Ecosystem services of estuarine and coastal areas: the basis for restoration?

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What are ecosystem services?

“The direct and indirect contributions of ecosystems to human well being” (TEEB, 2010)
PART 1: Intro

The concept of ecosystem services received increasing attention the last 20 years and is becoming a “buzz word”.

Number of publications dealing with “ecosystem services” in web of science between 2005 and 2013

Why did this simple concept receives so much attention?
The value of the world’s ecosystem services and natural capital


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The services of ecological systems and the natural capital stocks that produce them are critical to the functioning of the Earth’s life-support system. They contribute to human welfare, both directly and indirectly, and therefore represent part of the total economic value of the planet. We have estimated the current economic value of 17 ecosystem services for 16 biomes, based on published studies and a few original calculations. For the entire biosphere, the value (most of which is outside the market) is estimated to be in the range of US$16 - 54 trillion ($10^{13}$) per year, with an average of US$33 trillion per year. Because of the nature of the uncertainties, this must be considered a minimum estimate. Global gross national product total is around US$18 trillion per year.
Why are ecosystem services important?

1. It is a unifying concept which makes it possible to
   1. Make clear to a broader public what are the benefits we get from ecosystems
   2. Make a link between ecology and economy as ES can be valued in economic terms
This conflict is clearly unsustainable, but unfortunately worldwide still very common!
Ecosystem services
Why are ecosystem services important?

1. It is a unifying concept which makes it possible to
   1. Make clear to a broader public what the benefits are we get from ecosystems
   2. Make a link between ecology and economy as ES can be valued in economic terms

2. It is being taken up by several major international organisations
   1. EU, WB, UN,....
What are the ES from estuaries?
Human well being

Ecosystems and biodiversity

Structures and processes

Functions

Channels

Morphology

Salt marshes

Animal food

Benefits

(Economic) Value
Ecosystems and biodiversity

Structures and processes

Functions

Animal food

Benefits

(Economic) Value

Morphology
Salt marshes

Agricultural land

Human well being
Ecosystems and biodiversity

Structures and processes

Functions

Morphology
Salt marshes
Tidal Flats

Industrial/harbor area

Raw materials: Platform for building

Benefits

(Economic) Value

Human well being
Embanked area of Schelde estuary: 150,000 ha since 1500!

Embanked area in function of time

Cumulative surface embanked (ha)

Time (years)

Flanders

The Netherlands

Historische veranderingen in polderoppervlakte langs de Westerschelde

Cumulative surface embanked (ha)

Time (years)
Schelde at Dutch-Belgian border: 1867 - 1990
Deepening:
Section Lower Weser 1880 – recent times

Deepening:
Schelde estuary 1950 – recent times
Ecosystems and biodiversity

- Structures and processes
- Functions

Human well being

- Benefits
- (Economic) Value

Channels

Morphology

- marshes
- tidal flats

Dissipation of tidal energy
Sealevel rise in combination with morphological changes in the estuary resulted in an amplification of the tides!
Tidal amplitude: 1900-2008
Tidal damping/amplification
Amplification or damping?

Graph showing data points and regression lines for different datasets: 'Scheide', 'Elbe', 'Weser', and 'Humber'. The graph includes annotations for 'amplification' and 'damping', with R² values for each line: 0.89, 0.67, and 0.69.
Ruisbroek 1977
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, covergence length scale, bed roughness

Changes in the tidal characteristics are the driving force behind estuarine development
Ecosystems and biodiversity

- Structures and processes
- Functions

Primary Production

Human well being

- Benefits
- (Economic) Value
Figuur 2.9: Zomer- en jaargemiddelde chl a waarden in het zoete (km 103-151)
From net oxygen consumption to net oxygen production

P/R based on oxygen balance
Net oxygen consumption with high ammonia inputs
Net oxygen production with low ammonia inputs
Alternative stable states with intermediate ammonia inputs

Cox et al. Biogeosciences, 6, 2935–2948, 2009
NEW PROBLEMS?

FREQUENT DSI DEPLETION
Tidal marsh research (omes 1997)

Conservative export (+%) or import (-%)

Zomer 1997

Van Damme et al., 2008
Role of marshes

Exchange between marsh and pelagic

150 – 300 ton BSi

100 – 200 ton Si

Struyf et al. 2005

Universiteit Antwerpen
Primary production

<table>
<thead>
<tr>
<th>Geographic Area</th>
<th>North Sea (Reid et al. 1990)</th>
<th>Westerschelde (Soetaert et al. 1994)</th>
<th>freshwater tidal estuary (this study)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Production</td>
<td>200 g C m⁻² year⁻¹</td>
<td>41 g C m⁻² year⁻¹</td>
<td>260 g C m⁻² year⁻¹</td>
</tr>
</tbody>
</table>

