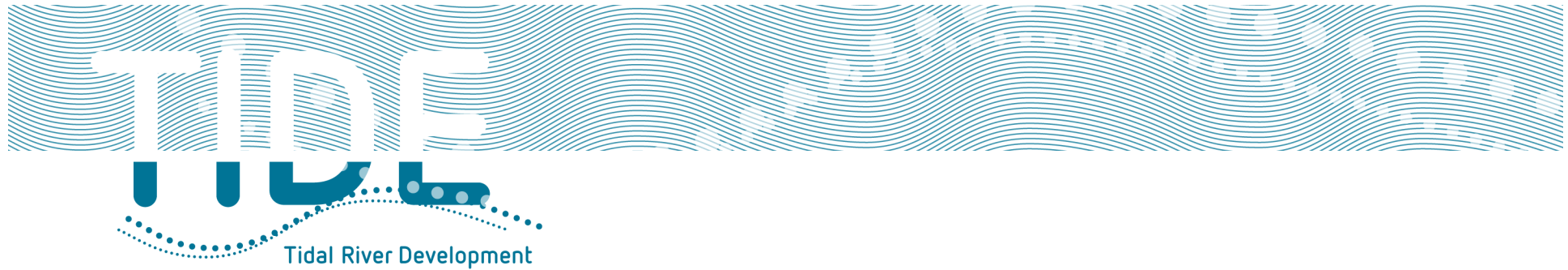


# Unravelling Estuarine Functioning

Prof. dr. Patrick Meire  
University of Antwerp

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## **This presentation is a compilation of results described in several reports contributing to WP3**

- Waterbouwkundig Labo; Wouter Vandenbruwaene, Yves Plancke
- Antwerp Port Authority: Stefaan Ides, Els Van Duyse
- University of Bremen: Kay Hamer
- University of Hull: Nick Cuts, Anita Franco, Mike Elliot
- Ministry of the Flemish community: Frederik Roose
- NLWKN: Sonja Saathof, Wilfried Heber
- Environment Agency: Sue Manson
- Deltares: Marcel Taal
- BfG: Andreas Scholl
- University of Antwerp: Lindsay Geerts, Stefan Van Damme, Tom Maris, Lotte Oosterlee, Annelies Boerema....

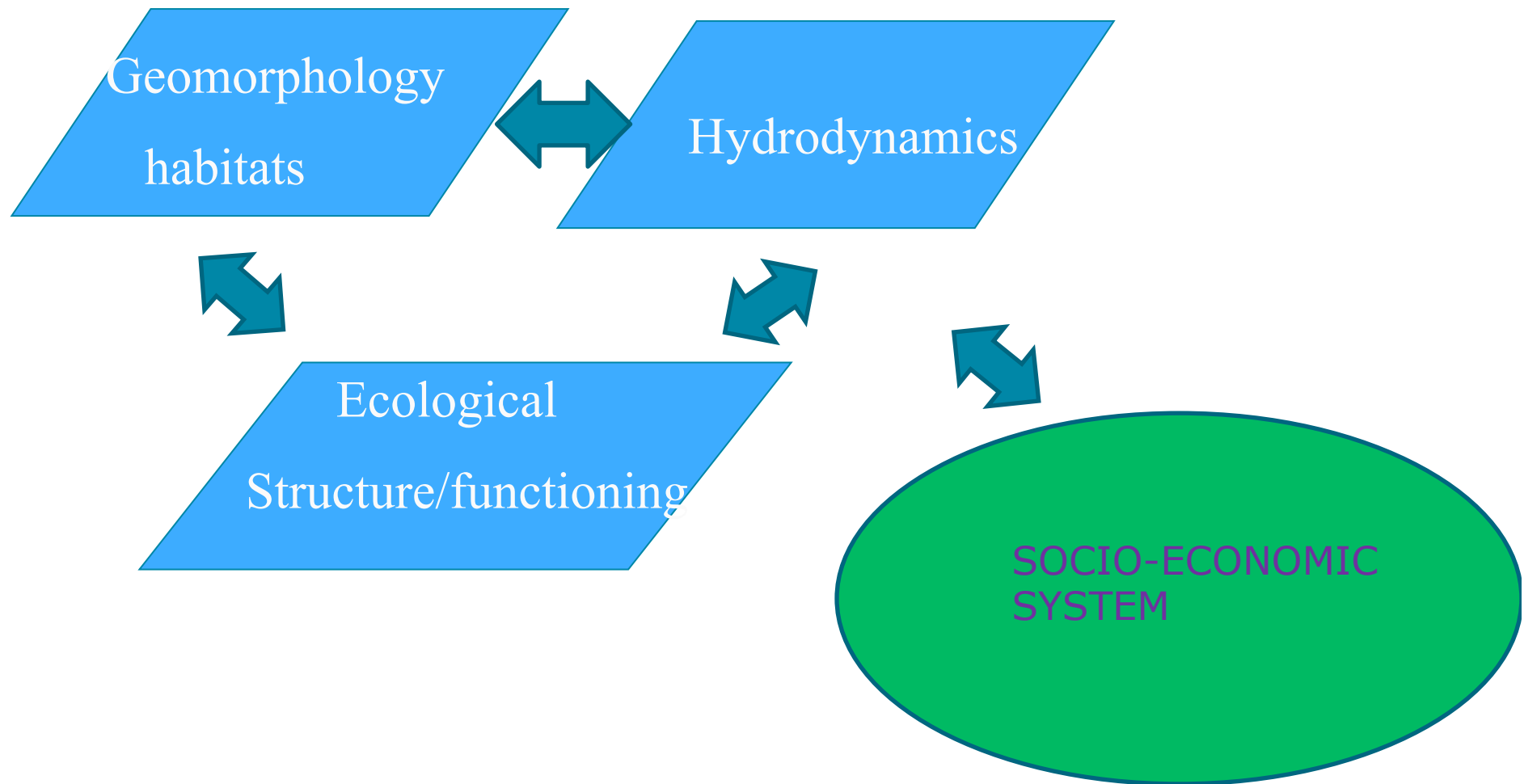
.....

# TIDE

Tidal River Development

## BIOPHYSICAL SYSTEM

# An Estuary



## INTRODUCTION

- An integrated management of this complex ecosystem should be based on a better understanding of the functioning of the **system** and how we derive the benefits from the system.
- → This was the aim of WP3 of the TIDE project

Ecosystems and biodiversity

Structures and processes

Functions



Human well being

Benefits

(Economic) Value



Animal food



Channels

Morphology

Salt marshes



Ecosystems and biodiversity

Structures and processes

Functions



Human well being

Benefits

(Economic) Value



Animal food

Morphology  
Salt marshes



Agricultural land



Ecosystems and biodiversity

Structures and processes

Functions



Raw materials:  
Platform for building

Human well being

Benefits

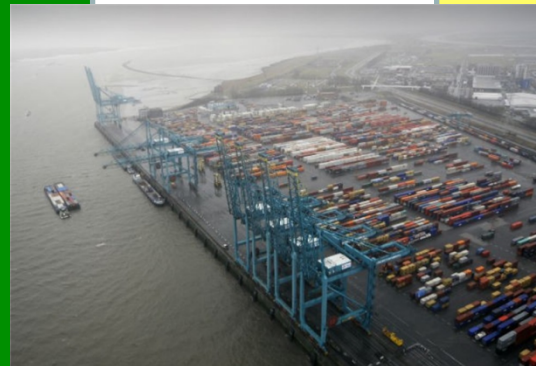
(Economic)  
Value



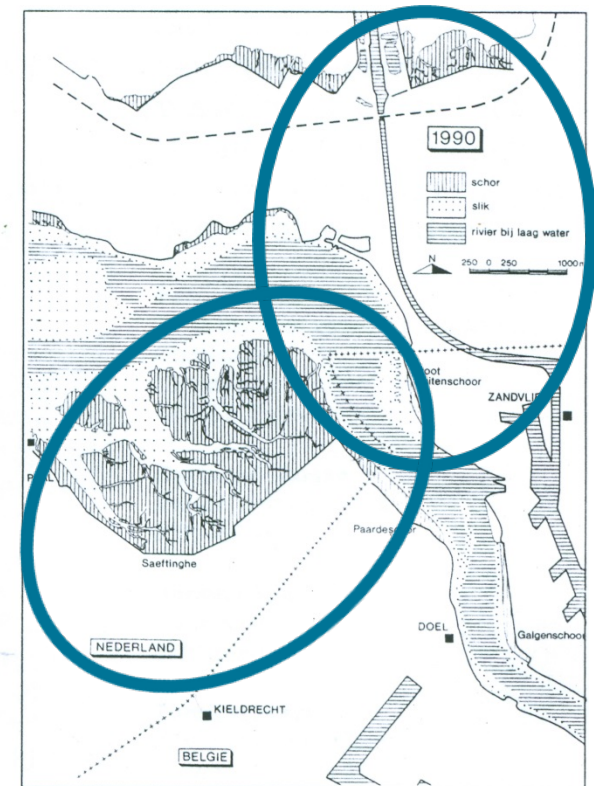
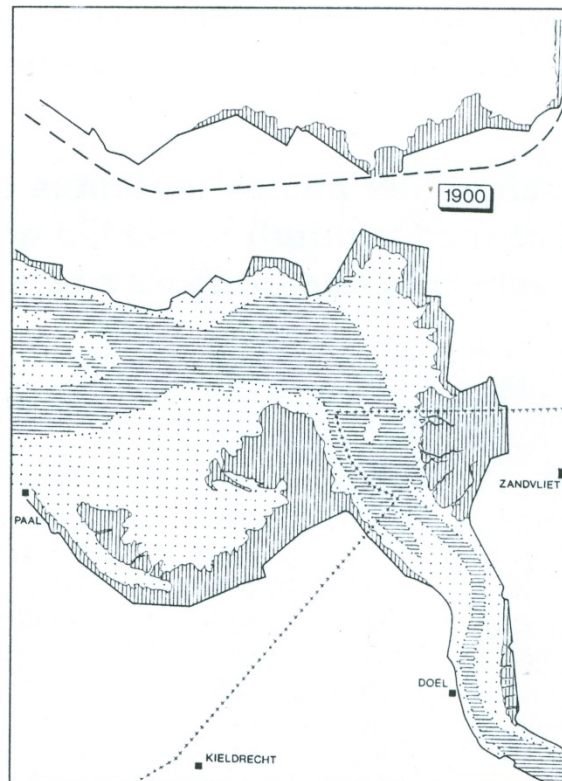
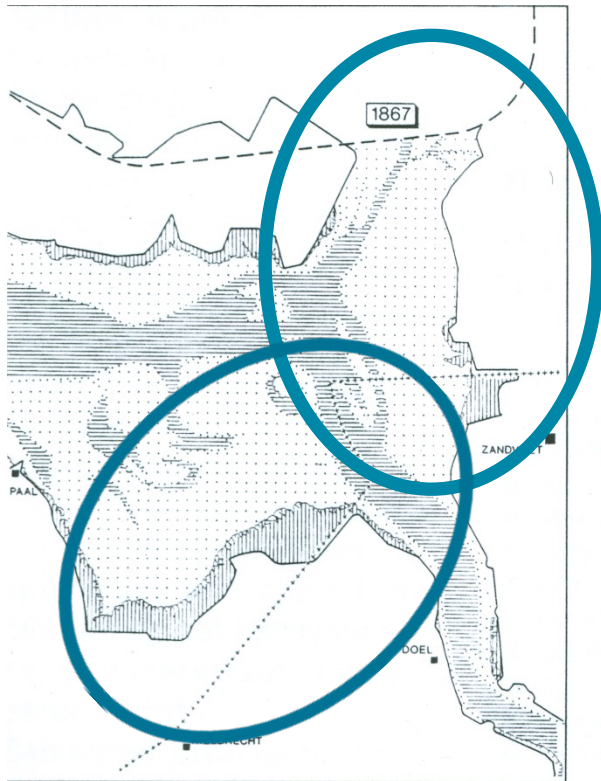
Morphology  
Salt marshes  
Tidal Flats



Industrial/harbor area



## Schelde at Dutch-Belgian border: 1867 - 1990

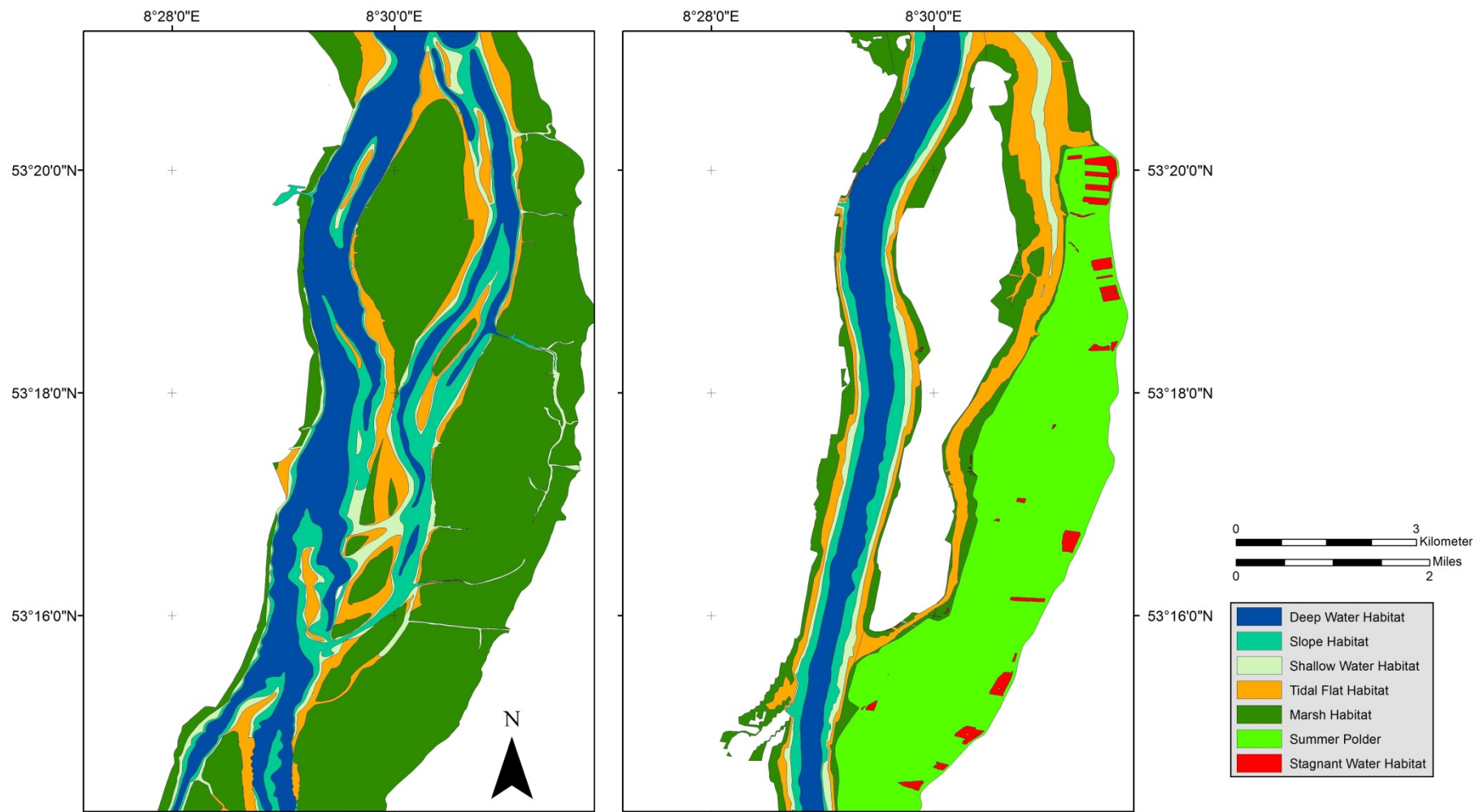


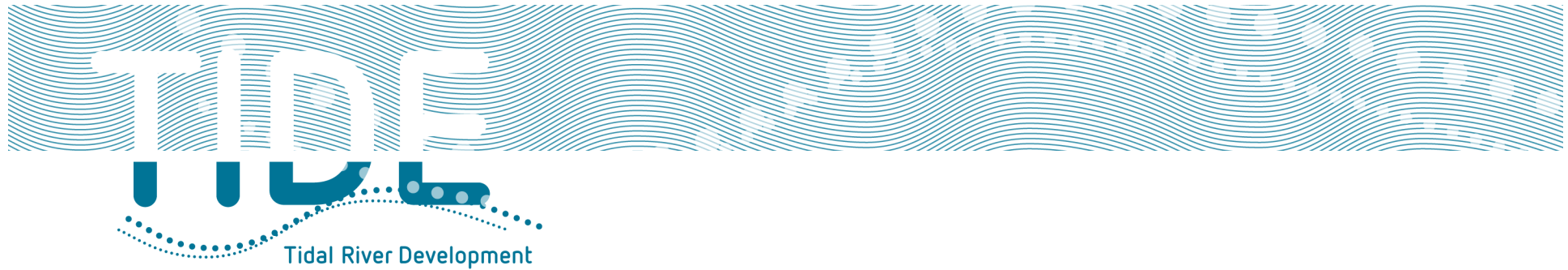
# TIDE

## Changes in habitat patterns Weser – Harriersand=( etween Vegesack and Brake)

End of  
19th century

recent





## Key message

- Habitat loss is apparent, mainly of intertidal areas and losses upstream although small in area compared to downstream parts are significant and sometimes relatively more important than the downstream losses.

Ecosystems and biodiversity

Structures  
and  
processes

Functions

Channels

Morphology

Water for  
navigation

Human well being

Benefits

(Economic)  
Value





Ecosystems and biodiversity

Human well being

Structures and processes

Functions

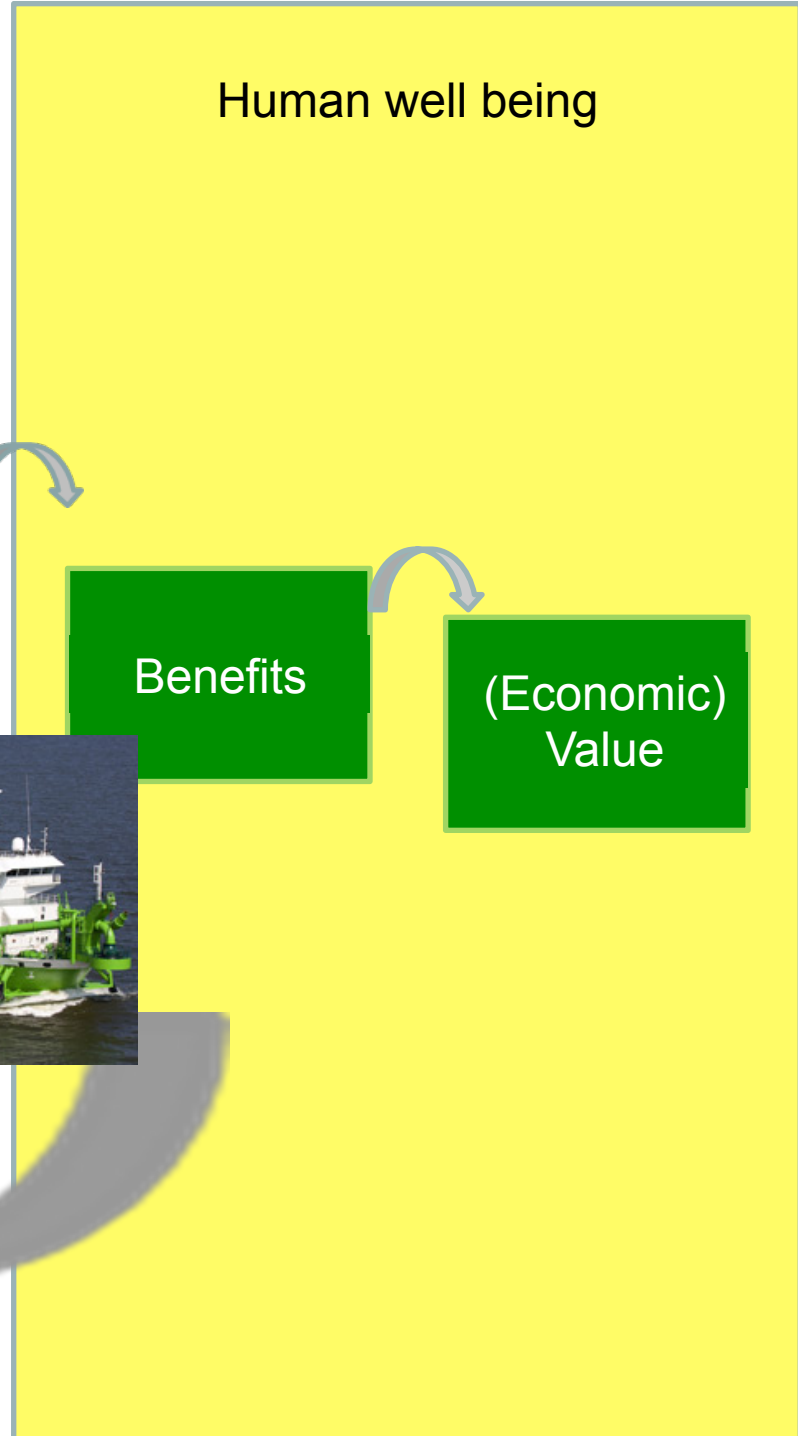
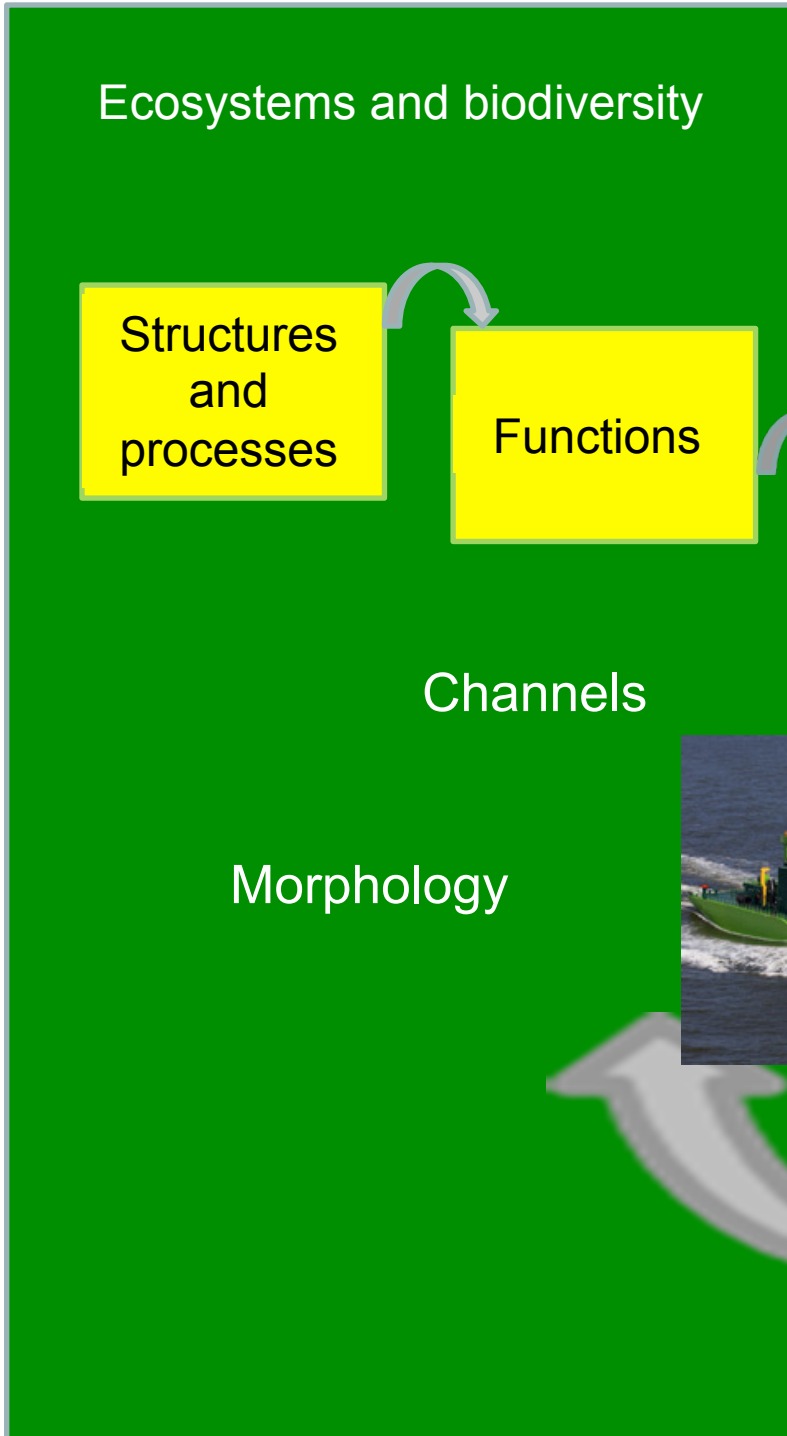
Water for navigation

