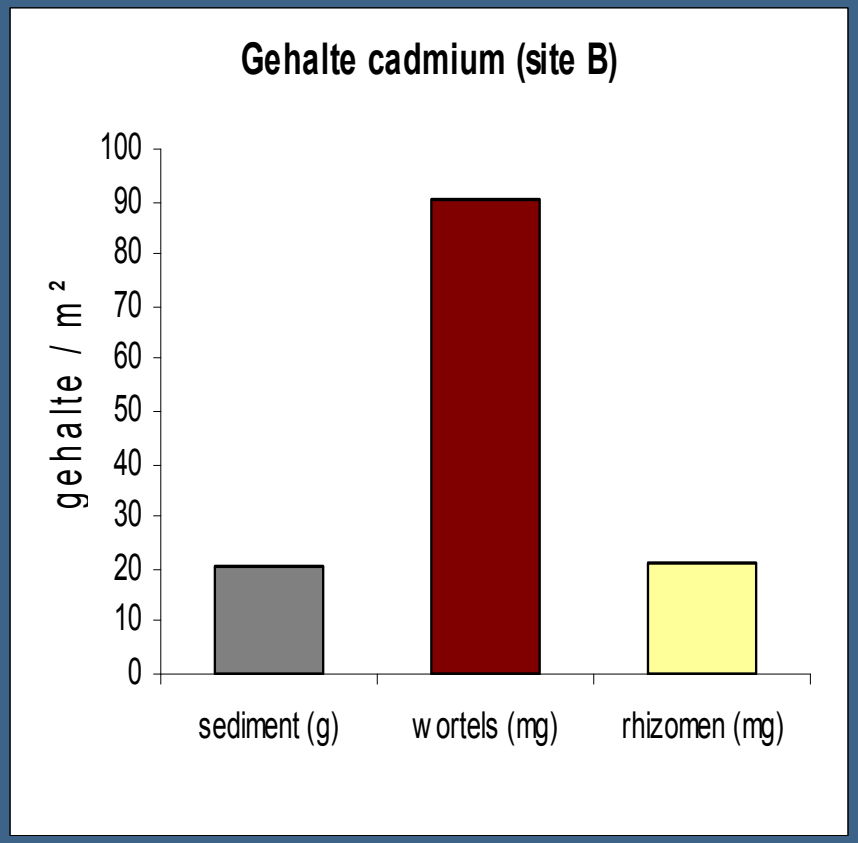

Concentratie Cd in het sediment
site A, ↑ inundatie
site B, ↓ inundatie
diepte (cm)
0-10
10-20
20-30
30-40
40-50
50-60
0
10
20
30
40
concentratie (mg/kg droge massa)


Concentratie Cd in het poriënwater (rhizons)
diepte (cm)
0-10
10-20
20-30
30-40
40-50
site A, ↑ inundatie
site B, ↓ inundatie
0,000
0,002
0,004
0,006
0,008
concentratie (mg/l)


Concentratie Cd in de wortels
0-10
10-20
20-30
30-40
40-50
50-60
diepte (cm)
inundation
inundation
0
200
400
600
concentratie (mg/kg droge massa)