Key Message

• Primary production as a crucial ecological process is dependent on:
  Morphology and changes lead to less favourable Zm/Zp ratio, decreasing PM
  Correct stoichiometry of nutrients and if unbalanced this causes major problems. Also habitat availability if crucial
Ecosystems and biodiversity

- Structures and processes
- Functions

Morphology

Water for navigation

Human well being

- Benefits
- (Economic) Value
Human well being

Ecosystems and biodiversity

Structures and processes

Functions

Morphology

Water for navigation

Dissipation of Tidal energy

Benefits

(Economic) Value
Human well-being

Benefits

(Economic) Value

Ecosystem services

Water for navigation

Dissipation of Tidal energy

Water quality regulation

Morphology

Water for navigation

Ecosystem services

Supply

Demand

Structures and processes

Functions

Ecosystems and biodiversity
An integrated strategy

• Requires:
  - Understanding the demand of ecosystem services
  - Quantification of ES == supply of ES

⇒ determine conservation objectives!
• What biodiversity we need to have (structural approach)?
• Which and how much services the ecosystem must deliver (functional approach)?
Schelde: disturbed estuary

Driving forces:
- Dredging & embankments
- Pollution
- Climate change

loss of ecosystem functions

Impact on:
- safety
- economy
- ecology
Schelde: solutions?

Sustainable solutions:

- Restoring functions
  - Flood control area: restoring safety
  - Controlled reduced tide: restoring ecology
## Ecosystem services: Supply

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

<table>
<thead>
<tr>
<th>Score</th>
<th>Habitat has...in supply of ES</th>
<th>Marsh</th>
<th>Intertidal steep</th>
<th>Intertidal flat</th>
<th>Subtidal shallow</th>
<th>Subtidal moderate deep</th>
<th>Subtidal deep</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>no importance</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>very low importance</td>
<td>4</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>moderate importance</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>Importance</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>Essential importance</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

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

- Requires:
  - Understanding the demand of ecosystem services
  - Quantification of ES == supply of ES

- determine conservation objectives!
- What biodiversity we need to have (structural approach)?
- Which and how much services the ecosystem must deliver (functional approach)?
An integrated strategy

• Goals for ecosystem services can be:
  - A volume of water that can be stored on marshes (safety)
  - Amount of primary production needed to sustain the nursery function
  - Retention of nutrients
  - Buffering tidal energy
An integrated strategy

- Understanding and quantification of ES
- Formulation of objectives
- The calculation of habitats surface needed
  - Safety
  - Tidal dissipation
  - Nutrient removal
  - Si delivery to sustain primary production
  - Populations of several target species
- Measures to maintain or restore habitats
Conservation Objectives (CO)

Final CO: \[ \Rightarrow \text{Max (surface } S_1, \ldots, S_n; F_1, \ldots, F_m) \]

\[ \Rightarrow \text{Habitat quality} \]
### Required surface of different habitats

<table>
<thead>
<tr>
<th>Habitat Type</th>
<th>Area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buitendijks brak</td>
<td>740</td>
</tr>
<tr>
<td>Buitendijks zoet</td>
<td>1040</td>
</tr>
<tr>
<td>Binnendijks bos alluviaal</td>
<td>570</td>
</tr>
<tr>
<td>Binnendijks anderen</td>
<td>370</td>
</tr>
<tr>
<td>Binnendijks grasland dotter (RBB)</td>
<td>840</td>
</tr>
<tr>
<td>Binnendijks grasland anderen</td>
<td>910</td>
</tr>
<tr>
<td>Binnendijks riet/ruigte</td>
<td>560</td>
</tr>
<tr>
<td>Binnendijks plas/oever</td>
<td>240</td>
</tr>
</tbody>
</table>
Spatial distribution of CO

The integrated approach
Intertidal marsh creation to solve estuarine problems

Marshes in 1200:  ~100 000 ha
Marshes now:       ~3260 ha
Marshes by 2030:   + 1500 ha
Some examples

Goal: flood control  ➔ storing water
Goal: water quality  ➔ reducing nutrient load and increasing Si concentration to achieve good stoichiometry!
Ecology:

- CRT: Introducing tidal nature
- Limited water exchange
- Twice a day!