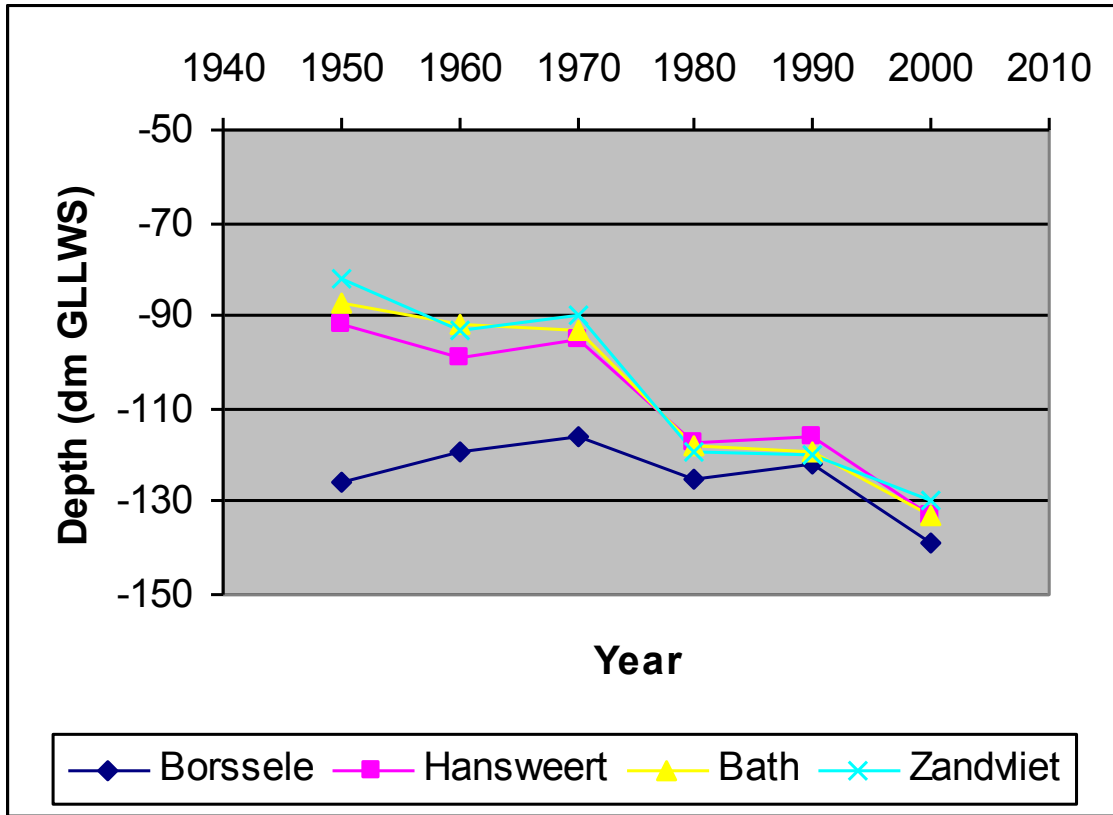
Channels

Benefits

(Economic) Value

Morphology

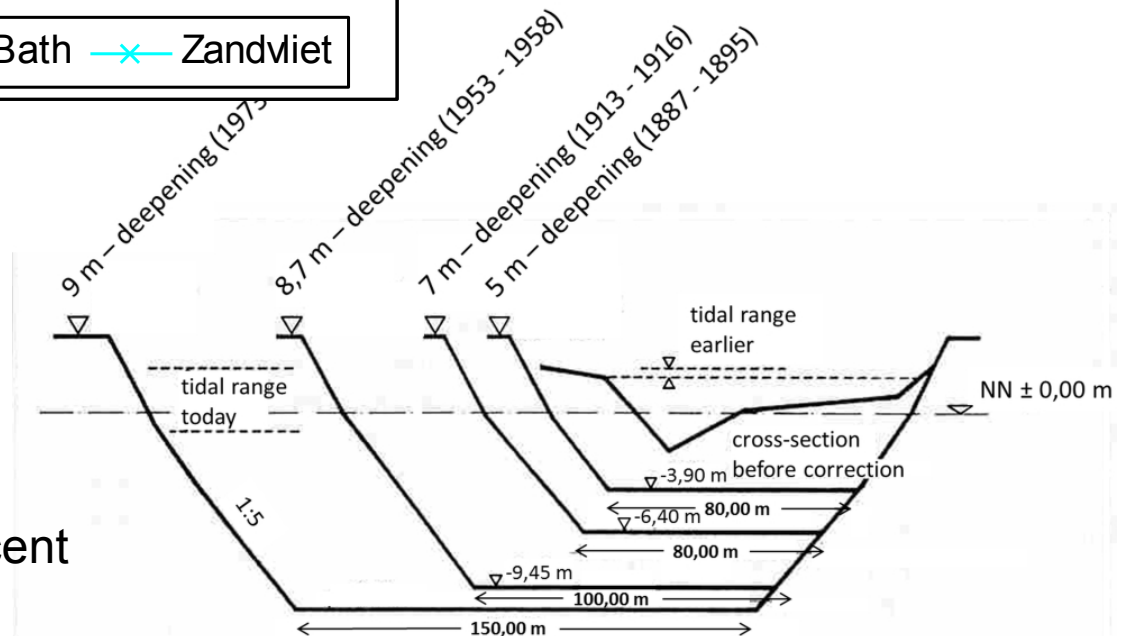


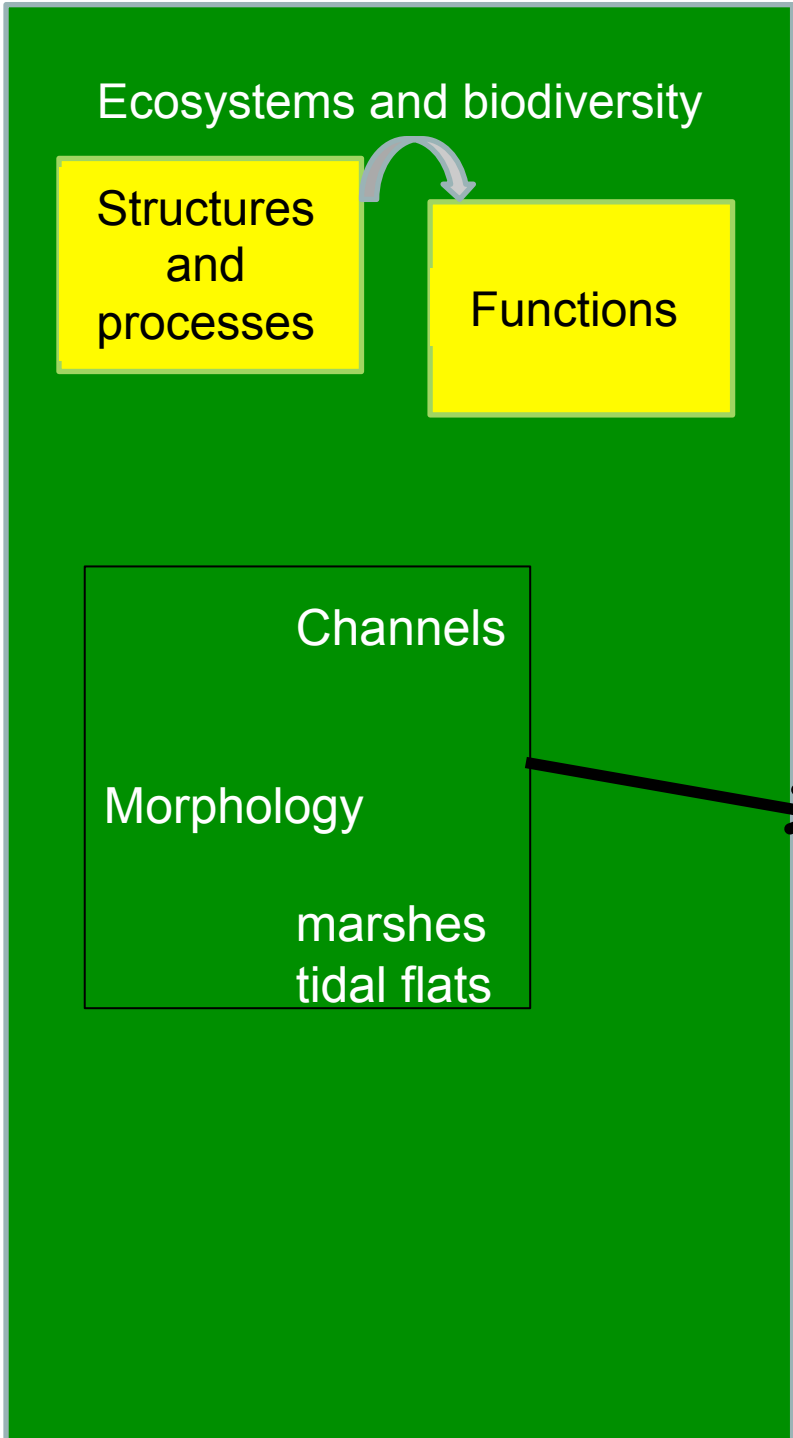


Deepening:  
Schelde estuary  
1950 – recent times

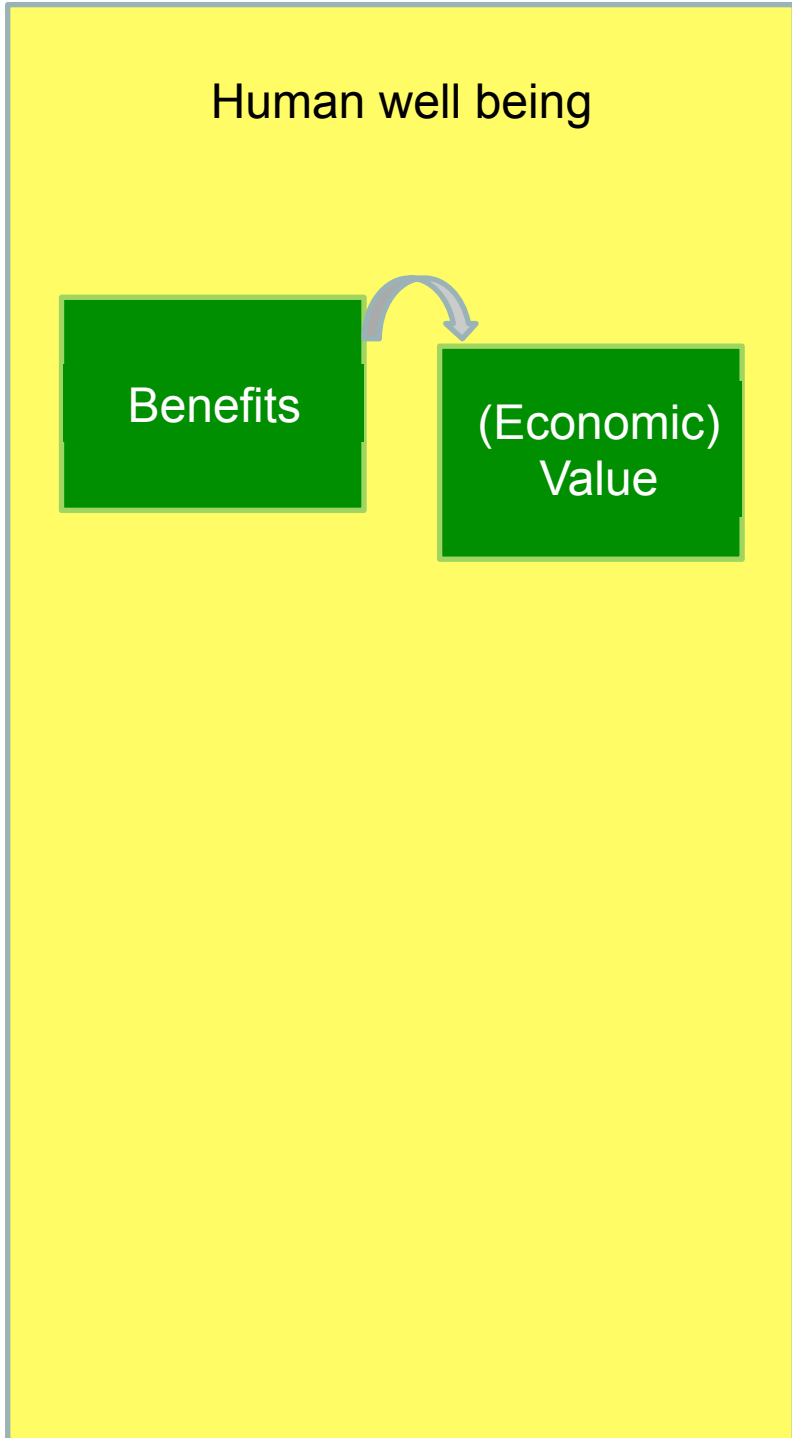


Deepening:  
Section Lower Weser 1880 – recent times

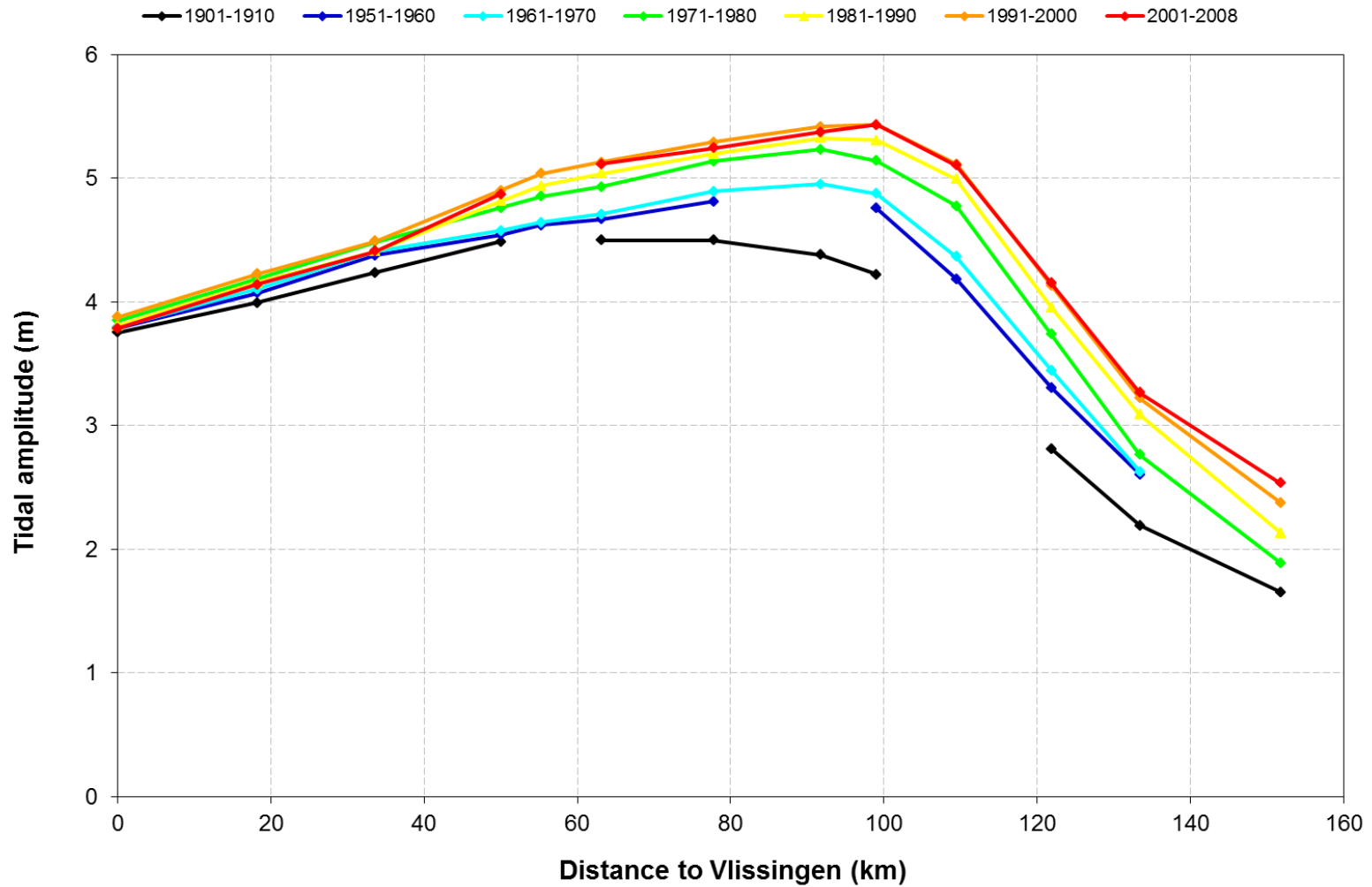




Dissipation of Tidal energy



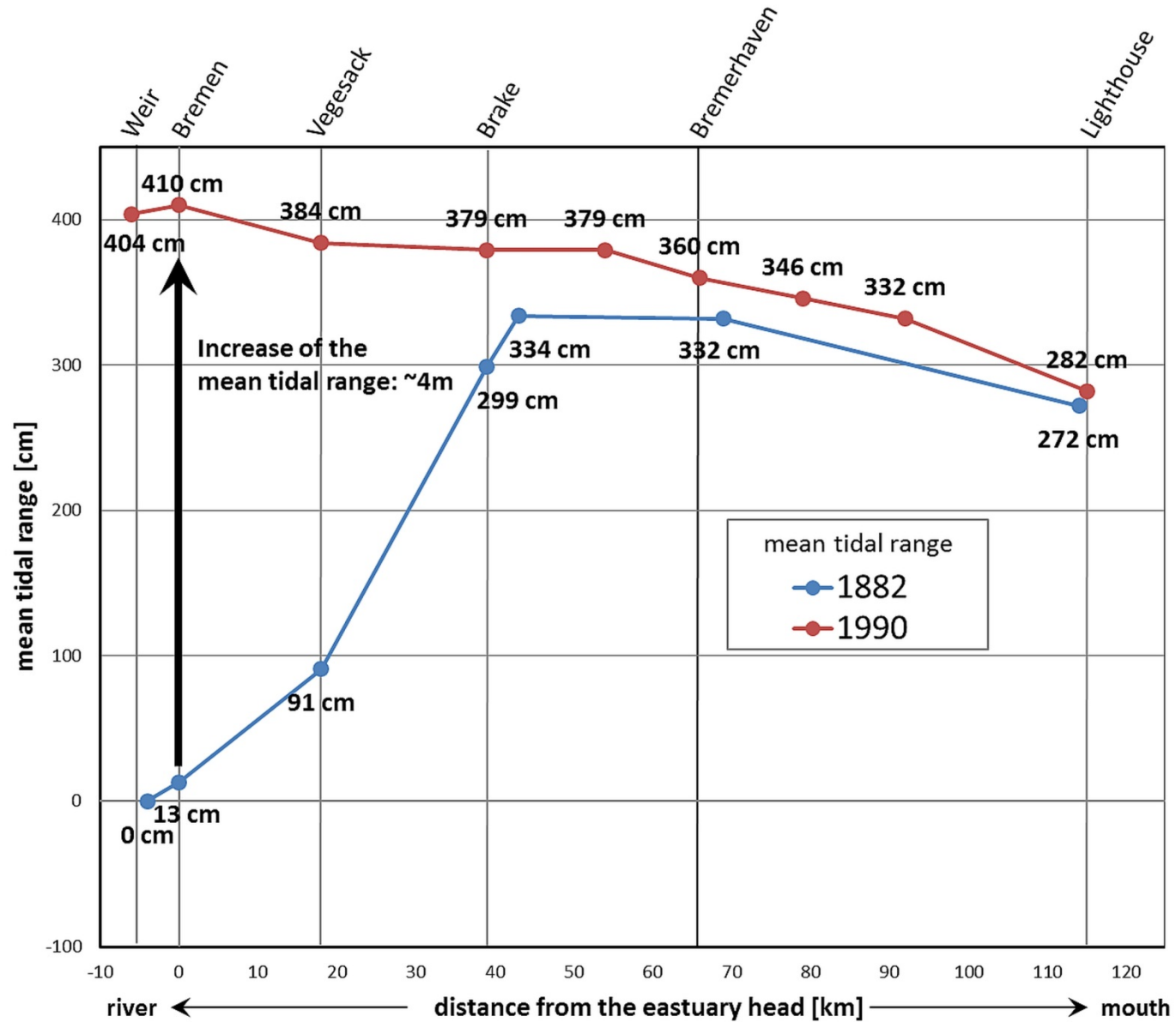
## Tidal amplitude: 1900-2008





# TIDE

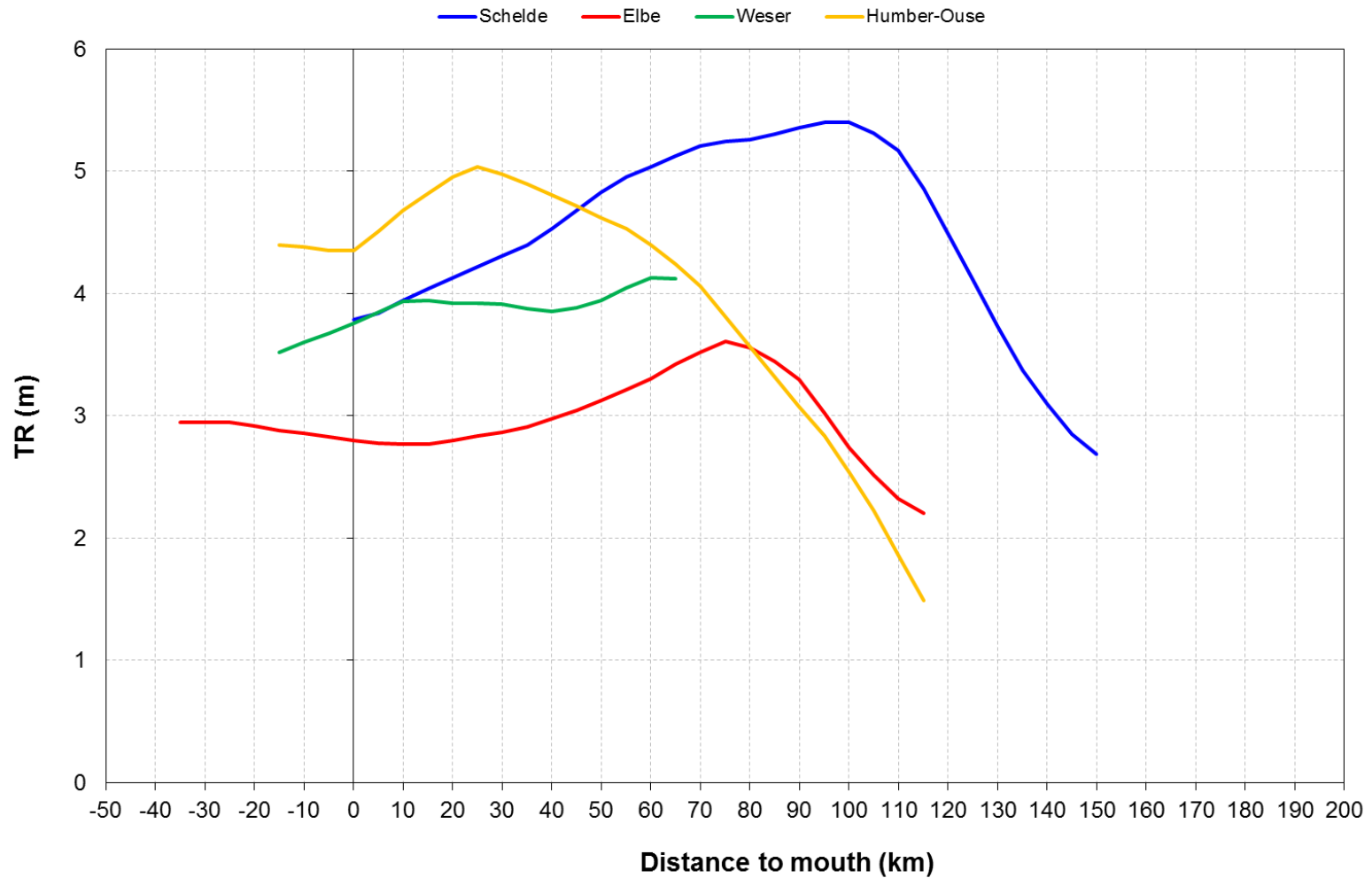
## Tidal range (1882 to 1990) along the Weser

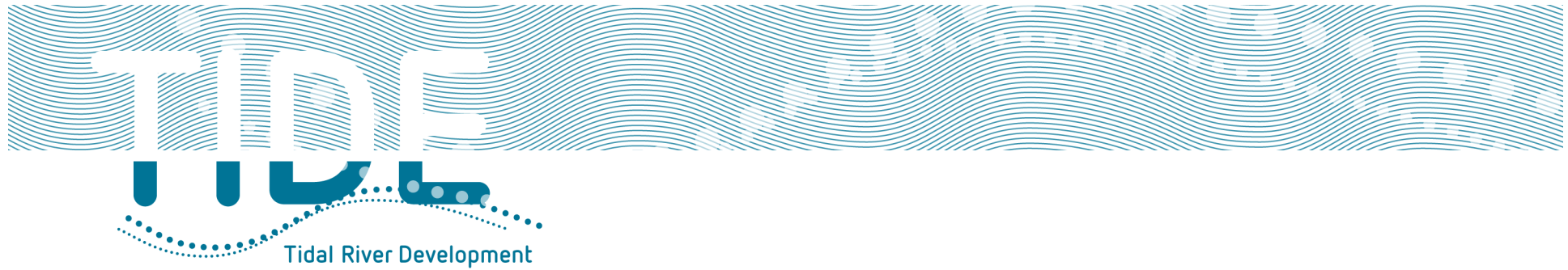




# Tidal damping/amplification

## Tidal range





## Tidal amplification i.r.t. morphology

- *Which factors influence the amplification of the tide in an estuary?*
  - *How can the tidal amplification in an estuary be stopped or even be reduced?*
-