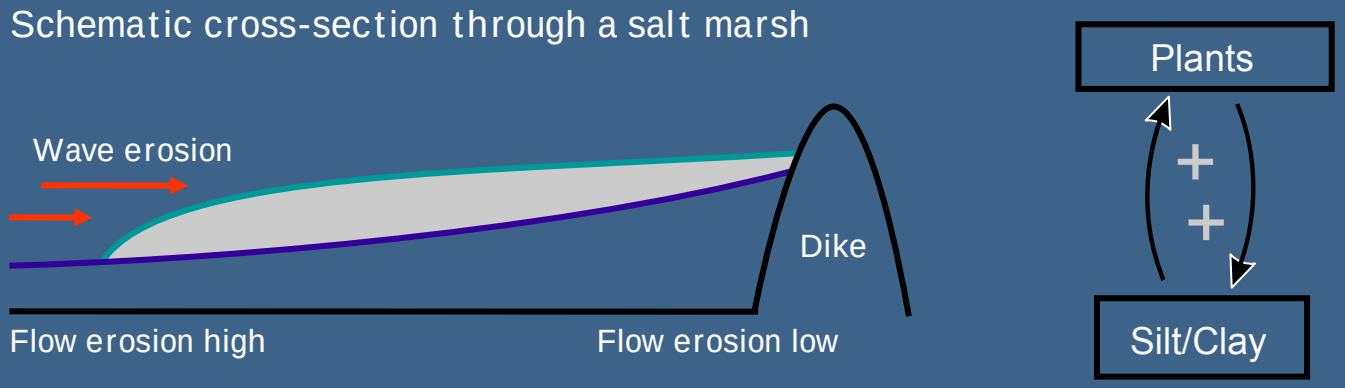


But all above ground biomass is under detection limit
➔Local conditions strongly impact availability
➔Will local conditions change?

No young marshes in estuary anymore
One of the aims of managed retreat is to restore the dynamics of the marshes

Salt marsh: natural dynamics between sedimentation and eriosion

after Van de Koppel et al 2005 Am. Natur.