Concept FCA - CRT

Safety: FCA
- Overflow dike
- Only during storm, full capacity
- 1 - 2 times/year

Ring Dike
Lowered FCA dike

FCA estuary
Outlet

Inlet

CRT polder

Ring Dike
Lowered FCA dike
Piloot project Lippenbroek

Management scenario Lippenbroek

1: Ring Dike
2: FCA dike
3: Inlet sluice
4: Outlet sluice

10 ha getijdenatuur in ontwikkeling sinds maart ‘06
Pilot project Lippenbroek

10 ha tidal nature since spring 2006
Introduction of macrotidal tides

- Reduction of tides with 3 meter
- No reduction of spring-neap tide variation
Intertidal marsh creation to solve estuarine problems

New marsh creation pilot project Lippenbroek

Sluice: exchange water & sediment
Water quality
Water quality

![Water quality graph](image)

**Graph Description:**
- The graph illustrates the oxygen levels (% sat) over time (hour).
- The graph shows three phases:
  - **Infow:** Oxygen levels increase significantly from 0 to 150% saturation over time.
  - **Stagnant:** Oxygen levels remain relatively stable, with minor fluctuations.
  - **Outflow:** Oxygen levels drop dramatically, indicating a change in water quality.

**Key Observations:**
- The water quality changes dramatically, especially during the outflow phase, indicating potential issues with oxygen levels.
- Understanding these changes is crucial for managing water quality in aquatic ecosystems.

**Image Caption:**
- The image captures a wave, symbolizing the dynamic nature of water quality changes.

**Conclusion:**
- Regular monitoring and analysis of water quality are essential for maintaining healthy aquatic environments.

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**Note:**
- The graph provides a visual representation of water quality changes, highlighting the importance of timely interventions to address oxygen levels.
- Further studies are necessary to understand the underlying causes and implement effective solutions.
Water quality: Silica

DSi verloop op 3/7/2006

- Lippenbroek
- Estuary

Graph shows the DSi (mg/l SiO₂) over time (hrs) with separate sections for Inflow and Outflow.
Water quality: nitrogen

Verwijdering van 1 kg N per ha per getij
Vegetation: colonisation of bare sites

Colonising species (40)

Low inundation frequency:
30 species
- Wetland + ruderal species
- Salix and Phragmites potentially dominant

Averaged inundation frequency:
27 species
- Ruderal + wetland species
- Salix, Phragmites, Typha: pot. dominant

High inundation frequency:
10 species
- typical wetland species
- Typha potentially dominant
Redy for the big work !?
Some examples

Goal: flood control ➔ storing water
Goal: water quality ➔ reducing nutrient load and increasing Si concentration to achieve good stoichiometry!
Goal: dissipation of tidal energy
Managed realignment

1990

1998
• Problem: very high tidal energy
• Goal: Tidal energy dissipation to natural proportions

\[ c = \sqrt{\frac{g \cdot A_c}{b_t}} \]

\[ c = \sqrt{\frac{g \cdot (A_c + 2A_s + A_i)}{(b_t + b'_t)}} \]

Measure: create shallow and intertidal areas
Intertidal marsh creation to solve estuarine problems

2. Tidal and storm surge attenuation

E.g. Effect of Saeftinghe marsh ~2500 ha

2D hydrodyn. model
Blue line = ref. 2009
Intertidal marsh creation to solve estuarine problems

2. Tidal and storm surge attenuation

E.g. Effect of Saeftinghe marsh ~2500 ha

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Blue line = ref. 2009
(Temmerman et al. 2013 Nature)

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University of Antwerp

[Image of a wetland ecosystem with labels: Reef, Wetland sedimentation, Wetland creation, Dyke, and text "Dyke et al. 2012 Nature"]]
Main goals to be achieved

• Increase the resilience of the system to dissipate the increased energy coming into the system
  - Tidal energy
  - Peak discharges from the catchment
• Increase the biogeochemical function to improve water quality and sustain production
Conclusions
conclusions

• Ecosystems deliver services to society:
  - Ecosystem services
• But are therefore dependent on the presence of species and habitats and their performance.
• ➔ not delivering these services has a high cost for society
Conclusions

• Can we improve ecosystem services to achieve sustainability?

  ➔ YES, IF

• We have a good understanding of the impact of past management on the present state of the system and the ecological services in particular

• We have a clear definition of goals describing the amount of ecosystems services the system is expected to deliver (volumes of water to store, nutrient retention, attenuation of the tide,....)
Conclusions

• Can we improve ecosystem services to achieve sustainability?

⇒ YES, IF

• We can translate required services into surfaces of habitat required

• We can find the right spatial configuration of the habitats
• The big economic value of ecological services is widely accepted
• We are able to make estuarine and coastal management plans in an integrated way so that both economic and ecological services are optimized.
• Essential is bringing all elements together in a truly integrated plan, that is decided by the government and that is implemented based on very intensive stakeholder participation where the overall goal of the plan is reconciled with some local interests.

• Managing ES of estuaries and coasts is the key to protect the biodiversity and not vice versa!!
Thanks for your attention