## TIDAL RANGE

# Amplification or damping?

**CONVERGENCE – Amplification**

→ Width



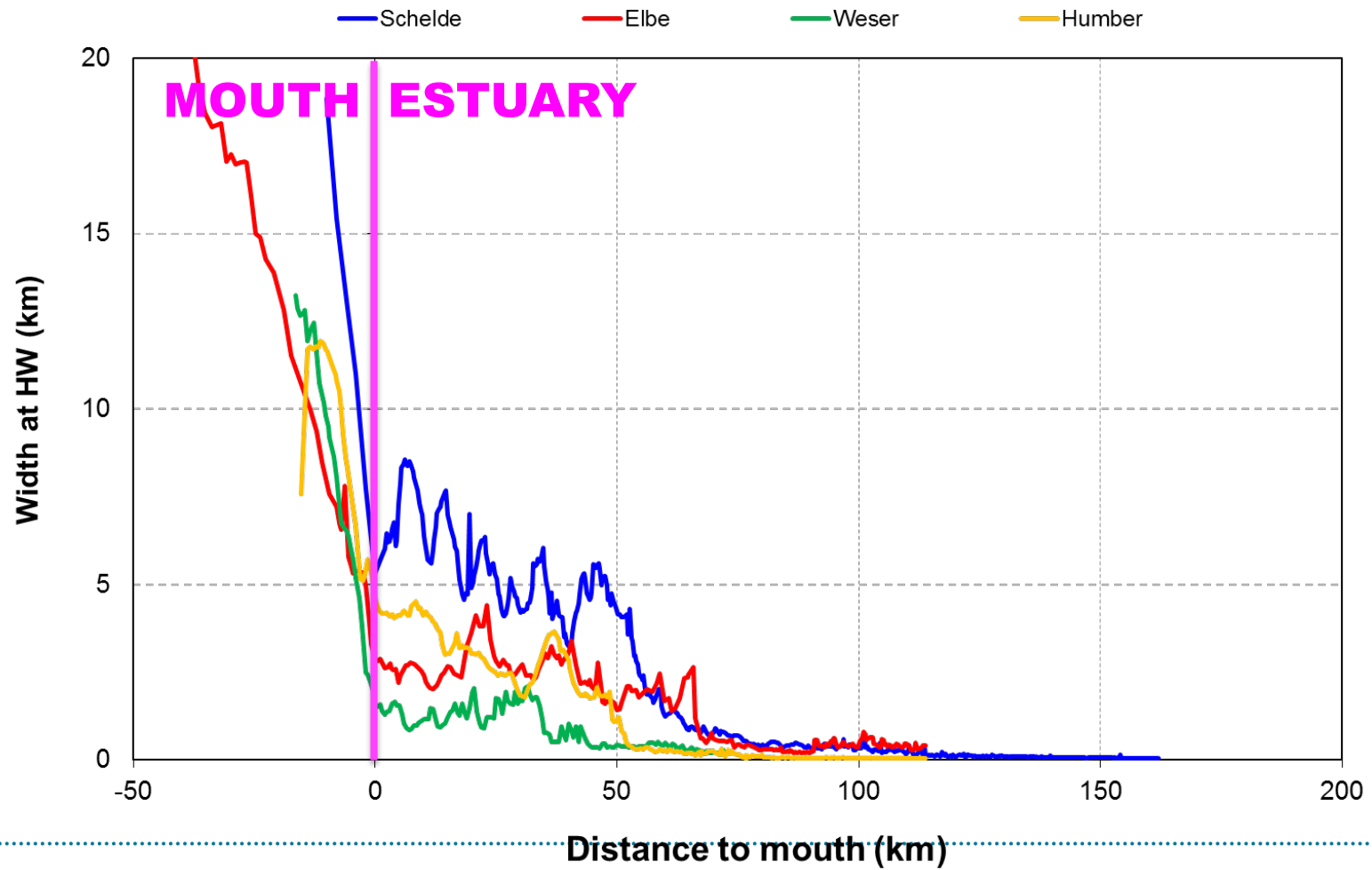
**FRICTION – Damping**

→ Depth

---

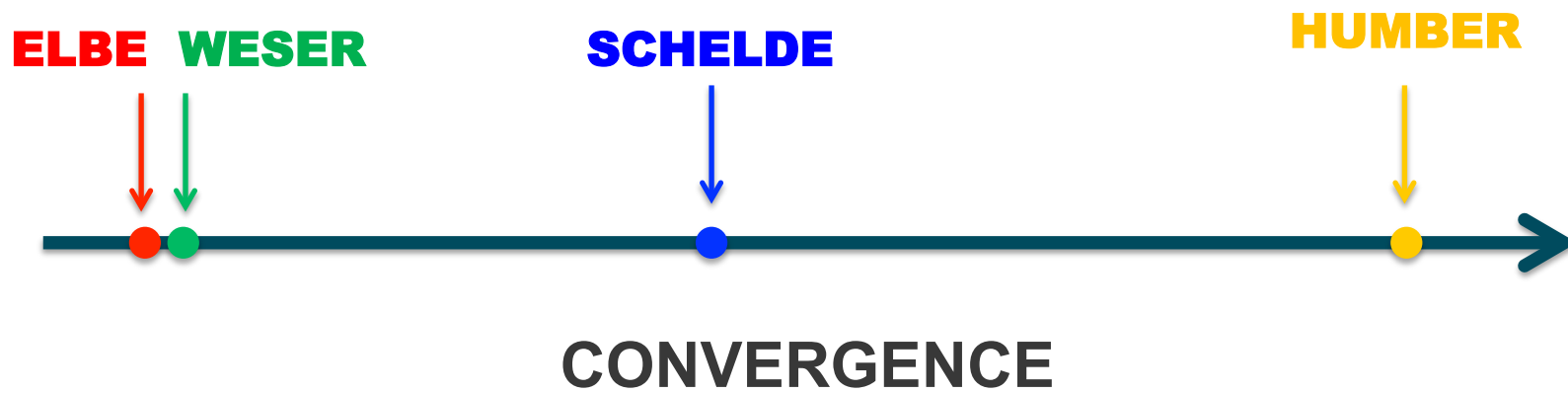


# Convergence

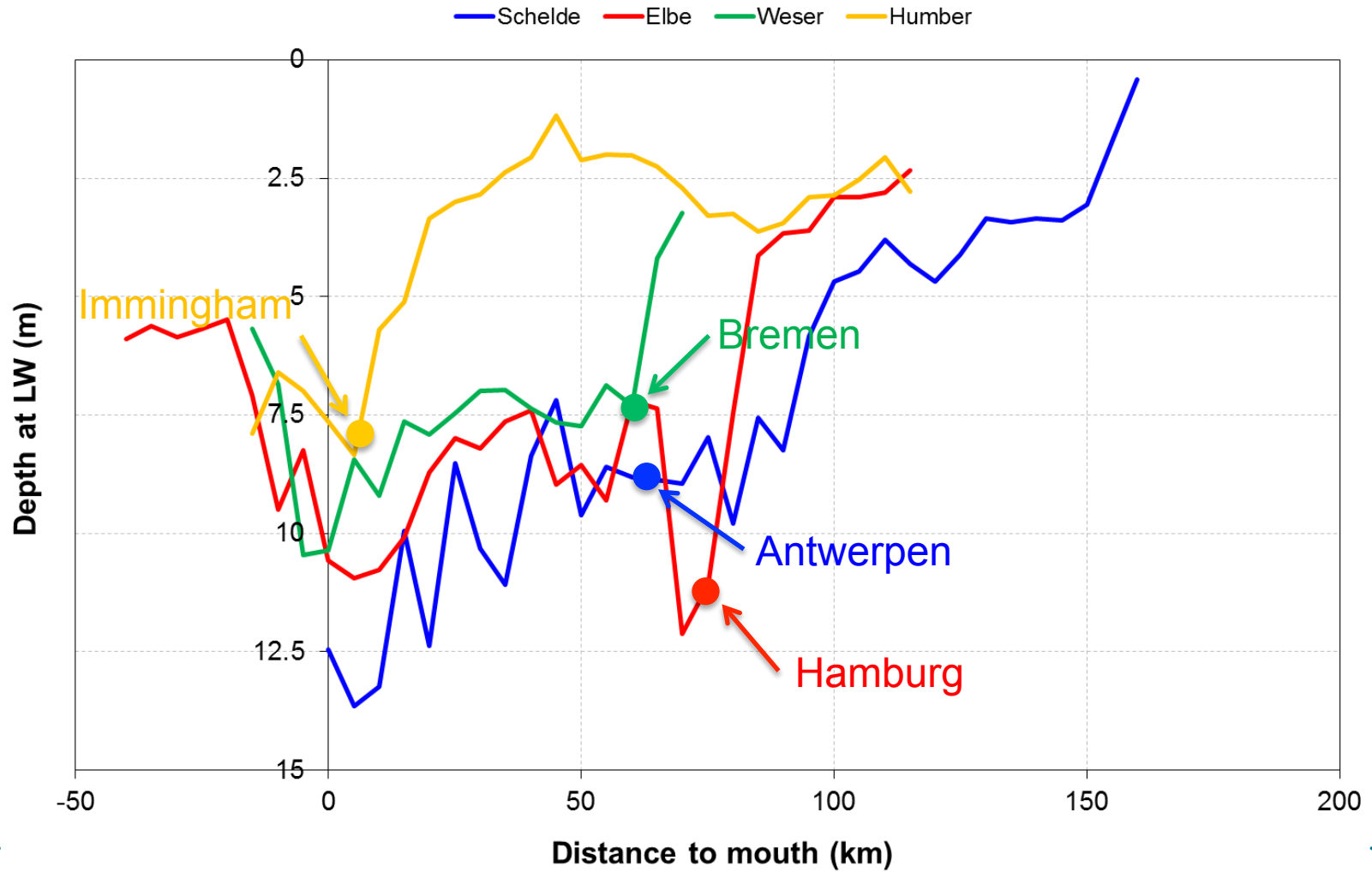


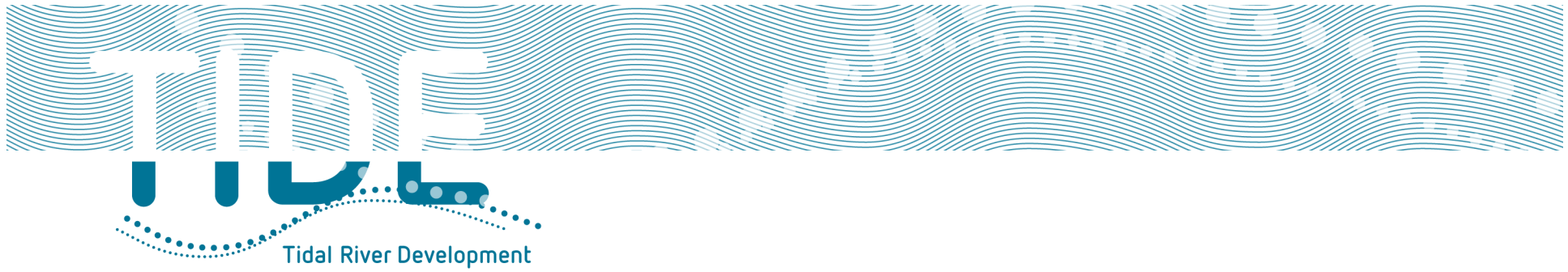


# Convergence

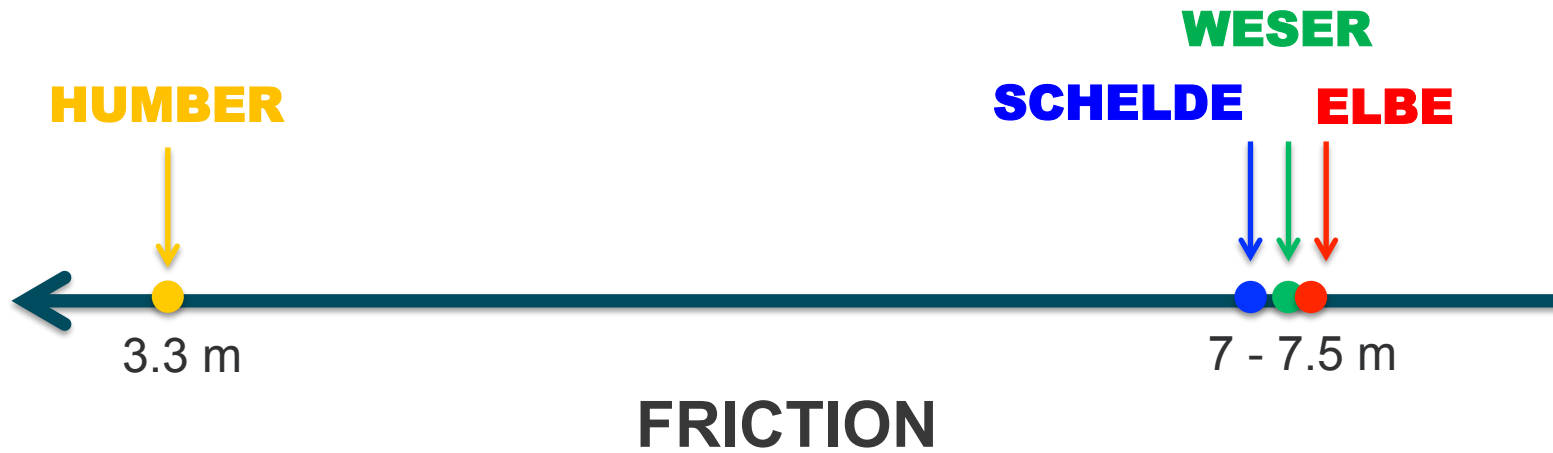


## Friction

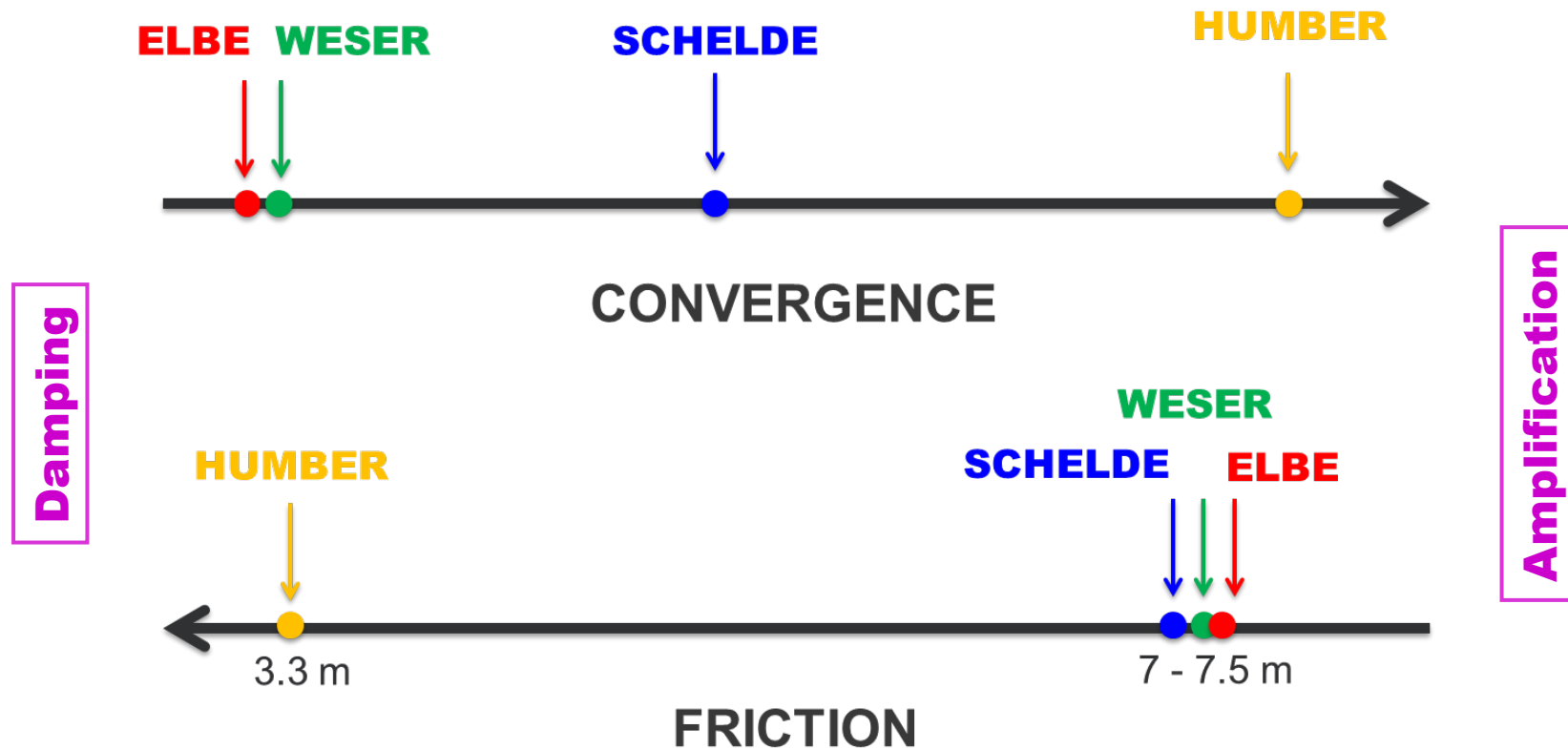




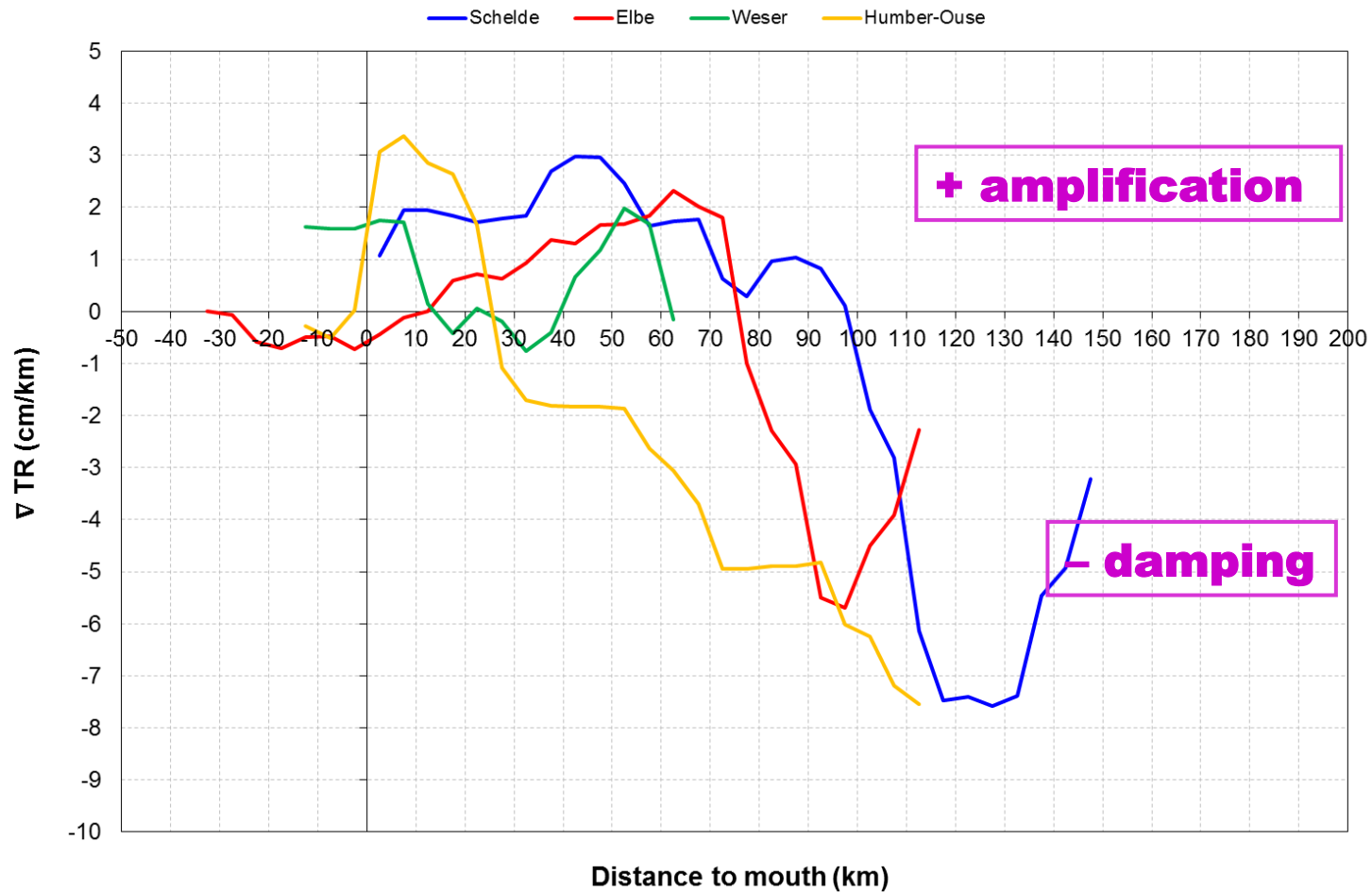
# Friction



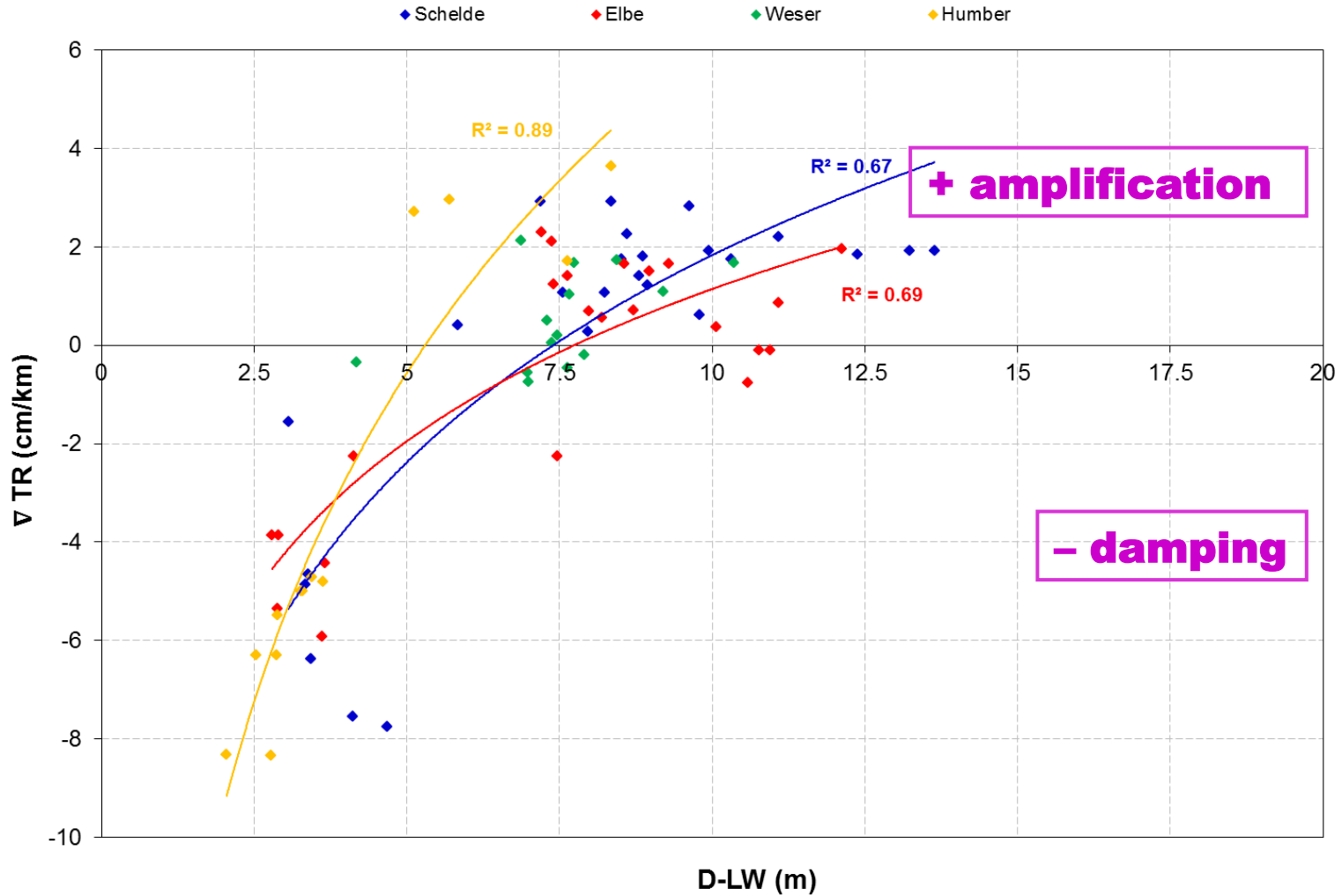
## Convergence versus friction



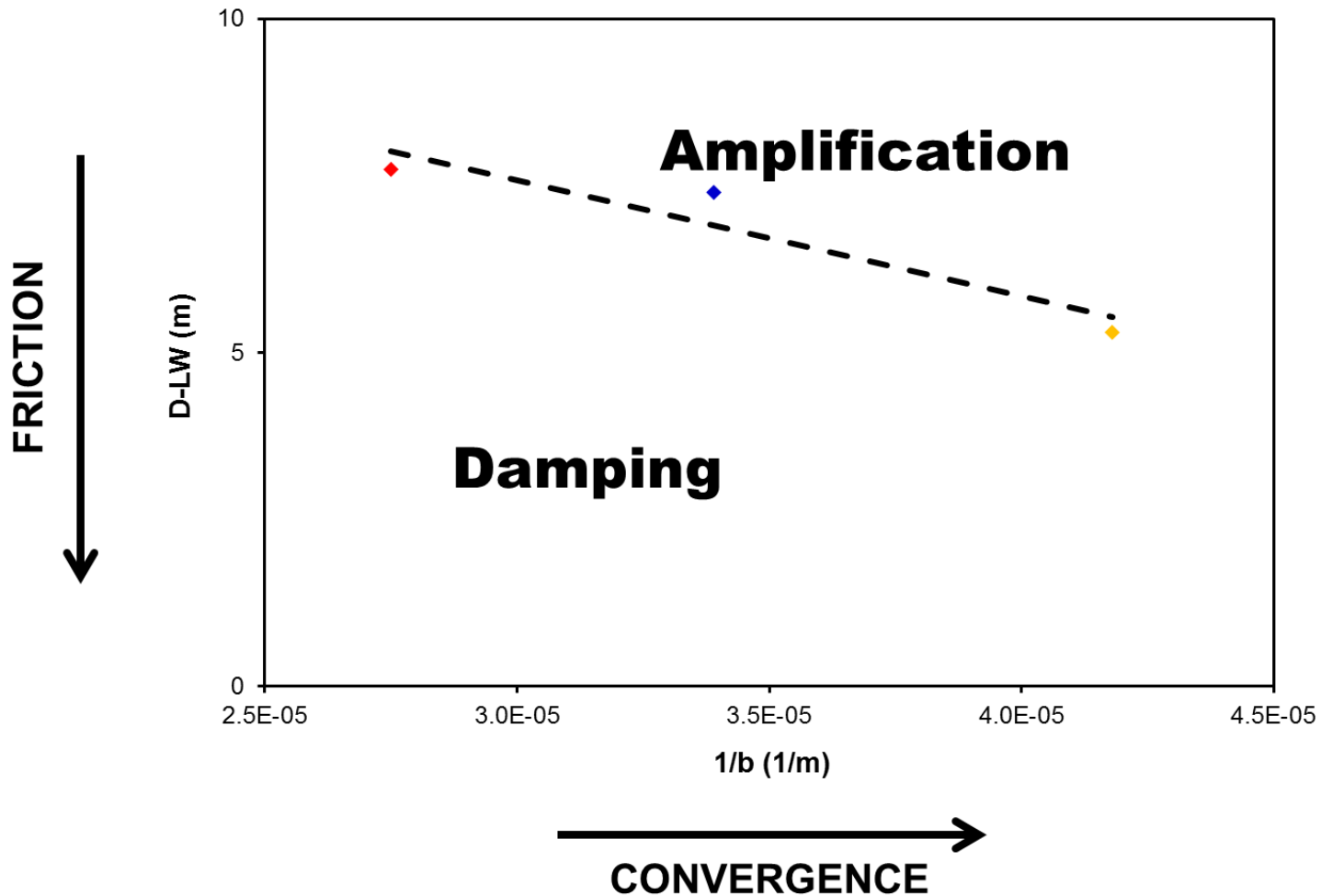
## Tidal damping/amplification

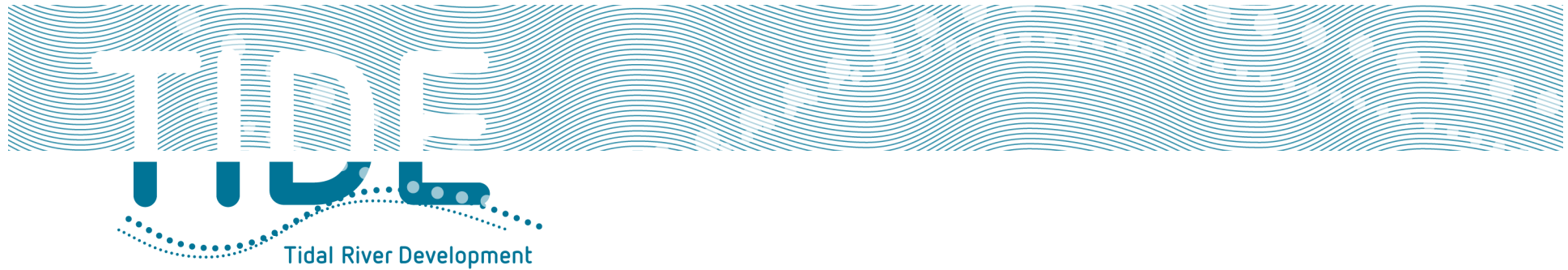


## Amplification or damping?



## Amplification or damping?





## Tidal characteristics: conclusions

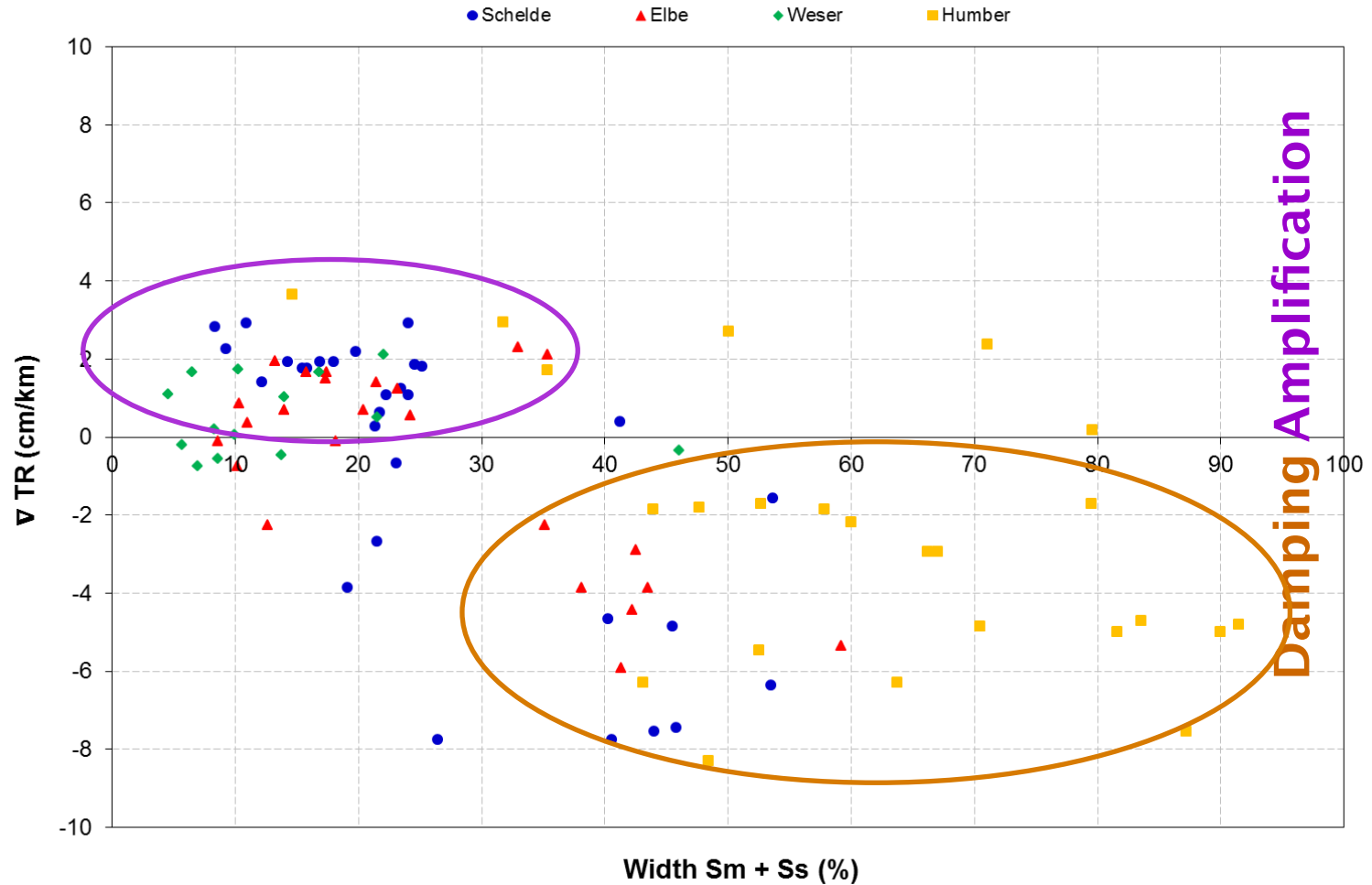
- DAMPING < 4.2 – 7.7 m deep < AMPLIFICATION
- The more convergent the estuary, the smaller the critical estuary depth

### BUT

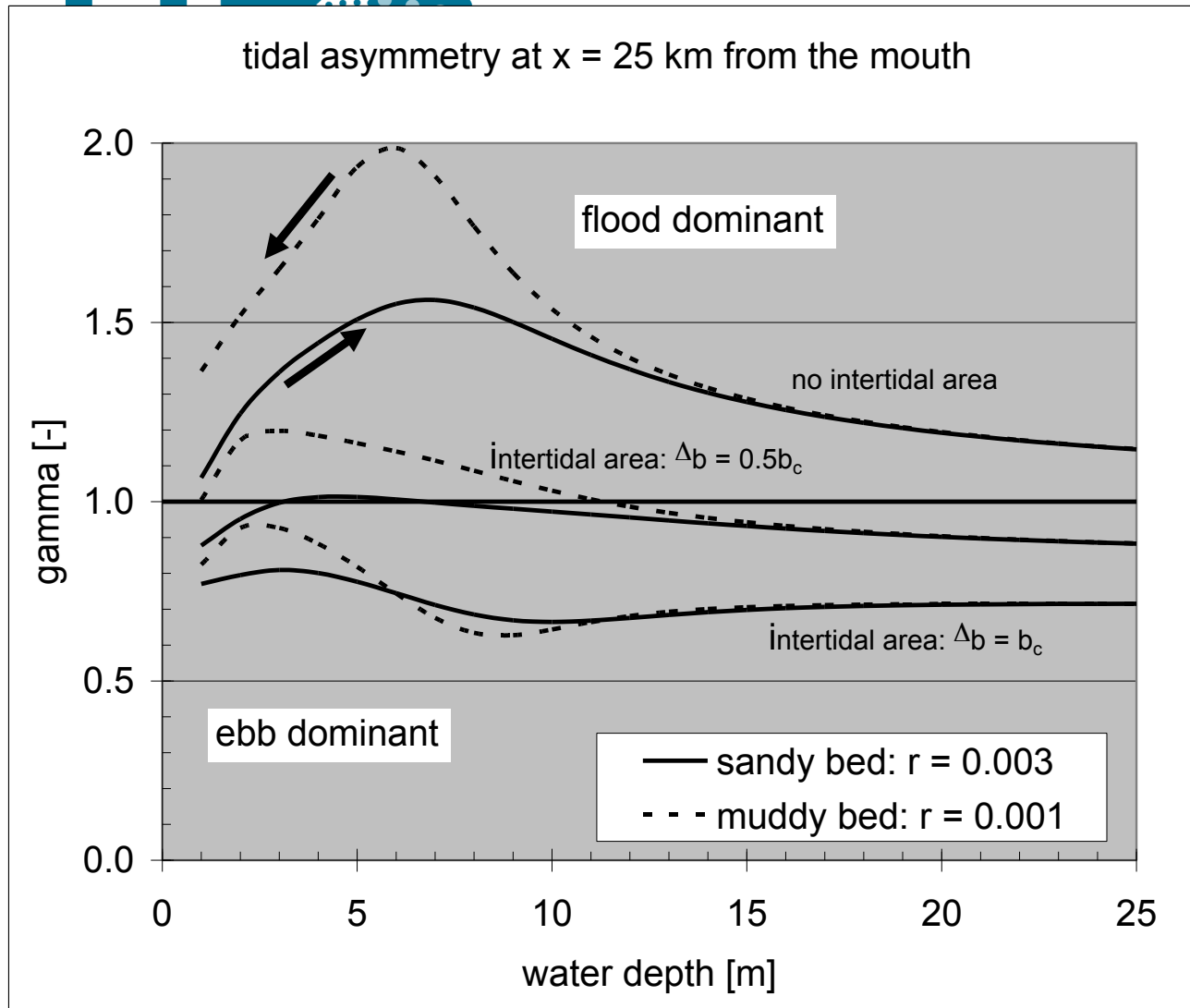
- More estuaries needed in analysis
  - Other proxies for friction
  - Not only tidal range, high and low water
-



## Habitats and the vertical tide (tidal range)

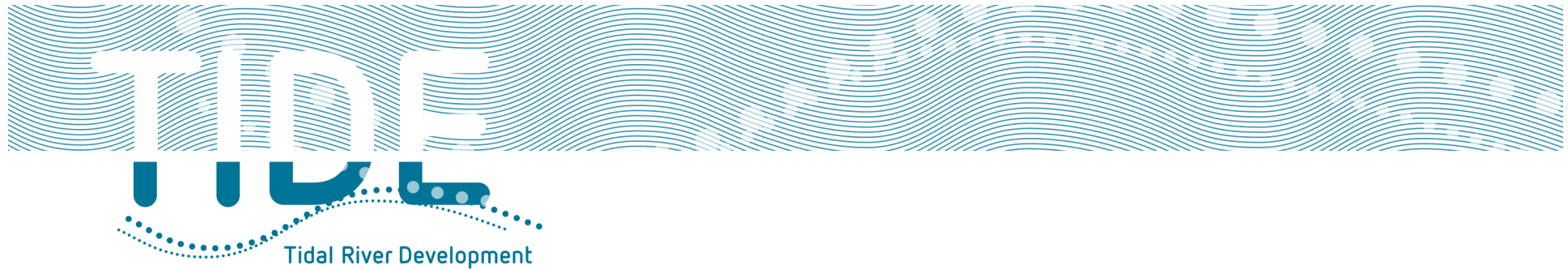


# TIDE



**Note:**  
**Sort of Hysteresis**

Han Winterwerp



## Key Message

- Habitat loss has a significant impact on the tidal propagation
    - Intertidal and subtidal areas are crucial habitats causing friction