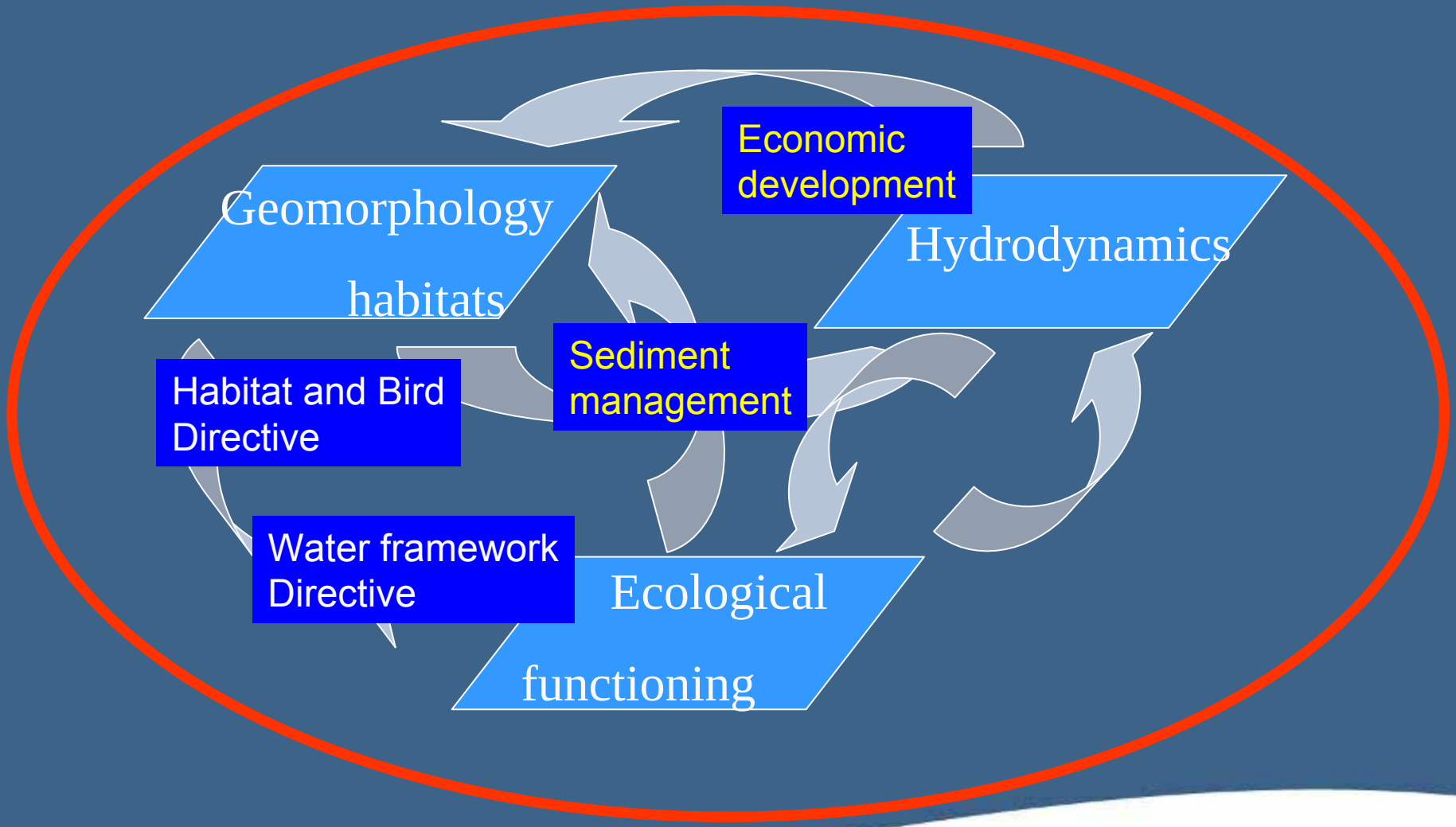


Natural marshes are very dynamic: an equilibrium between Sedimentation and erosion