    - channel depth, relative surface intertidal area, convergence length scale, bed roughness
  - Changes in the tidal characteristics are the driving force behind estuarine development
-

- Management measures should aim at controlling the tidal development and prevent a regime shift to occur
- Clear goals be defined for the tidal characteristics
- Restoration of the intertidal is a key factor!

- In restoration projects, the impact of the realignment should be focussed much more on its impact on tidal characteristics than on structural biodiversity.
- This must be taken into account in compensation schemes

# TIDE

Tiger River Development

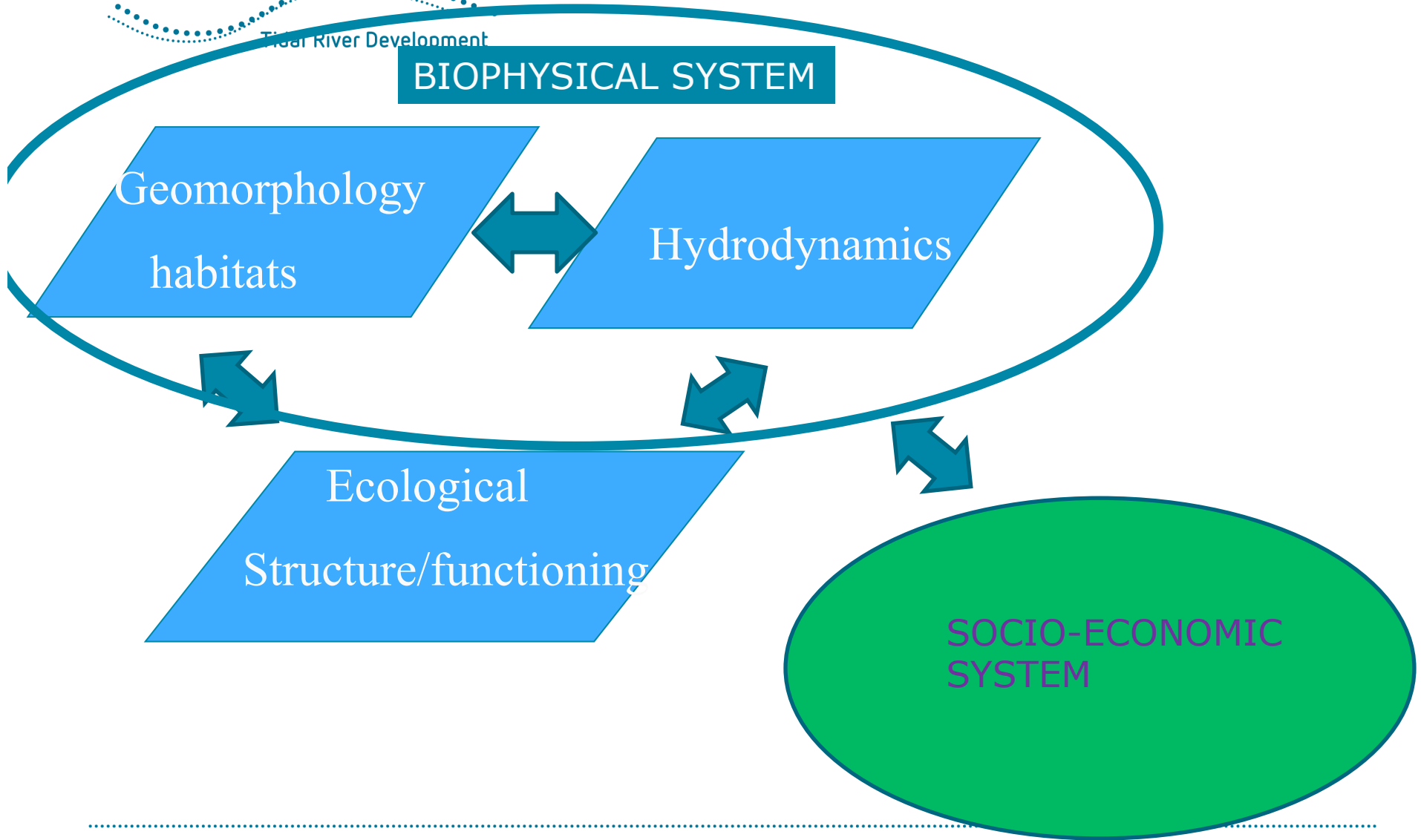
## BIOPHYSICAL SYSTEM

Geomorphology  
habitats

Hydrodynamics

Ecological  
Structure/functioning

SOCIO-ECONOMIC  
SYSTEM



Ecosystems and biodiversity

Structures  
and  
processes



Functions

Primary Production

Human well being

Benefits

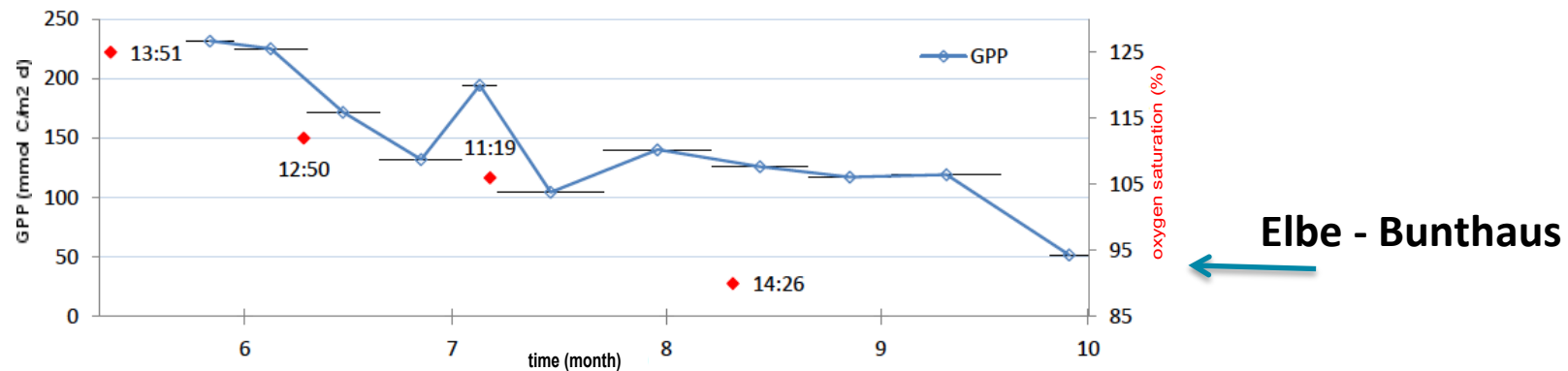


(Economic)  
Value

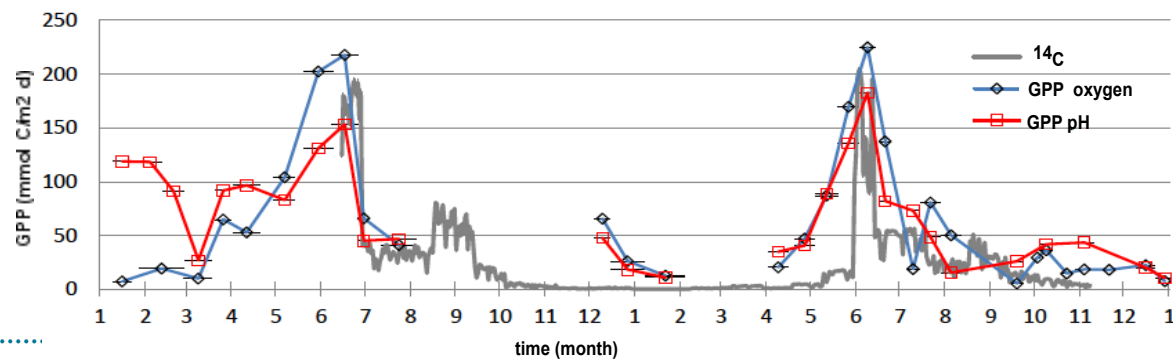


# Primary production

- Not true PP
- **Gross PP estimates and DO oversaturation**

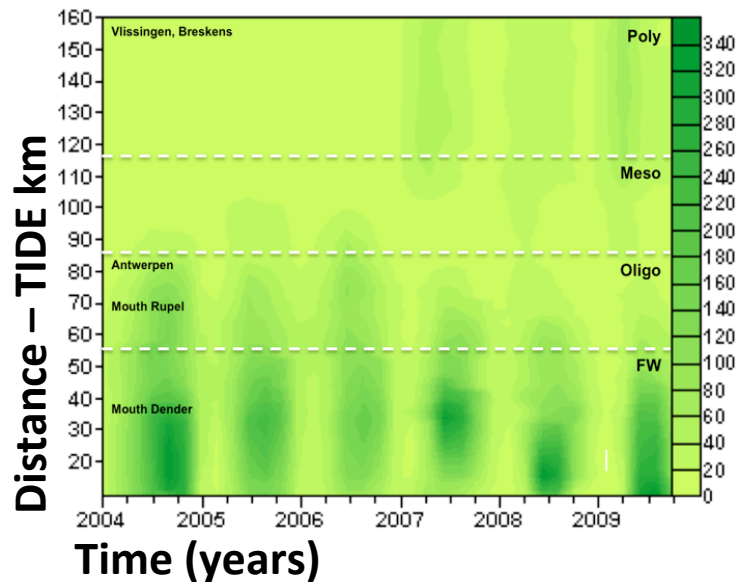


**Scheldt - Kruibeke**

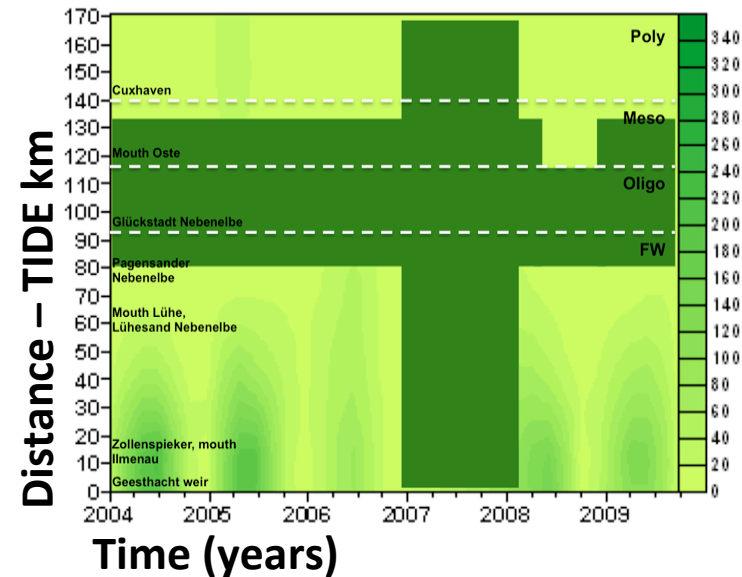


# Primary production

## Scheldt



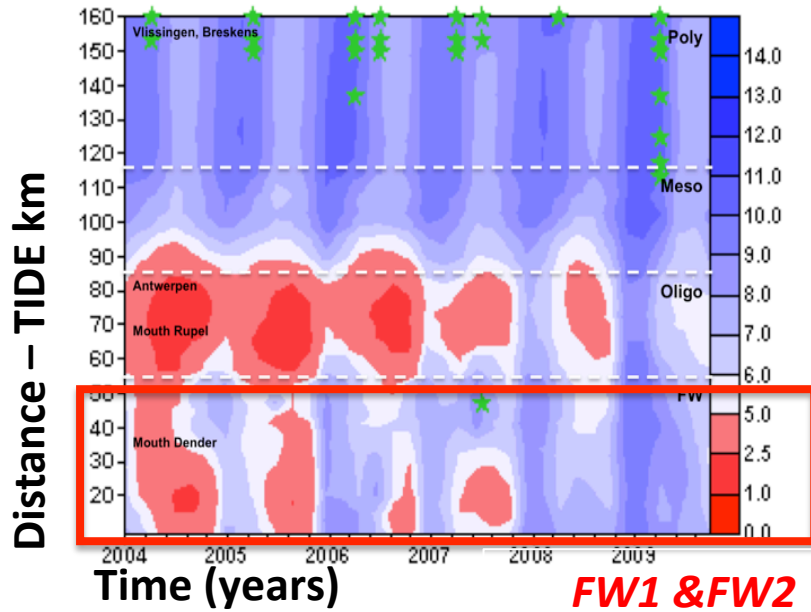
## Elbe



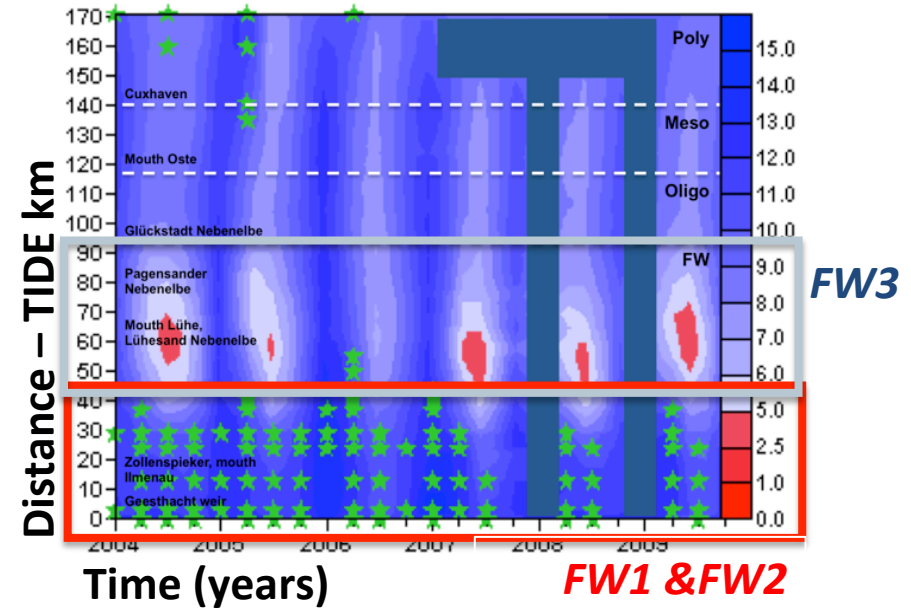
- Chlorophyll *a* highest upstream!
- In the Scheldt up to twice time as high compared to chl *a* in the Elbe
- Chl *a* proxy for biomass