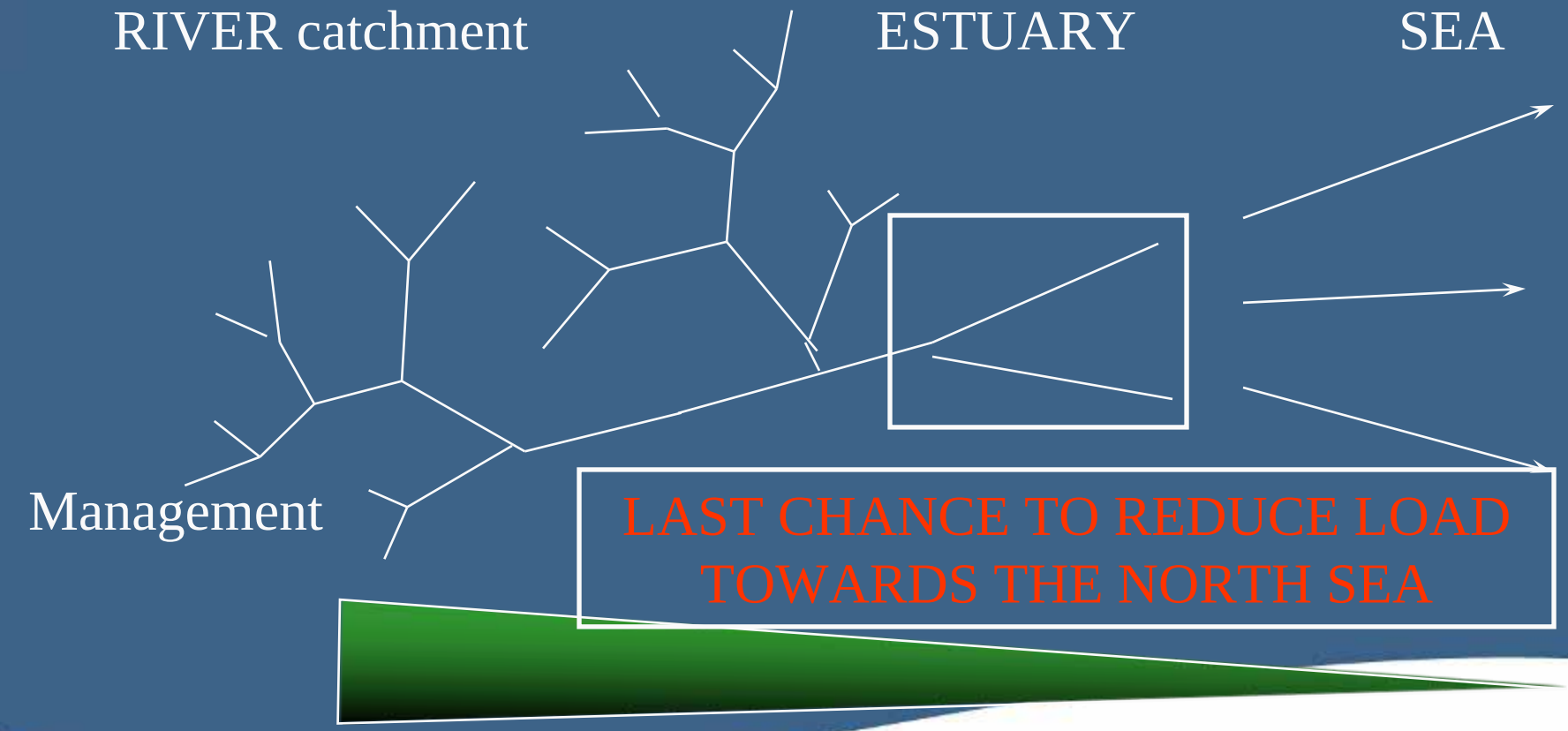
Simulated salt marsh development

Development of clat thickness and vegetation density along a transect
(MP3-movie not included in this ppt)

The System


Economic development
Geomorphology
habitats
Hydrodynamics
Sediment management
Habitat and Bird Directive
Water framework Directive
Ecological
functioning