## Primary production

### Scheldt

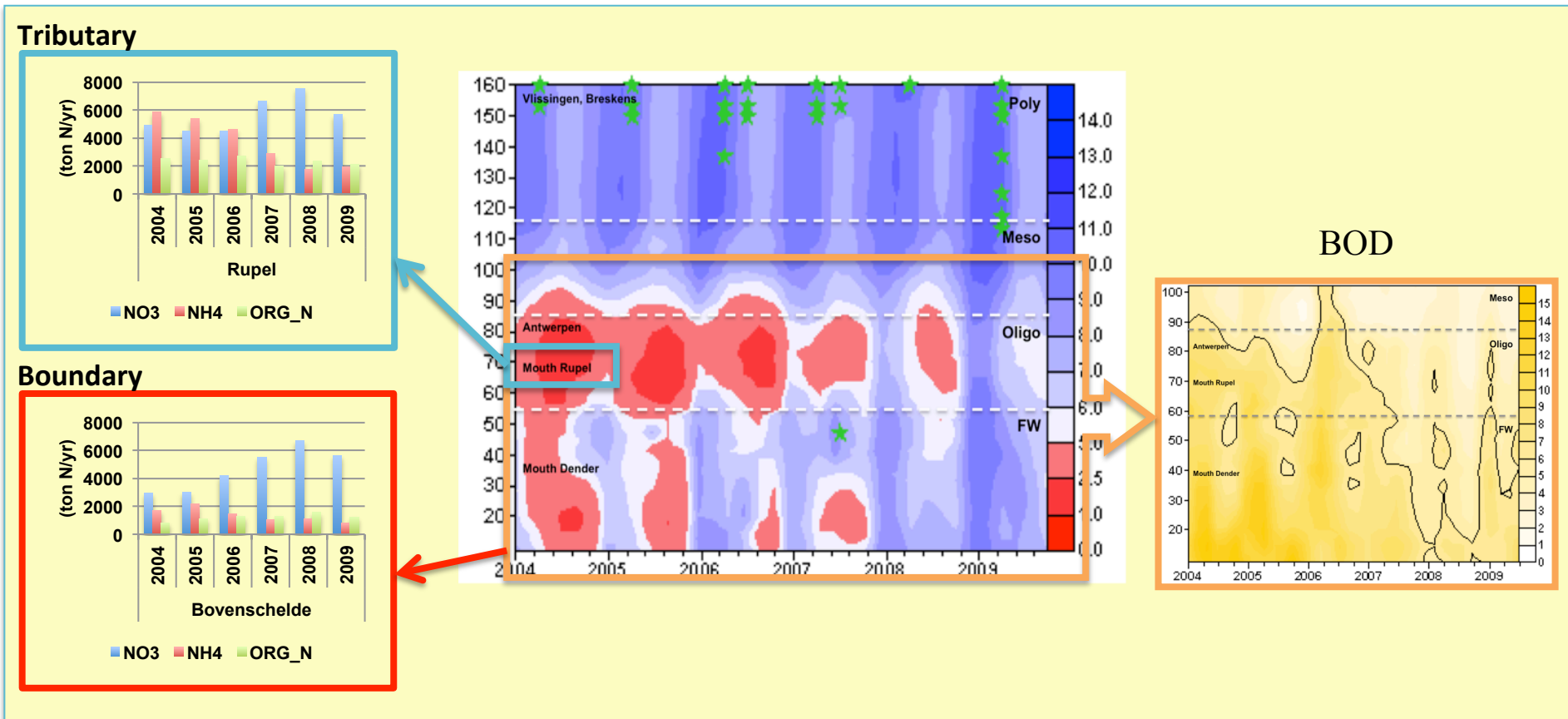


### Elbe



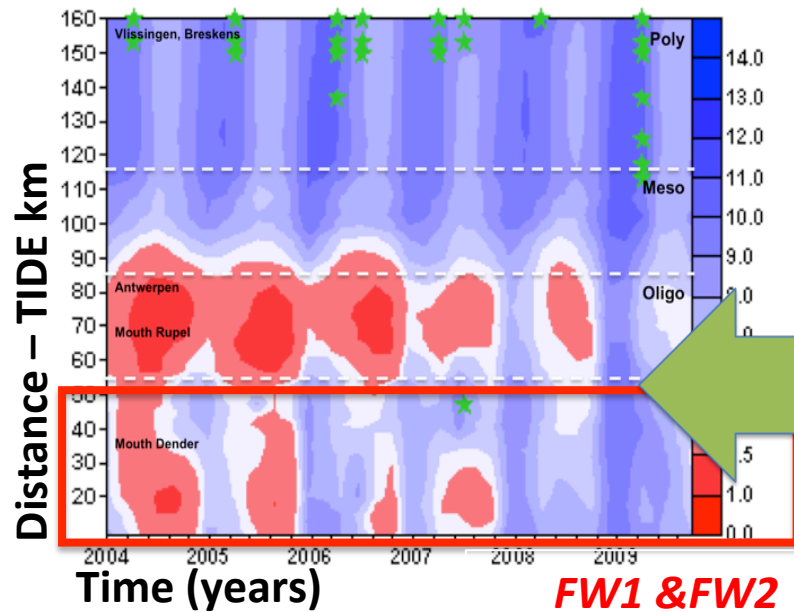
# Dissolved oxygen

- DO sag in the Scheldt can be attributed to water quality
- With recent improvements, the DO sag became less critical (> 5mg/l)

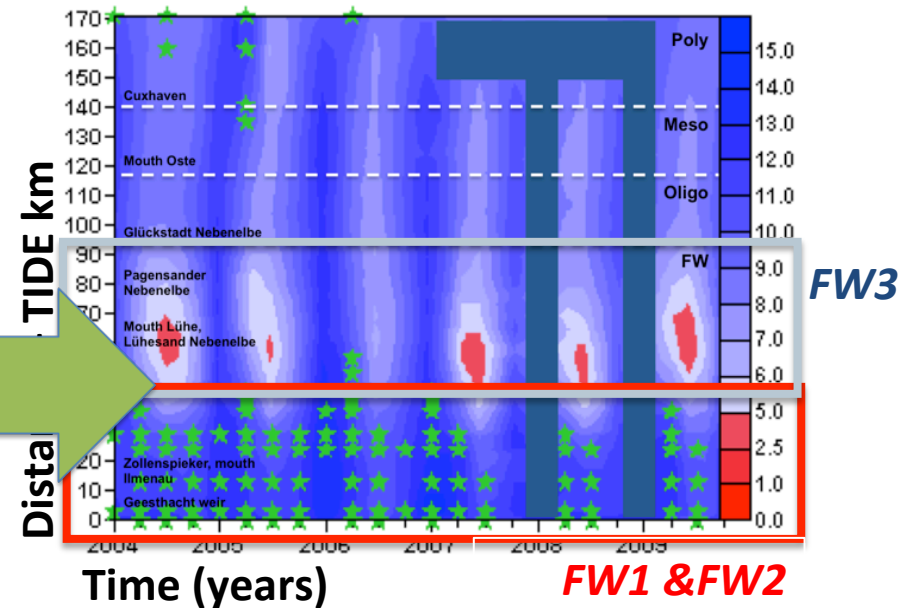


## Primary production

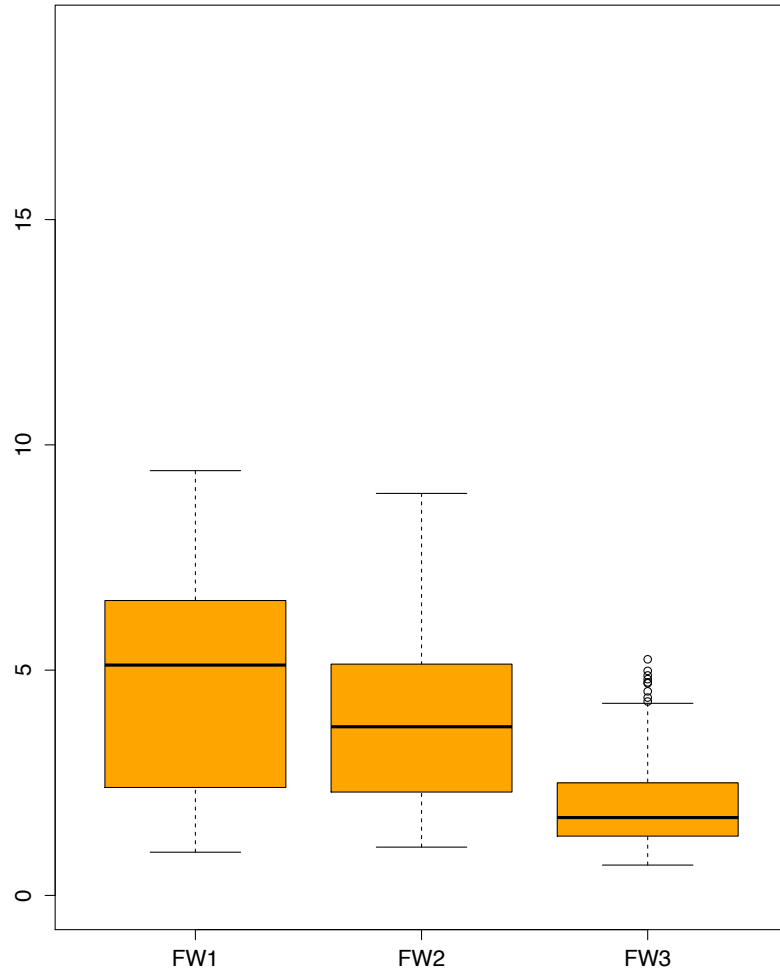
### Scheldt



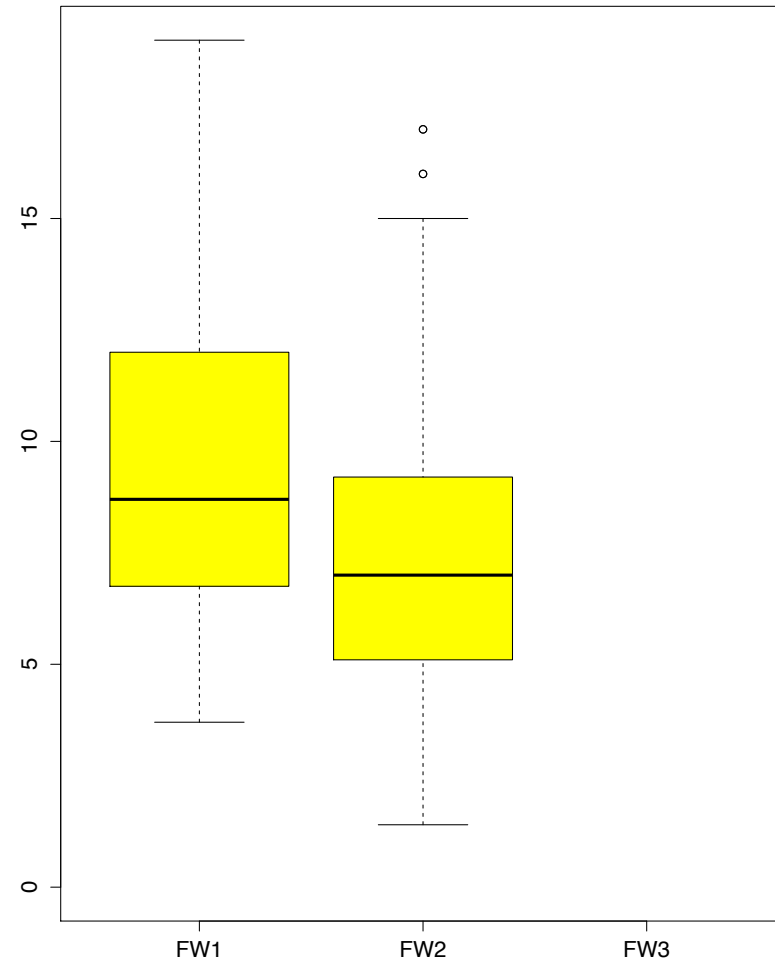
### Elbe



Elbe

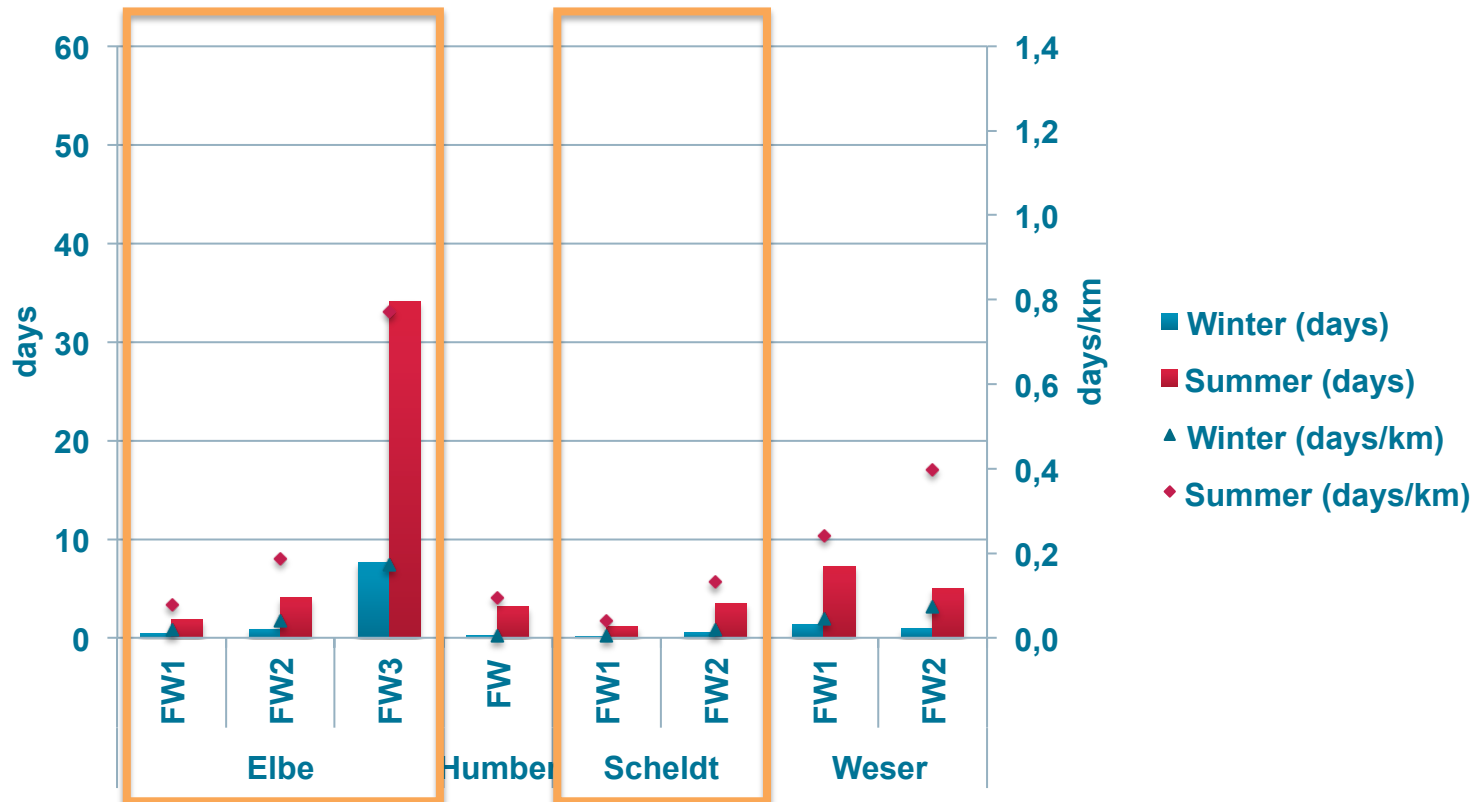


Schelde



# Primary production

- **Residence time, light climate, dissolved silica limitation!**



# Primary production (1)

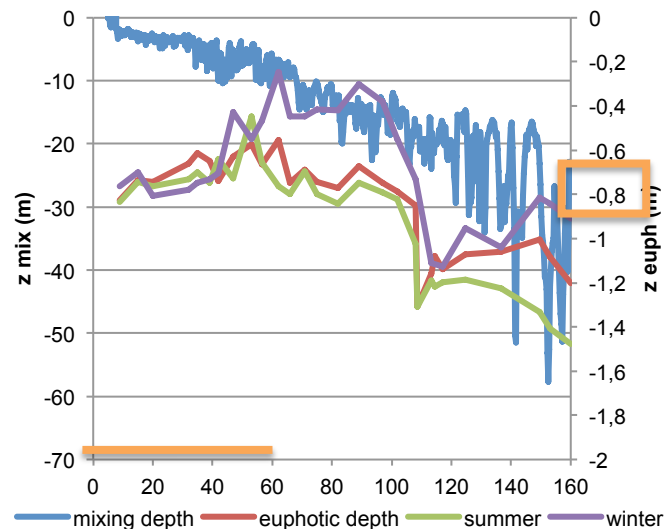
- Residence time, **light climate**, dissolved silica limitation!

— Freshwater zone

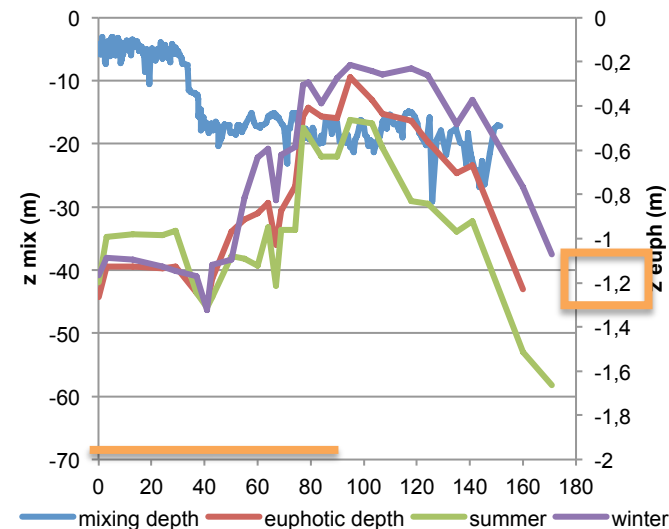
$$K_d = 0,053 \cdot SPM + 2,27$$

$$z_{euph} = (-1/K_d) \cdot \ln(0,01)$$

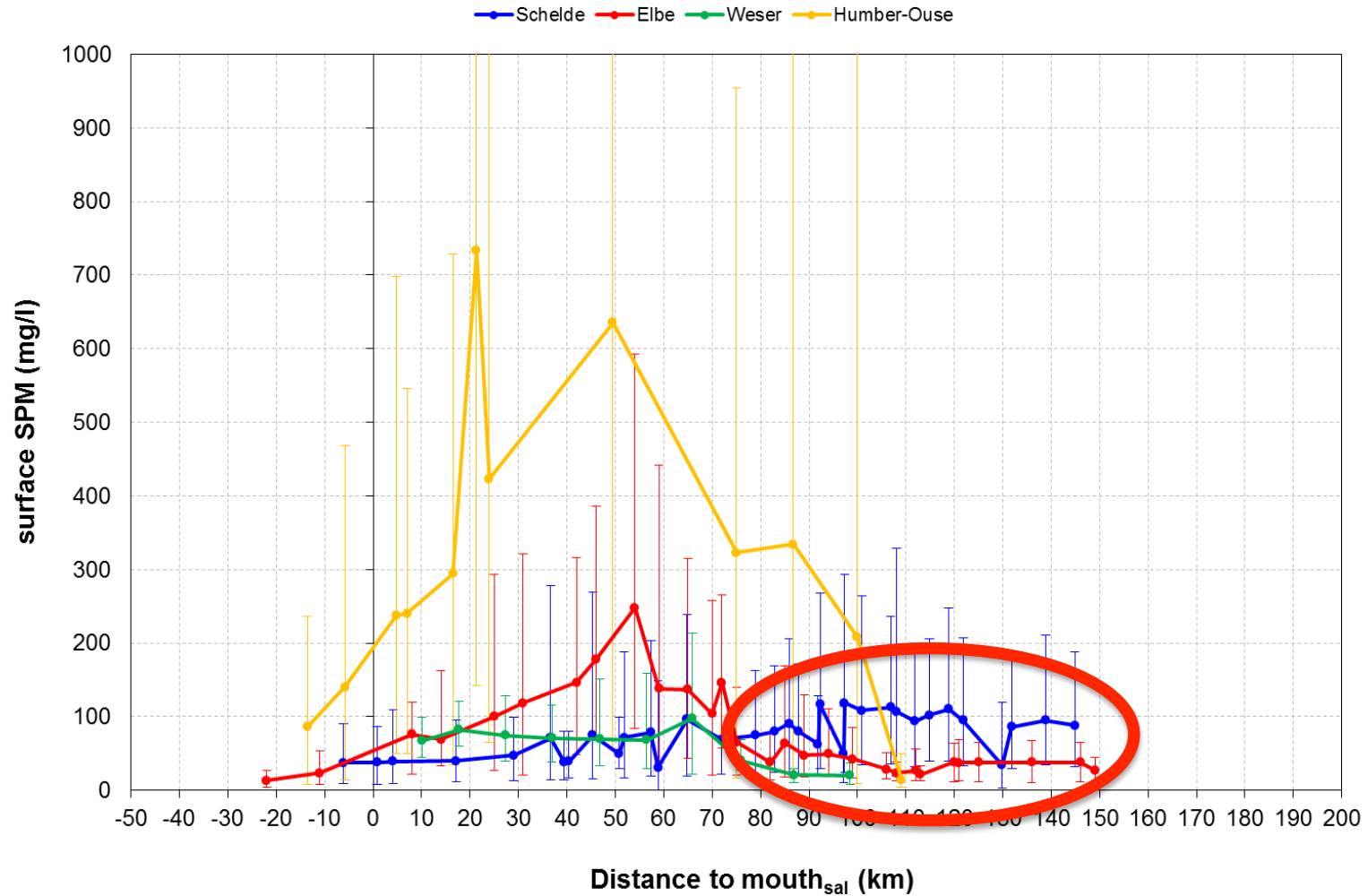
## Scheldt



## Elbe



## Surface SPM



# Primary production (1)

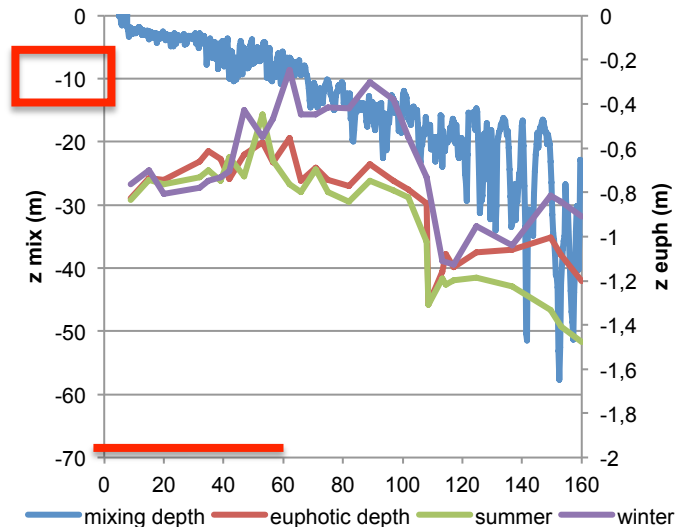
- Residence time, **light climate**, dissolved silica limitation!