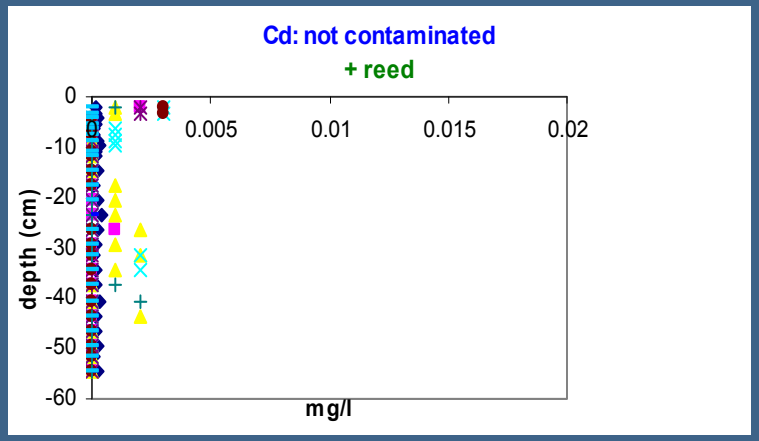
River-estuary-sea continuüm

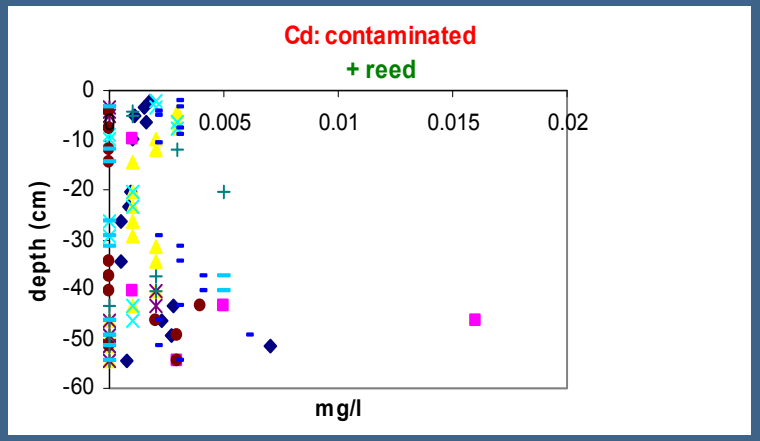


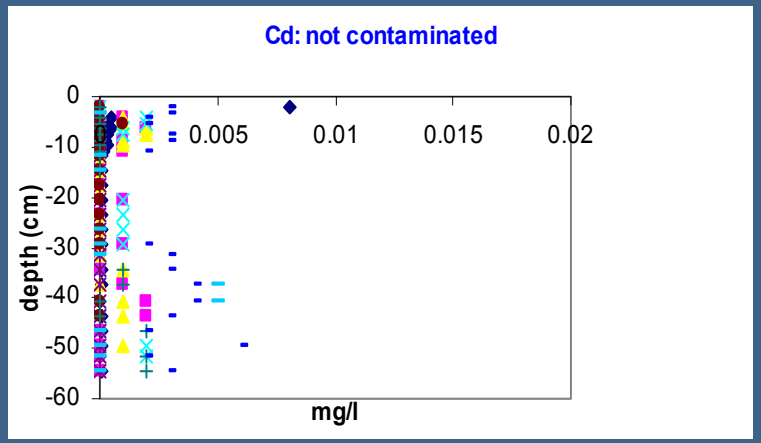
Conclusion

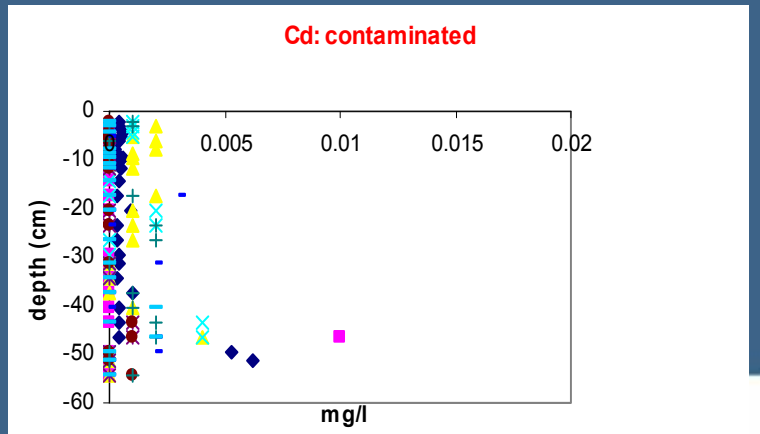
- Sediment management is a crucial part of integrated water management taking into account spatial relations
- Sediments have both very negative and very positive impacts on the ecosystems:
  - Too much ➔ impact on productivity and habitat characteristics
  - Too little ➔ habitat sustainability
- Sediment quality is a major problem for habitat development and dynamics
- An integration of several EU directives is necessary to achieve an true integrated water management

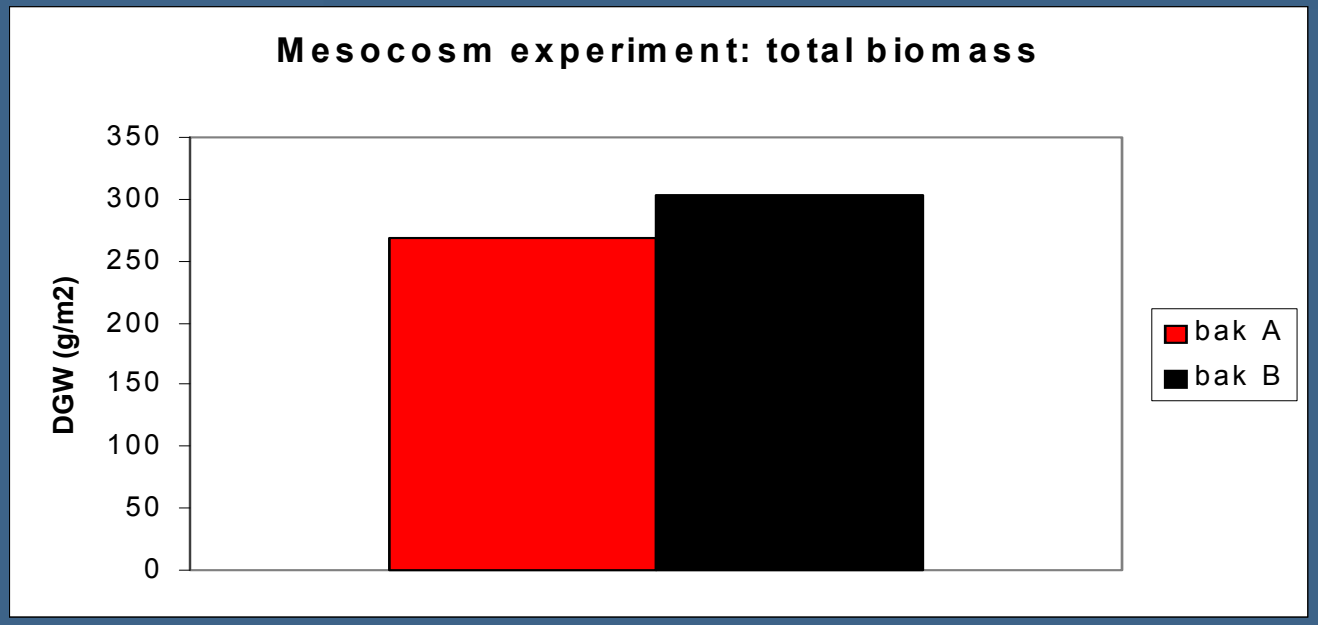
Pore water: Cd,

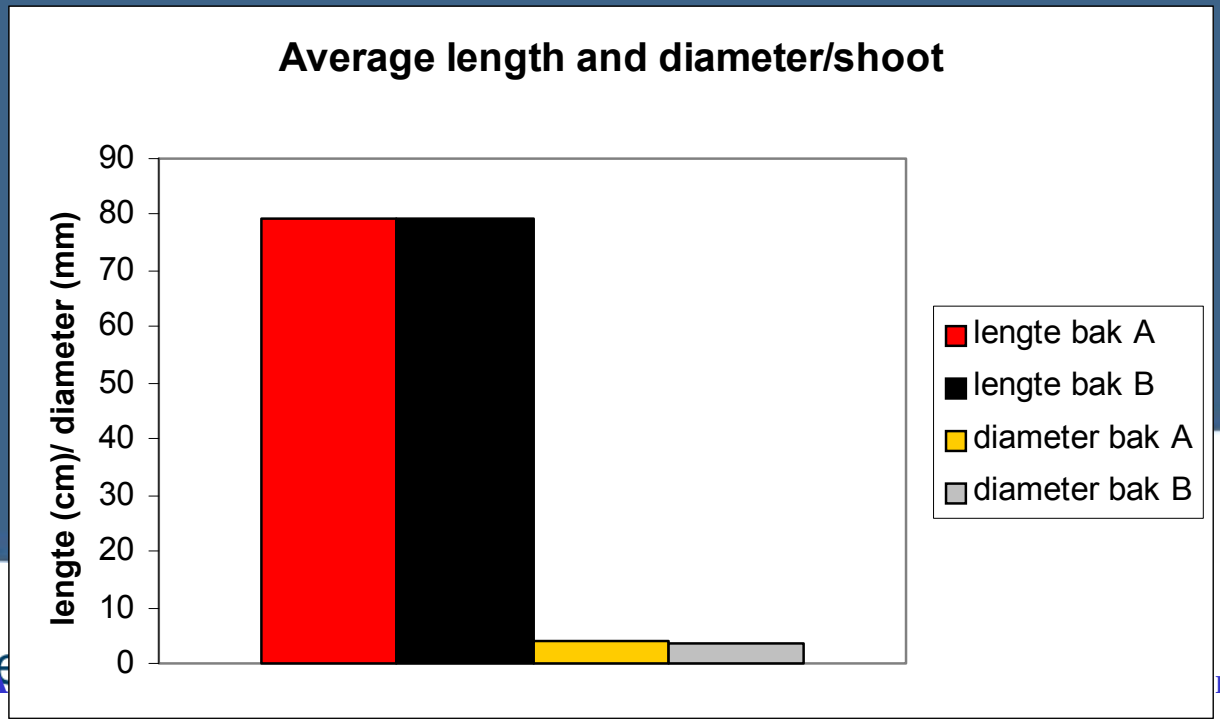









Mesocosm experiment: total biomass
DGW (g/m2)
350
300
250
200
150
100
50
0
bak A
bak B


Average length and diameter/shoot
lengte (cm)/ diameter (mm)
90
80
70
60
50
40
30
20
10
0
lengte bak A
lengte bak B
diameter bak A
diameter bak B