— Freshwater zone

$$K_d = 0,053 \cdot SPM + 2,27$$

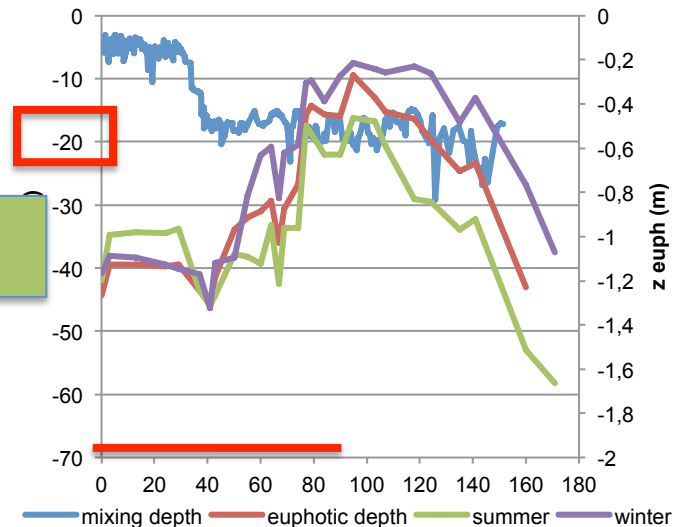
$$z_{euph} = (-1/K_d) \cdot \ln(0,01)$$

## Scheldt



## Elbe

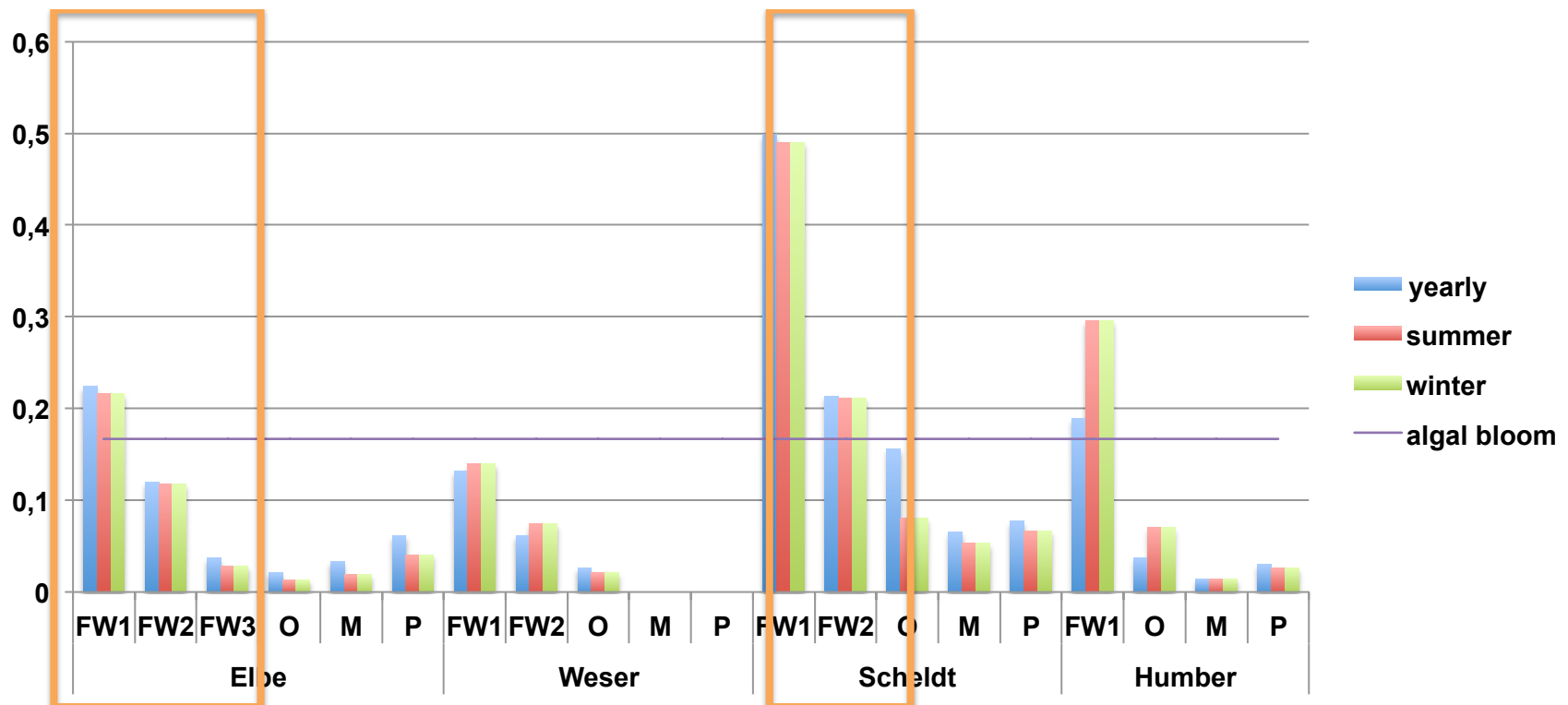
**BUT**



# Primary production (1)

- Residence time, **light climate**, dissolved silica limitation!

$z_{\text{euph}}/z_{\text{mix}}$  ratio > 1/6 ?



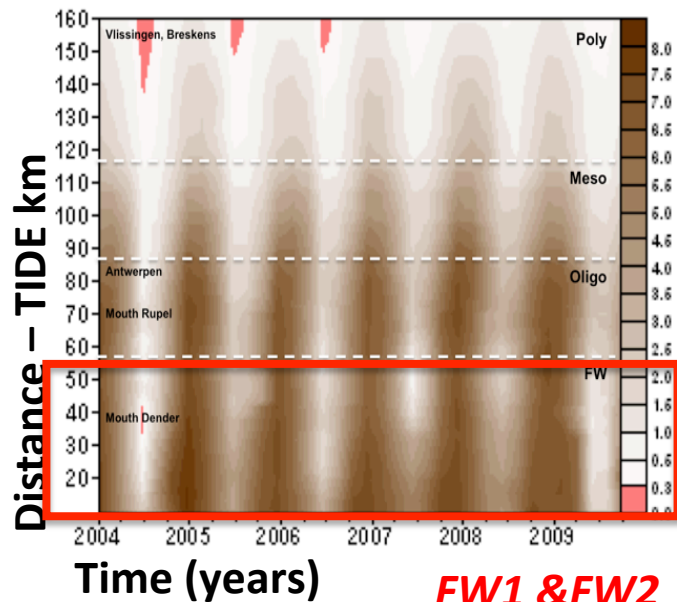


# Primary production

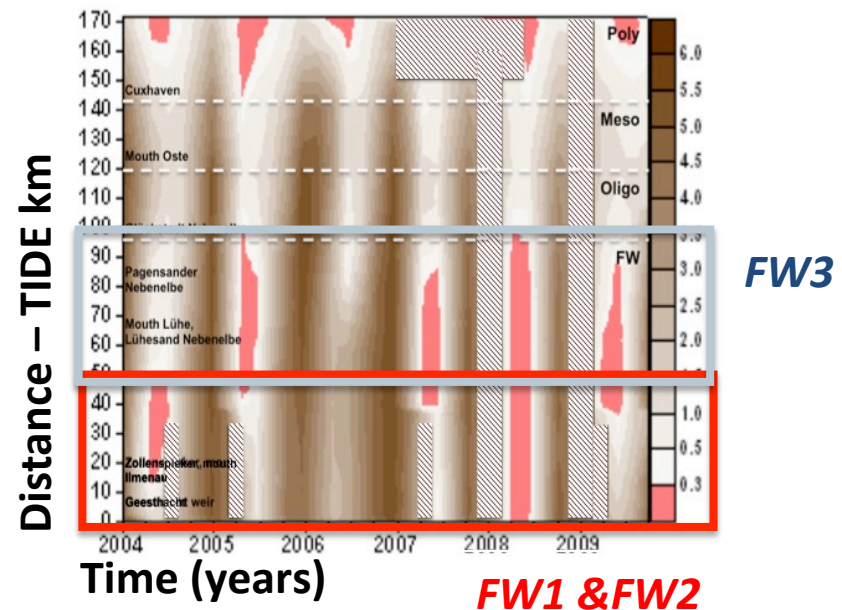
- Residence time, light climate, **dissolved silica limitation!**

[DSI] < 0.3 mg/l ?

## Scheldt

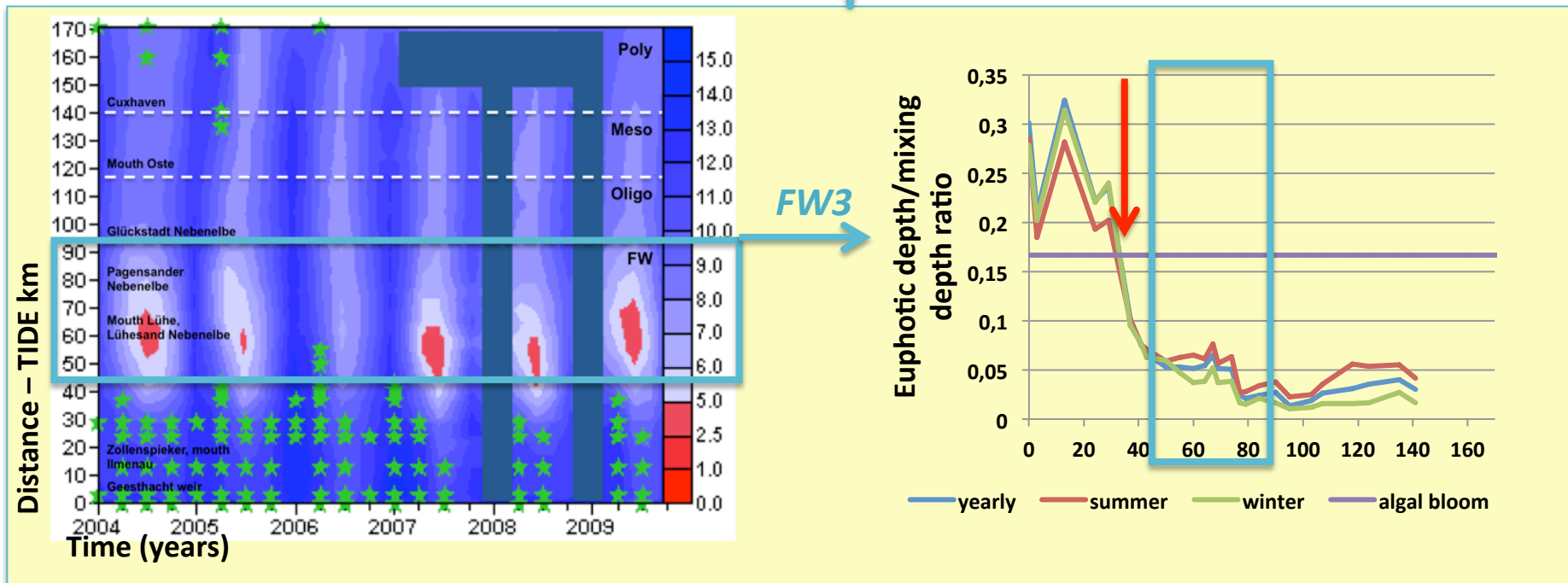
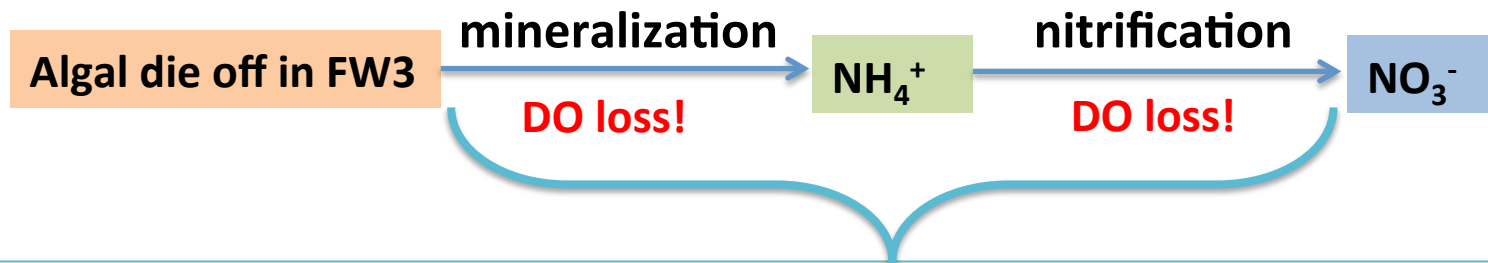


## Elbe



# Dissolved oxygen (2)

- Also DO sag can be related to *morphology* in the **Elbe**



# Nutrients (3)

- Filter function for e.g. nutrients one of the most valuable ESS

→ See poster for example of N removal

With recent improvements of water quality the the processes in the sediment gain in importance



**Intertidal habitat!**

Again morphology appears to be able to change the functioning of the estuary (filter function for N decreases)



**Geometry of the estuary!**



## Key messages

- Clear indications for the interaction between residence time, shallow/intertidal area and  $Z_m/Z_e$  and their crucial role in the productivity and filter function and water quality
  - Significant differences between estuaries in filterfunction
  - As water quality and filter function are likely to be linked to morphology this should also be taken into account in the management
-

# Ecosystems and biodiversity

Structures  
and  
processes

Functions

Morphology

Water for  
navigation

# Human well being

Benefits

(Economic)  
Value



# Ecosystems and biodiversity

Structures and processes

Functions

Morphology

Water for navigation

Dissipation of Tidal energy

# Human well being



Benefits

(Economic) Value



# Ecosystems and biodiversity

Structures and processes

Functions

Morphology

Water for navigation

Dissipation of Tidal energy

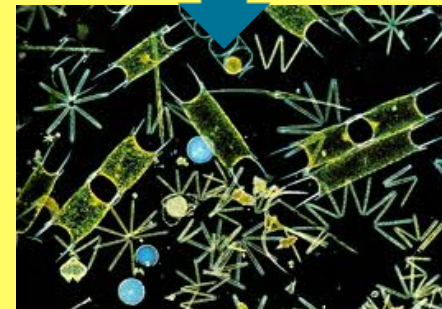
Water quality regulation



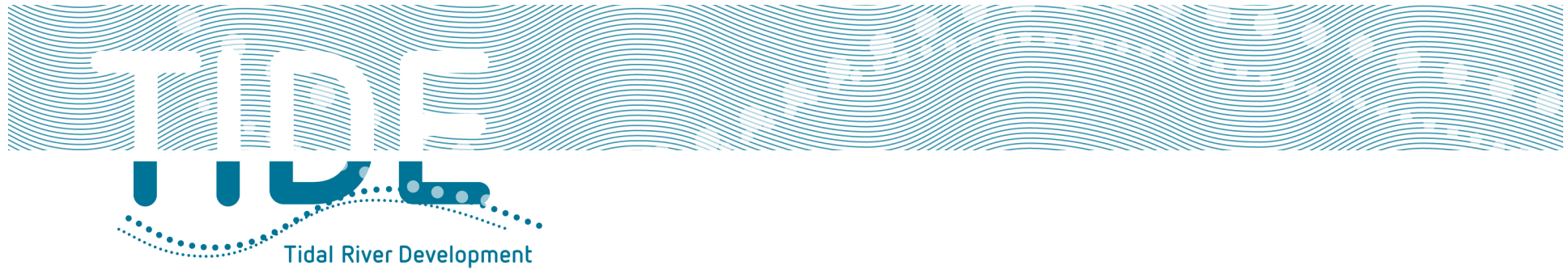
# Human well being

Benefits

(Economic) Value

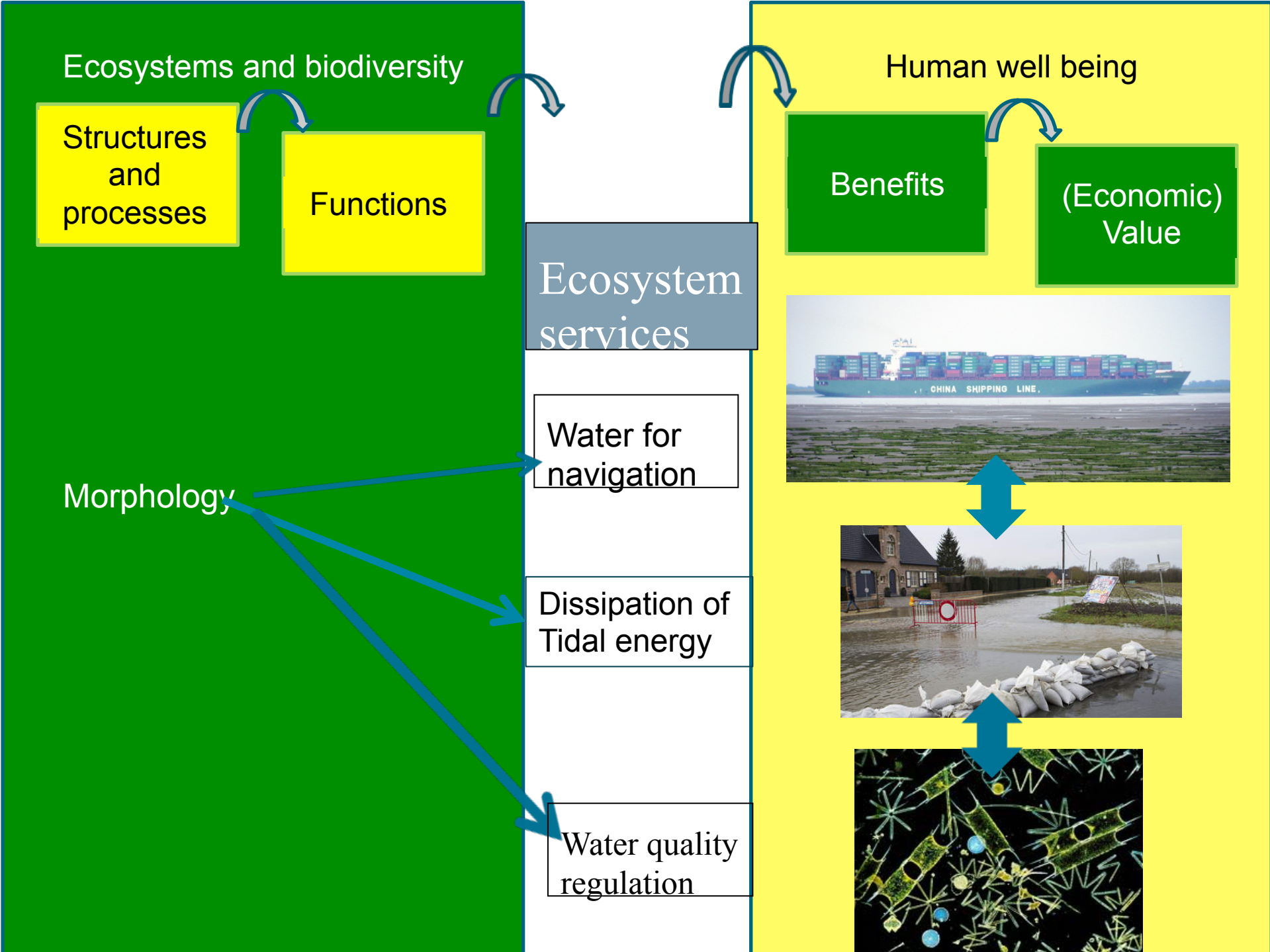


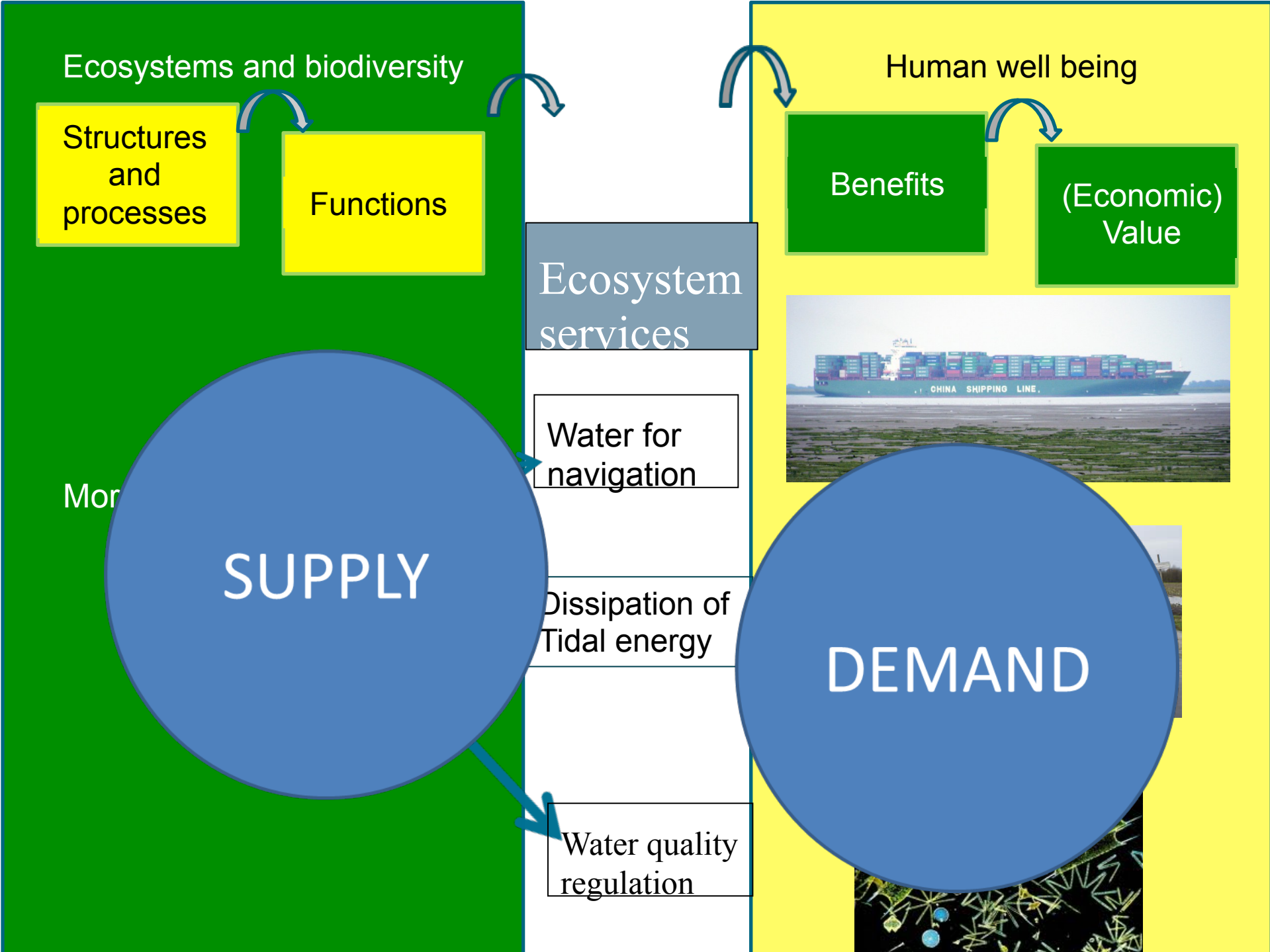
- The study of a system needs a common denominator.
- **ecosystem services**, ‘these aspects of ecosystems, utilized actively or passively, to produce human well-being’ is a likely candidate

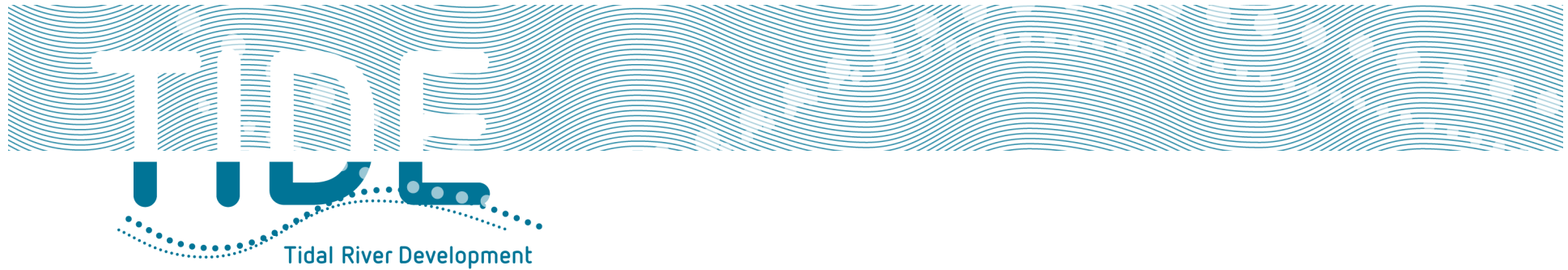


- Concept of ecosystem services is becoming recognized as concept with a high potential to link the different parts of the biophysical system and to link this with the socio-economic system
- The possibilities of this concept were explored in TIDE









- STEP 1
- Defining estuarine ecosystem services
  - Ongoing debate about classification of ES and definitions
    - pragmatic approach
  - → Long list of 44 ecosystem services was made after discussions with TIDE partners



## How essential are the services produced?

# Selection of 20 “important” ES for TIDE

Important Ecosystem Services in TIDE estuaries	Category
Food: Animals	Provisioning
Water for industrial use	Provisioning
Water for navigation	Provisioning
Climate regulation: Carbon sequestration and burial	Regulating
Regulation extreme events or disturbance: Flood water storage	Regulating
Regulation extreme events or disturbance: Water current reduction	Regulating
Regulation extreme events or disturbance: Wave reduction	Regulating
Water quantity regulation: drainage of river water	Regulating
Water quantity regulation: dissipation of tidal and river energy	Regulating
Water quantity regulation: landscape maintenance	Regulating
Water quantity regulation: transportation	Regulating
Water quality regulation: transport of pollutants and excess nutrients	Regulating
Water quality regulation: reduction of excess loads coming from the catchment	Regulating
Erosion and sedimentation regulation by water bodies	Regulating
Erosion and sedimentation regulation by biological mediation	Regulating
"Biodiversity"	Supporting
Aesthetic information	Cultural
Opportunities for recreation & tourism	Cultural
Inspiration for culture, art and design	Cultural
Information for cognitive development	Cultural



## The DEMAND survey

- STEP 2: Mainstreaming the concept among TIDE partners and determine in an interactive way which are the most important ES to further analysed in TIDE? (guidance document)
  - *“How important is service X?”*
    - Score 1-5
    - Per estuary (4)
    - Per salinity zone (4)
  - **importance is seen as the demand for an ES**
-



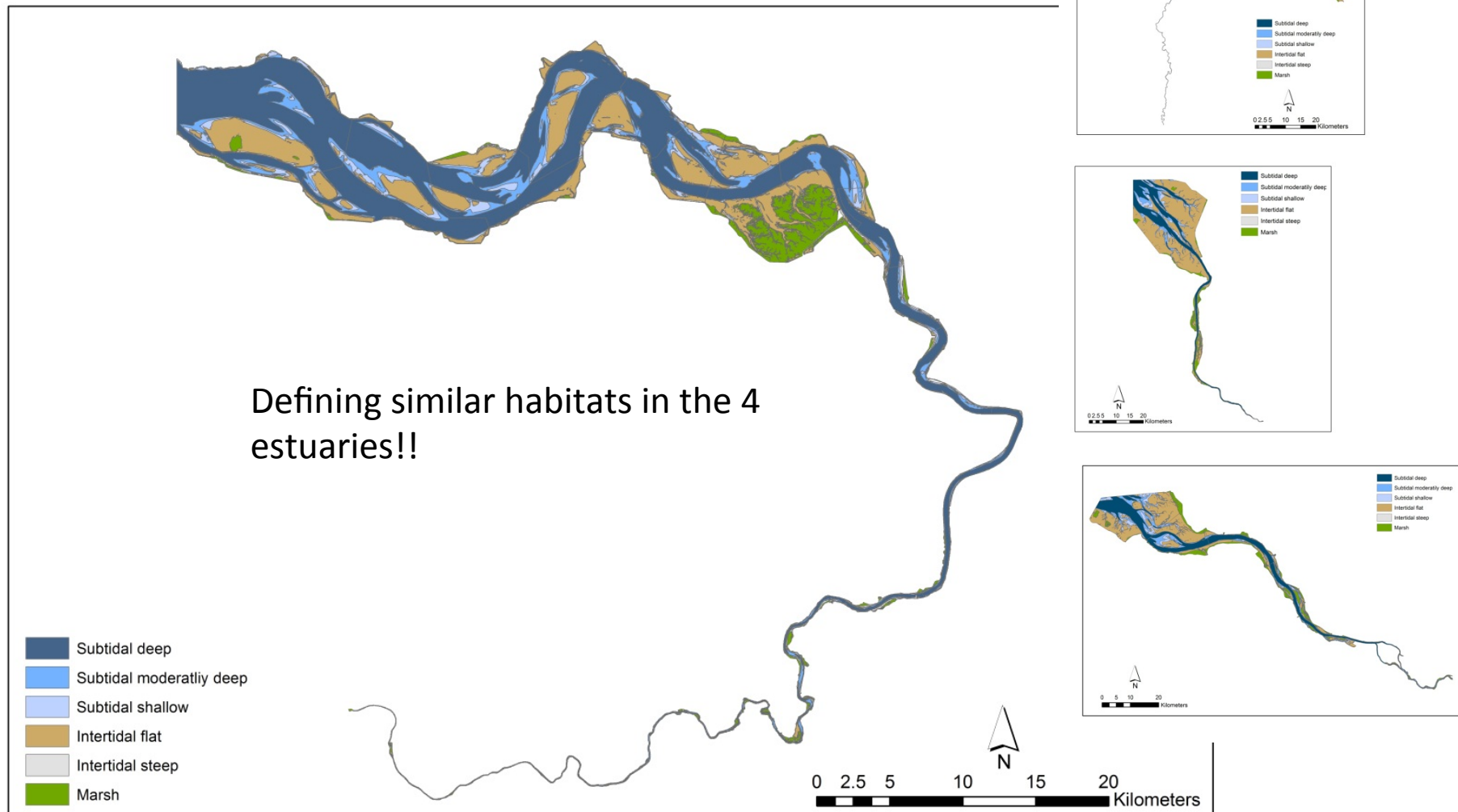
How are the services linked to natural structures?



## The SUPPLY survey

- ***STEP 3: The supply***
  - The ES are delivered by habitats (and species), the **Service Providing Units**
  - “How important is Habitat x for supply of service Y?”
    - Per estuary (4)
    - Per zone (4)
  - 12 scientific/professional respondents
-

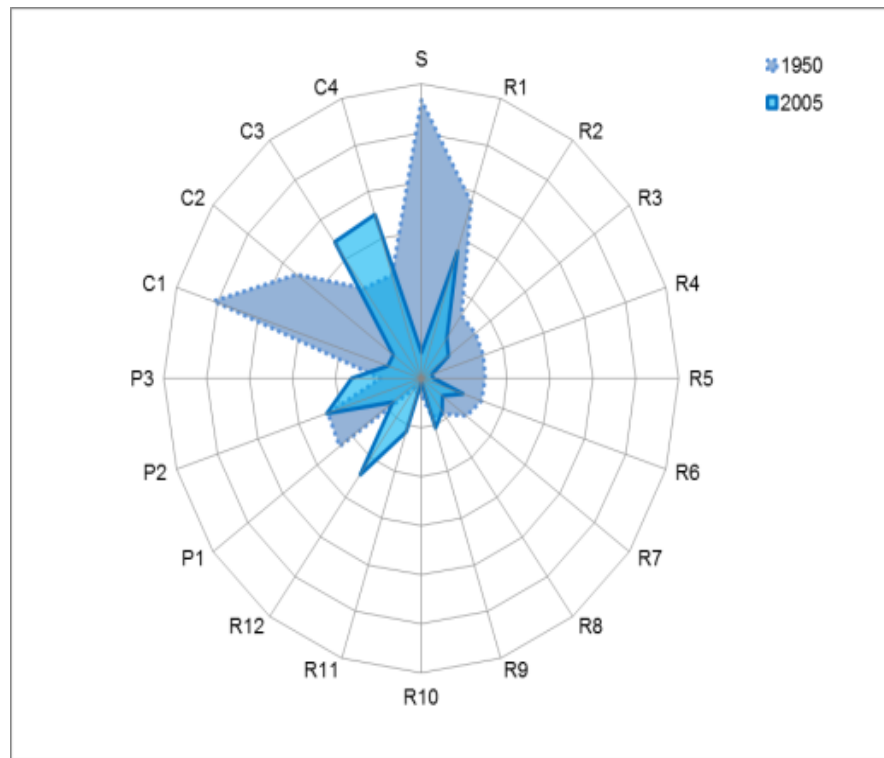
# For all estuaries: 6 habitats





## How did the delivery of ES change over time?

- Step 4: A historical analysis
  - Insight that loss of a single habitat results in the loss of bundle of ES



Example: Weser 1950-2000



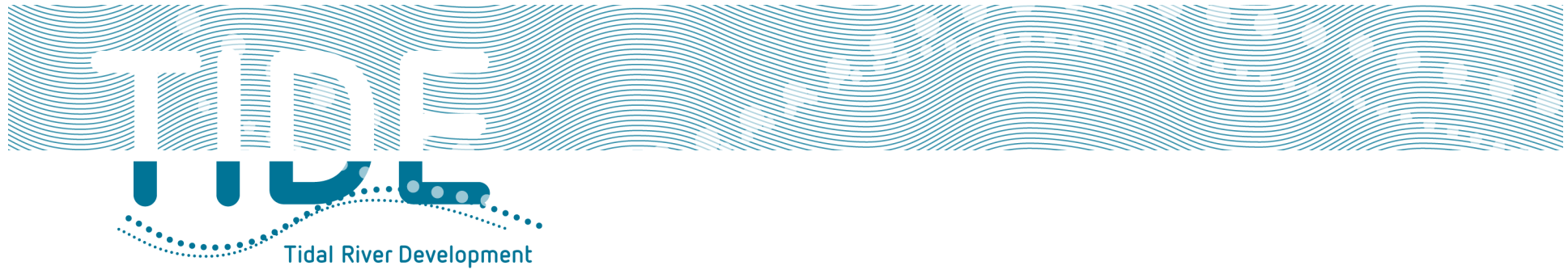
## Key messages

- The concept of ES was adopted by all participants and there is large agreement on the usefulness of the concept.
  - ES approach gives a clear framework for a qualitative assessment of the importance of different habitats
  - Insight of the importance of intertidal areas not only for biodiversity but for supporting and regulating services is becoming apparent.
  - The concept of ES is a good communication tool for an interdisciplinary approach
-



## Key message

- The concept of ES gave us a better insight in the **real impact** of changes in the estuary
  - Habitat loss resulted in a significant **loss of regulating services**
  - → **Loss of ecosystem services leads to an economic loss.**
-



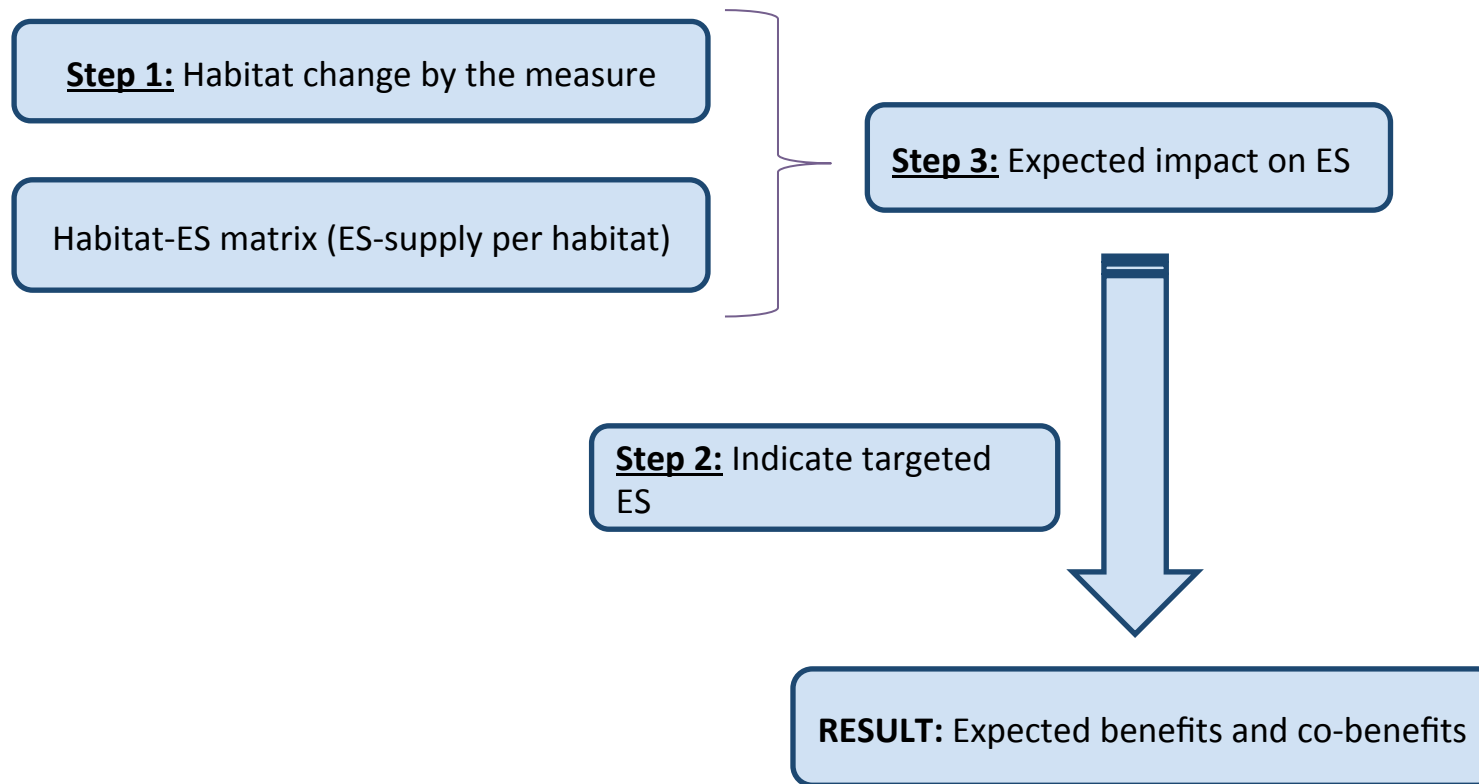
## **From ES concept to management practice**

- Can ES help us to decide on which measures, management to take?



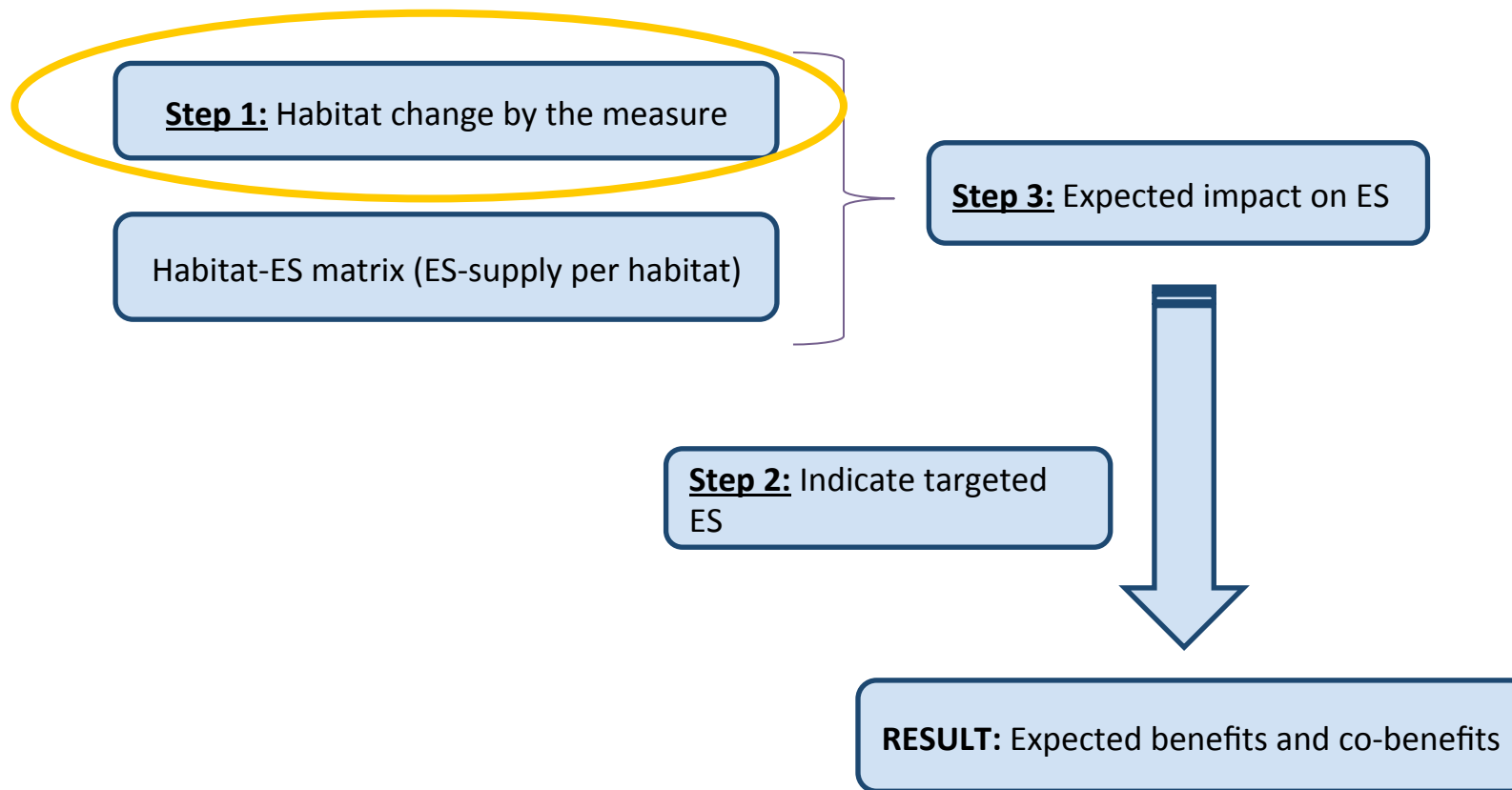
# Expected impact of management measures on ecosystem services

## Approach:



# Expected impact of management measures on ecosystem services

## Approach:



# Expected impact of management measures on ecosystem services

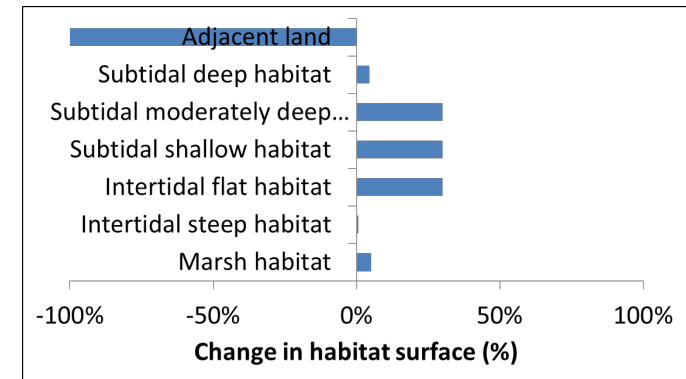
## Step 1: Habitat change by the measure

e.g. Spadenlander Bush (in freshwater zone Elbe estuary)

**BEFORE**



**AFTER**

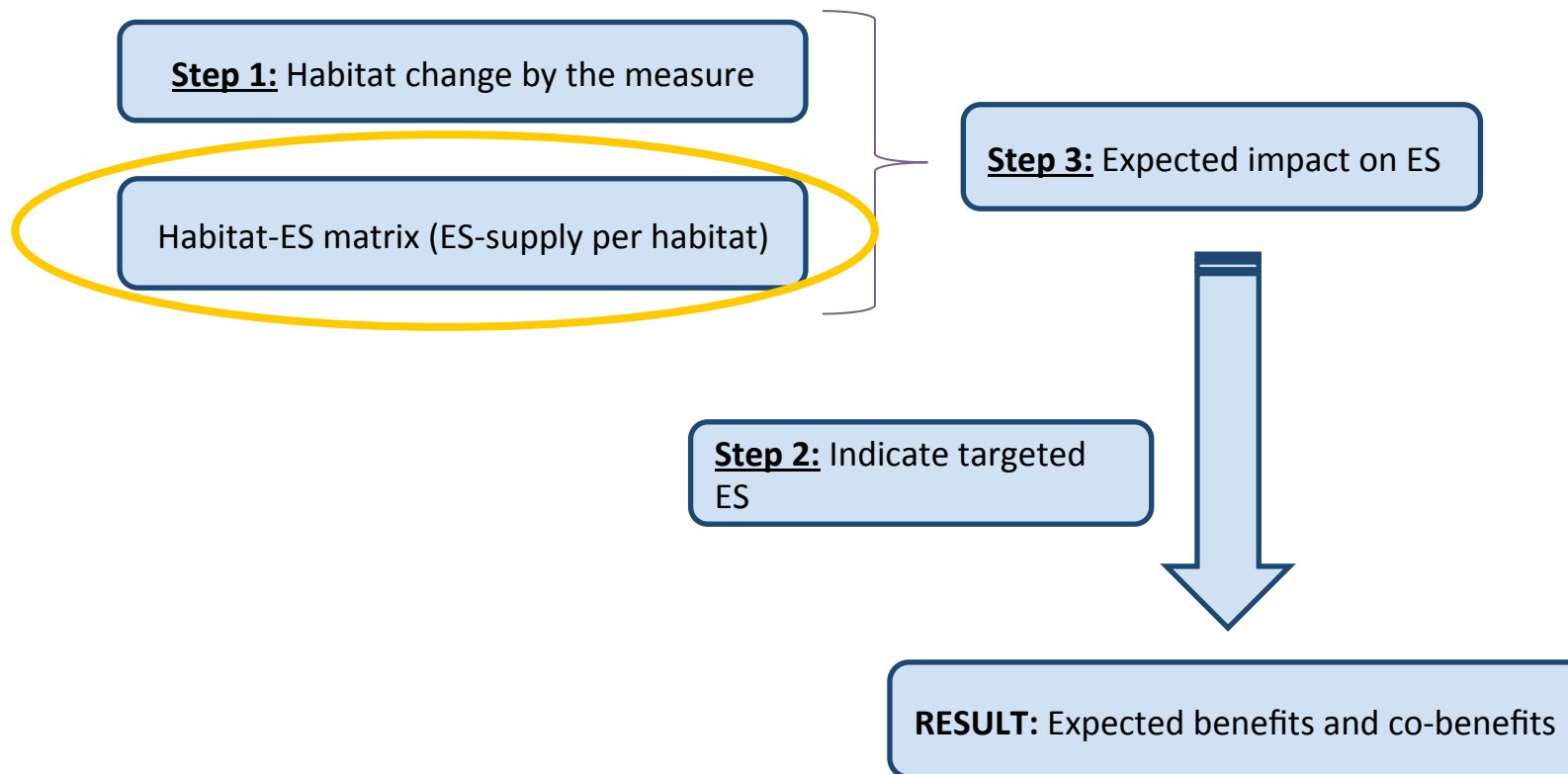


### Created habitats:

- Marsh (5%)
- Intertidal steep (0.5%)
- Intertidal flat (30%)
- Subtidal shallow (30%)
- Subtidal moderately deep (30%)
- Subtidal deep (4.5%)

# Expected impact of management measures on ecosystem services

## Approach:



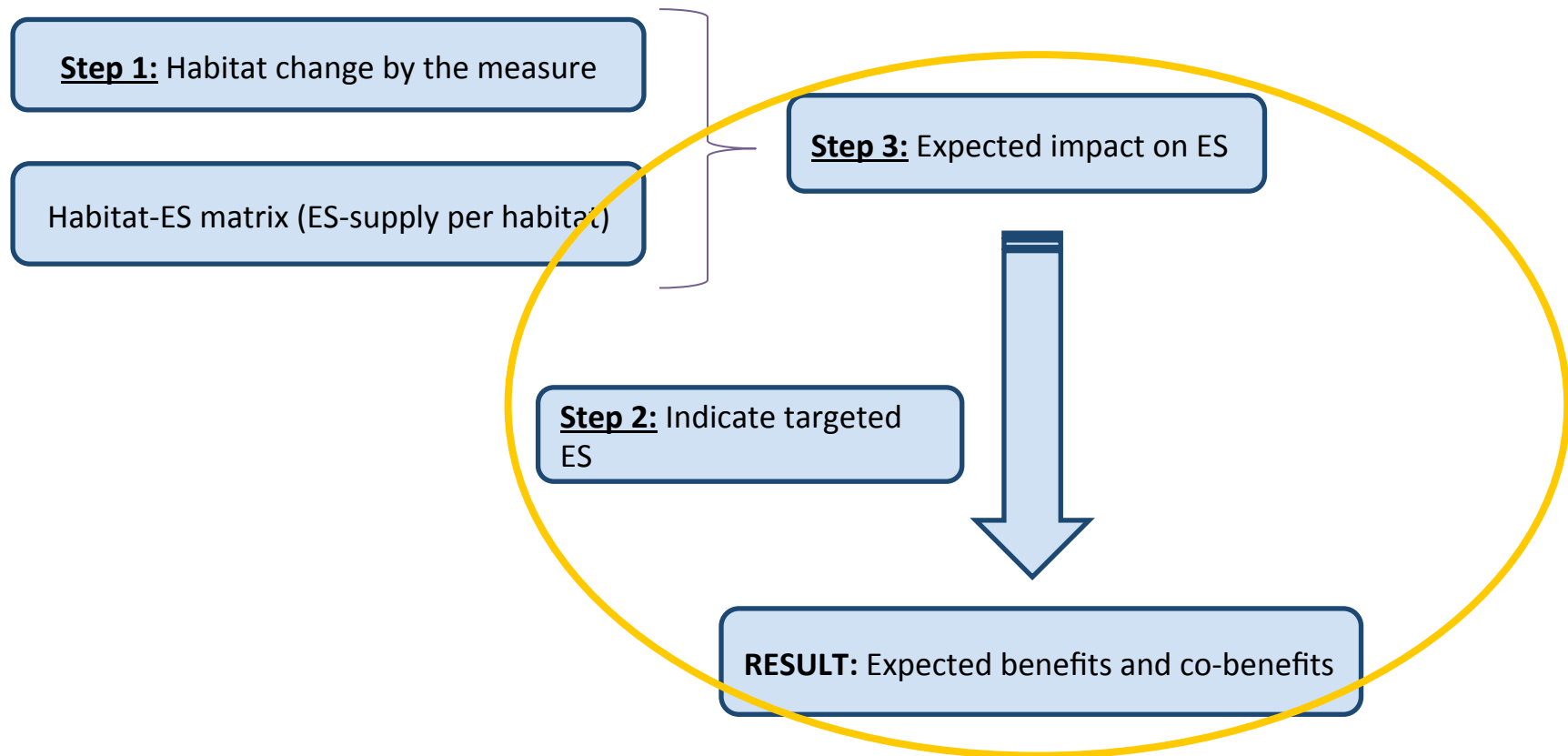
# Expected impact of management measures on ecosystem services

## Habitat-ES matrix: ES-supply score per habitat type

	Score	Habitat has...in supply of ES							
	1	no importance	Marsh	Intertidal steep	Intertidal flat	Subtidal shallow	Subtidal moderatley deep	Subtidal deep	
	2	very low importance							
	3	moderate importance							
	4	Importance							
	5	Essential importance							
"Biodiversity"	5	3	5	4	3	3			
Erosion and sedimentation regulation by water bodies	4	2	5	5	4	4			
Erosion and sedimentation regulation by biological mediation	4	2	4	3	1	1			
Water quality regulation: reduction of excess loads coming from the catchment	5	2	3	3	2	2			
Water quality regulation: transport of pollutants and excess nutrients	2	2	2	3	3	4			
Water quantity regulation: drainage of river water	2	2	3	2	2	2			
Water quantity regulation: transportation	1	1	1	1	3	5			
Water quantity regulation: landscape maintenance	4	2	3	3	2	1			
Water quantity regulation: dissipation of tidal and river energy	2	2	3	3	3	1			
Climate regulation: Carbon sequestration and burial	4	2	3	3	2	1			
Regulation extreme events or disturbance: Wave reduction	3	3	3	2	1	1			
Regulation extreme events or disturbance: Water current reduction	3	2	3	3	2	1			
Regulation extreme events or disturbance: Flood water storage	4	3	3	2	2	1			
Water for industrial use	2	2	1	2	3	3			
Water for navigation	1	1	1	1	3	4			
Food: Animals	3	2	2	2	2	2			
Aesthetic information	4	3	4	3	3	3			
Inspiration for culture, art and design	4	3	4	4	4	4			
Information for cognitive development	4	4	4	4	4	4			
Opportunities for recreation & tourism	3	2	3	3	4	4			

# Expected impact of management measures on ecosystem services

## Approach:



# Expected impact of management measures on ecosystem services

## Step 2&3 and results

Step 2: indicate targeted ES

Step 3: Expected impact per ES  
= habitat change (%) × ES-supply score

Cat.	Ecosystem Service	Targeted?	Expected impact
S	"Biodiversity"	0	2
R1	Erosion and sedimentation regulation by water bodies	0	2
R2	Water quality regulation: reduction of excess loads coming from the catchment	0	1
R3	Water quality regulation: transport of pollutants and excess nutrients	0	1
R4	Water quantity regulation: drainage of river water	0	0
R5	Erosion and sedimentation regulation by biological mediation	0	1
R6	Water quantity regulation: transportation	0	0
R7	Water quantity regulation: landscape maintenance	0	1
R8	Climate regulation: Carbon sequestration and burial	0	1
R9	Water quantity regulation: dissipation of tidal and river energy	1	1
R10	Regulation extreme events or disturbance: Wave reduction	0	0
R11	Regulation extreme events or disturbance: Water current reduction	0	0
R12	Regulation extreme events or disturbance: Flood water storage	0	1
P1	Water for industrial use	0	0
P2	Water for navigation	1	0
P3	Food: Animals	0	0
C1	Aesthetic information	0	1
C2	Inspiration for culture, art and design	0	2
C3	Information for cognitive development	0	2
C4	Opportunities for recreation & tourism	0	1

**Legend: expected impact**

3	very positive
2	positive
1	slightly positive
0	neutral
-1	slightly negative
-2	negative
-3	very negative

# Expected impact of management measures on ecosystem services

## Step 2&3 and results

Step 2: indicate targeted ES

Step 3: Expected impact per ES  
= habitat change (%) × ES-supply score

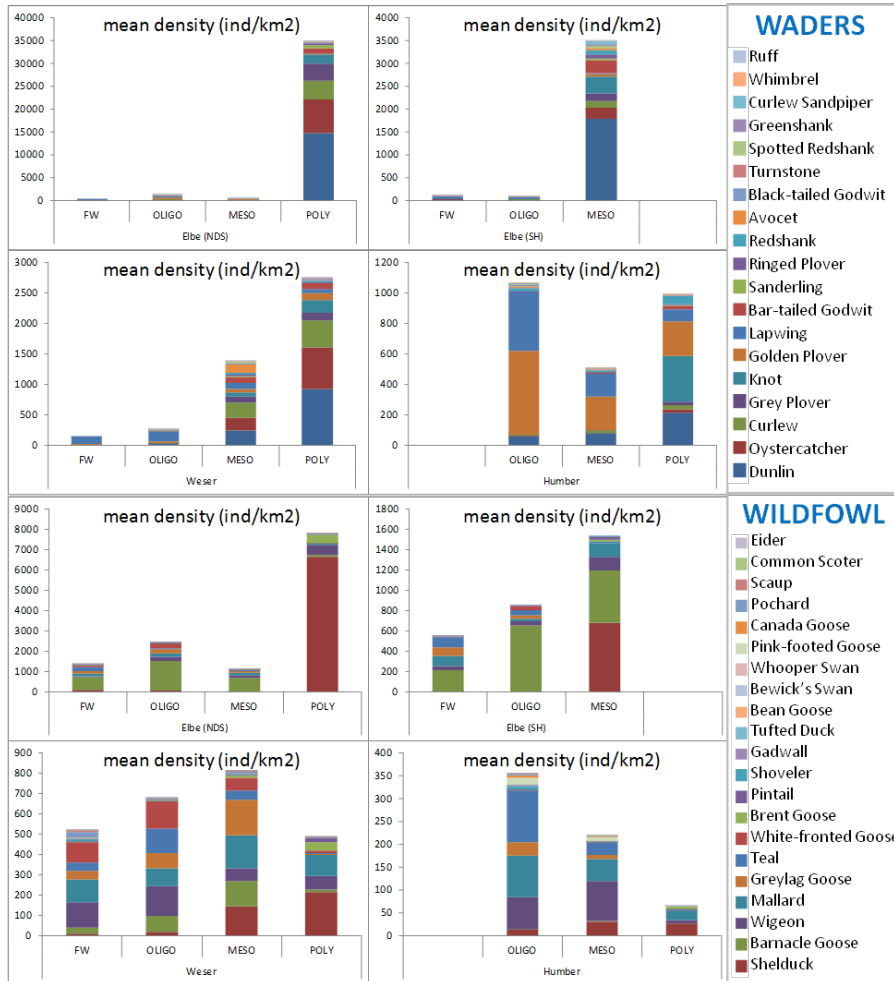
Cat.	Ecosystem Service	Targeted?	Expected impact*
S	"Biodiversity"	0	2
R1	Erosion and sedimentation regulation by water bodies	0	2
R2	Water quality regulation: reduction of excess loads coming from the catchment	0	1
R3	Water quality regulation: transport of pollutants and excess nutrients	0	1
R4	Water quantity regulation: drainage of river water	0	0
R5	Erosion and sedimentation regulation by biological mediation	0	1
R6	Water quantity regulation: transportation	0	0
R7	Water quantity regulation: landscape maintenance	0	1
R8	Climate regulation: Carbon sequestration and burial	0	1
R9	Water quantity regulation: dissipation of tidal and river energy	1	1
R10	Regulation extreme events or disturbance: Wave reduction	0	0
R11	Regulation extreme events or disturbance: Water current reduction	0	0
R12	Regulation extreme events or disturbance: Flood water storage	0	1
P1	Water for industrial use	0	0
P2	Water for navigation	1	0
P3	Food: Animals	0	0
C1	Aesthetic information	0	1
C2	Inspiration for culture, art and design	0	2
C3	Information for cognitive development	0	2
C4	Opportunities for recreation & tourism	0	1

**Legend: expected impact**

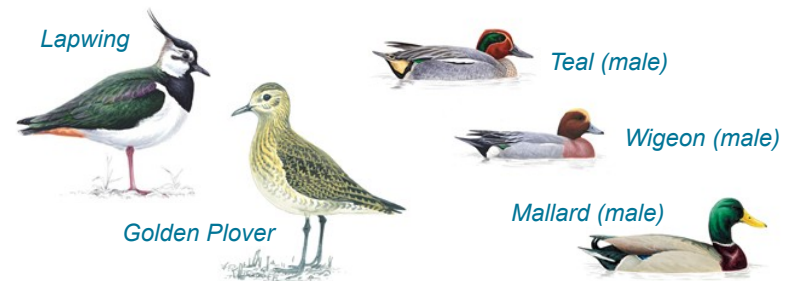
3	very positive
2	positive
1	slightly positive
0	neutral
-1	slightly negative
-2	negative
-3	very negative

**Many co-benefits!**  
i.e. ES not targeted, but positive expected impact

Analysis identified **spatial factors** to have a higher influence on bird density variability than temporal ones



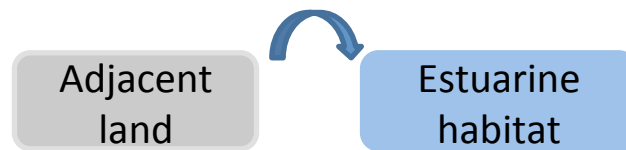
- Outer zones of estuaries support more diverse and dense bird assemblages  
*This is likely to be a result of the greater availability of suitable habitats both in these estuarine zones and in their proximity to adjacent coastal areas (e.g., Elbe)*
- However, locally, inner (oligohaline) areas may also be relevant in supporting abundant populations of some bird species  
*e.g. Lapwing, Golden Plover, Teal, Wigeon and Mallard in the Humber*



# Expected impact of management measures on ecosystem services

→ More examples are presented on the [poster](#) “Ecosystem services screening of TIDE estuaries”

## Conclusions:



=> **Many benefits and co-benefits regarding estuarine ES**



↳ **Positive and negative effects on estuarine ES,** depending on importance of the involved habitat types for the ES

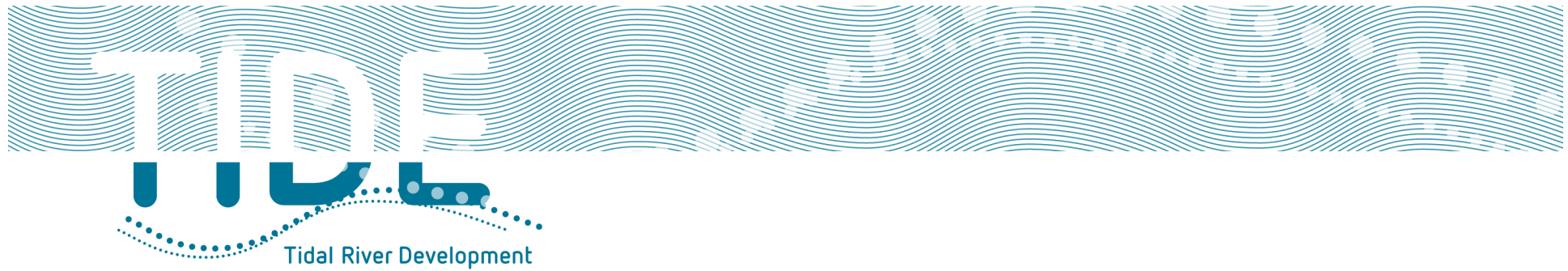
## Remarks:

- Assumption: linear surface-supply relationship
- Limited to the estuary and estuarine ES (effects lost adjacent land not included!)
- Limited to the boundaries of the measure (effects only in the project site)



## From ES concept to management practice

- Step 5: Quantification of ES and and better understanding underlying processes:
  - Derive measurable indicators of ES
  - Try to quantify AND understand underlying processes
  - → Interestuarine comparison
  - → literature review
-

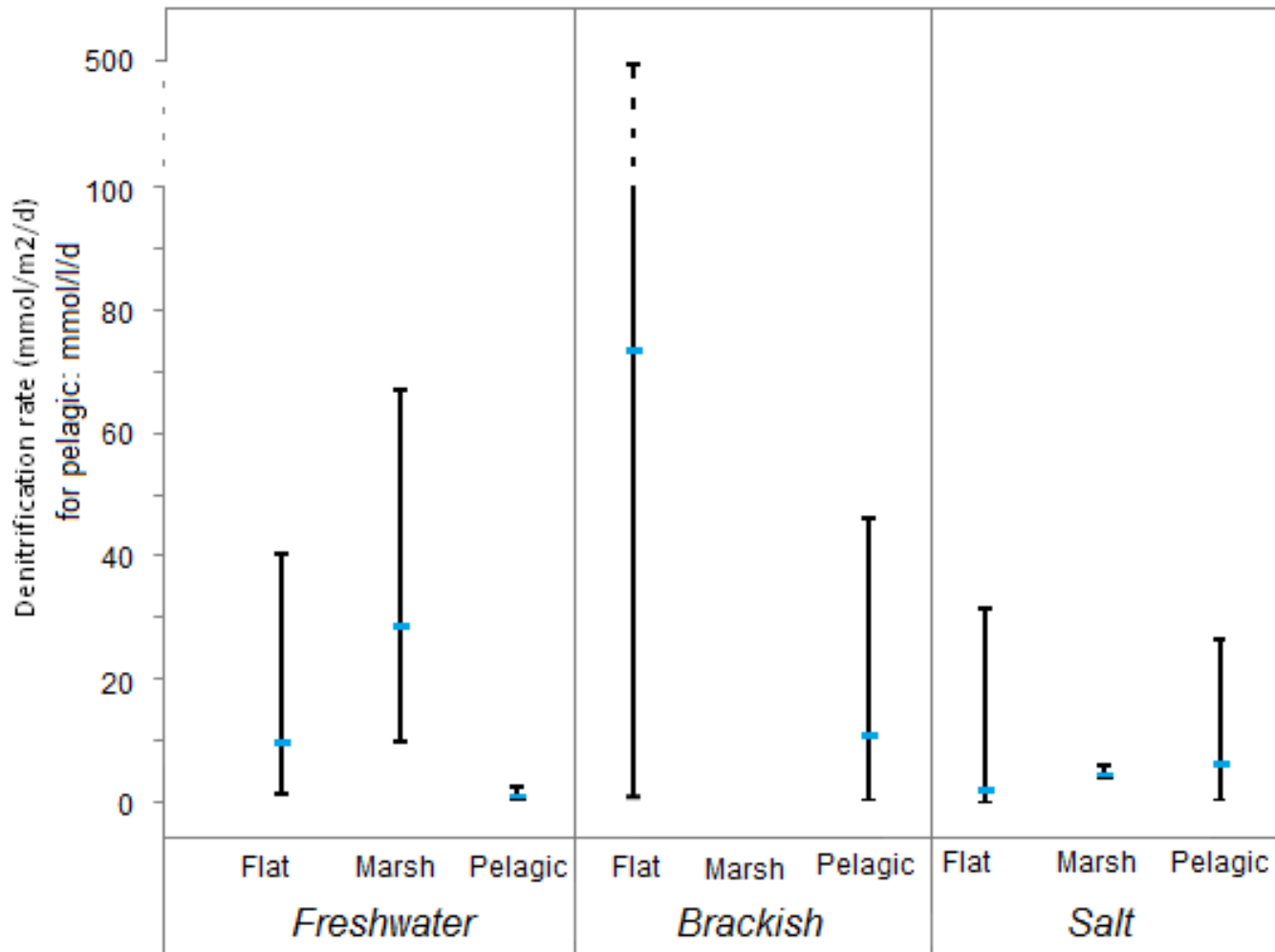


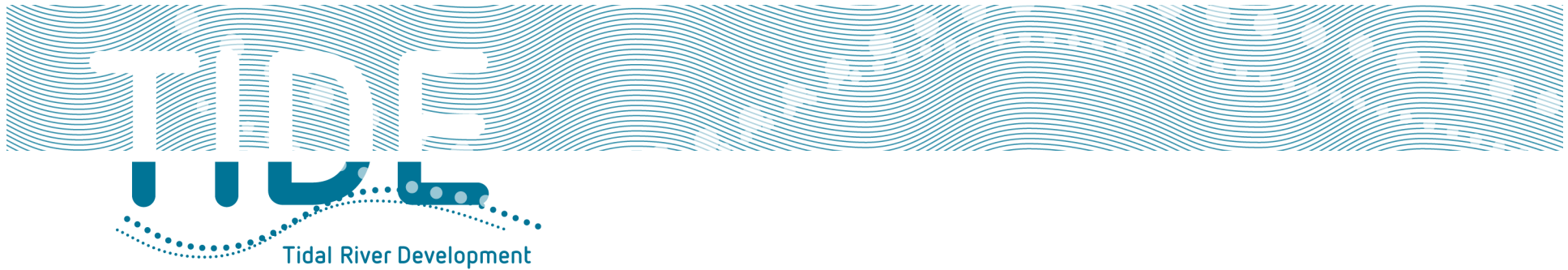
Ecosystem Service	“subservice”	indicator	measurement
Climate regulation			
	Carbon sequestration	Carbon burial	g C/m <sup>2</sup> *y
	Microclimate regulation	Temperature buffering	Net heat flux
Waste treatment			
	N removal	Load reduction	% of input leaving estuary
Water quantity regulation:			
	dissipation of tidal and river energy	Tidal damping	

3)

<b>Denitrification rates (mmol/(m<sup>2</sup>/d); mmol/(l/d) for pelagic)</b>				
<b>Habitat</b>	<b>Mean</b>	<b>Min</b>	<b>Max</b>	<b>References</b>
Fresh flat	9.79	1.21	31.61	Ogilvie et al. 1997; Barnes et al. 1998; Rysgaard et al. 1999
Fresh marsh	28.8	9.6	48	Gribsholt et al., 2006
Fresh pelagic	0.68	0.00 9	1.56	Abril et al. 2000; Sebilo et al. 2006; Vanderborght et al. 2007
Brackish flat	73.67	0.7	470.78	Barnes et al. 1998; Rysgaard et al. 1999; Cabrita & Brotas 2000; Trimmer et al. 2000; Dong et al. 2000; Nielsen et al. 1995; Thornton et al. 2007
Brackish marsh	-	-	-	-
Brackish pelagic	11.06	0.05	35	Vanderborght et al. 2007; Abril et al. 2010; Billen et al. 1985
Salt flat	1.93	0	29.38	Hofmann et al. 2008; Ogilvie et al. 1997; Rysgaard et al. 1999; Cabrita & Brotas 2000; Trimmer et al. 2000; Thornton et al. 2007; Middelburg et al. 1995; Rysgaard et al. 1995; Risgaard-Petersen 2003; Texeira et al. 2010; Rocha & Cabral 1998; Risgaard-Petersen 2000; Jensen et al. 1996; Jickells et al. 2000; Nielsen et al. 2001
Salt marsh	4.455	3.77	5.14	Erikson et al. 2003
Salt pelagic	6.27	0.03	20	Sebilo et al. 2006; Vanderborght et al. 2007

# TIDE





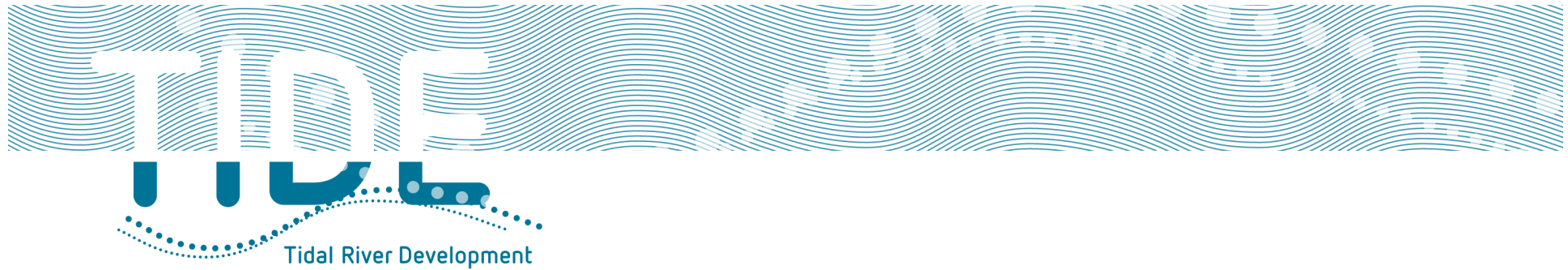
→ Underlying processes of service have high variability, cross-system, temporally and spatially! A mean doesn't say anything, only the range.

- It is very important to know the factors influencing these numbers. → need for site specific, tailor-made research

- Numbers are for existing situations.

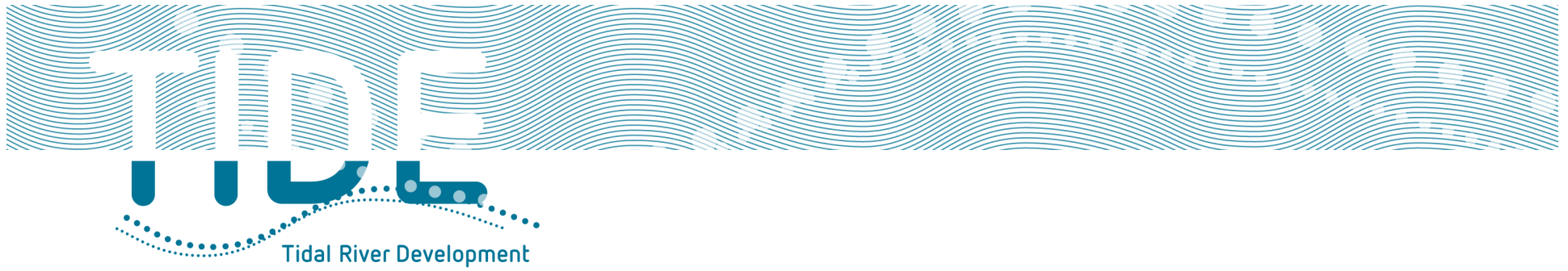
- Units (measurement inconsistencies)

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- → Loss of ecosystem services leads to an economic loss.
  - Economic valuation of ES was not included within TIDE but a guidance document how to estimate the economic value of the ES is being prepared.
  - This report contains:
    - The methodology of economic valuation
    - Quantitative info on ES





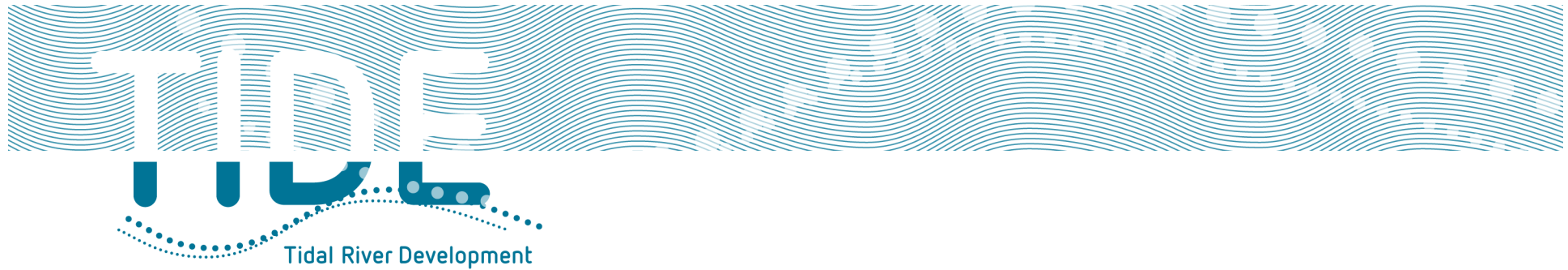
# CONCLUSIONS





## Importance for management

- Estuaries are complex systems and human impacts have lead to a decrease in ES resulting in an overall loss of natural capital
  - Developments in the tidal characteristics determine the system and changes in morphology impact the tides and the combined hydromorphological changes impact the ecological functioning
  - Goals for the tidal characteristics must be set and restoration must be based on measures that drive the system towards these goals. This is far beyond the classical goals from WFD, EBHD, safety plans etc.
-



- The concept of ES gives a framework for integrating this goals → **FORMULATE GOALS FOR ES!!**
- Restoration of habitats is necessary and will result in big savings on maintenance costs and should add to the delivery of ES
- Better understanding of the functioning is a crucial step towards better management and detailed monitoring programs are necessary. An interestuarine comparison is key to a better understanding



Thanks for your attention