ANNELIES BOEREMA, KATRIEN VAN DER BIEST AND PATRICK MEIRE

ECOSYSTEM SERVICES: TOWARDS INTEGRATED MARITIME INFRASTRUCTURE PROJECT ASSESSMENTS

ABSTRACT

Ecosystem services (ES) are defined as the benefits that humans derive from nature. These services represent different benefits for human well-being. The ES framework helps to analyse the impacts humans have on ecosystems and the feed-back effects these changes have for the ecosystem benefits to humans. Today many industries, including those in the maritime sector, are in the process of applying ES to evaluating their processes of manufacturing and delivering products.

To that end, the Ecosystem Management Research Group (ECOBE), Department of Biology, University of Antwerp, Belgium and the International Association of Dredging Companies (IADC) have joined forces to explore the subject as regards dredging. This article is the first result of that research. The aim of this joint effort is to show that with the use of ES a more integrated evaluation of the consequences of maritime infrastructure projects can be achieved. The presented method of ES evaluation is applied to a dredging-related case study: tidal marsh restoration in the Polders of Kruibeke, located in the Zeeschelde, the Belgian part of the tidal River Scheldt.

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INTRODUCTION

Ecosystem services (ES) are the benefits that humans derive from nature (MEA 2005, TEEB 2010). There are different types of ES which result in different benefits for human well-being, such as security, basic materials for a good life, health and good social relations (Figure 1). The different types of ES are:
- provisioning services (e.g., food, wood),
- regulating services (e.g., air quality regulation, water quality regulation) and
- cultural services (e.g., opportunities for recreation, cultural heritage).

Furthermore, biodiversity and supporting services are an underlying group of ecosystem functions (e.g., nutrient cycling, primary production), which are important for the delivery of the other three categories of services. The ES framework forms the bridge between ecosystems and human well-being (socio-cultural context) and explains the relationship between both "worlds" (Figure 2). In addition, this framework helps to analyse the impacts humans have on ecosystems and the feed-back effects these changes have for the ecosystem benefits to humans.

To illustrate the significance of the application of ES evaluation to the maritime sector, a dredging-related case study – tidal marsh restoration in the Polders of Kruibeke, located in the Zeeschelde, the Belgian part of the tidal River Scheldt – is presented.

ECOSYSTEM SERVICE EVALUATION FOR INTEGRATED PROJECT ASSESSMENT

Ecosystem service evaluation could be used as a method for an integrated assessment of specific maritime and dredging projects. The method consists of four basic steps (Table I):
- In step 1, the different habitat types that are affected by the project are identified.
- In step 2, all ES delivered by those habitat types are identified and the relevant ES for the specific project selected.

Above: One benefit of Ecosystem Services is addressing the challenges of flooding. At the Polders of Kruibeke in Belgium, a new dike will be built land inwards (the horizontal line in the middle going from the River Scheldt to the right). This new ring dike should protect the houses just outside the site when the flood area fills during storm tide.

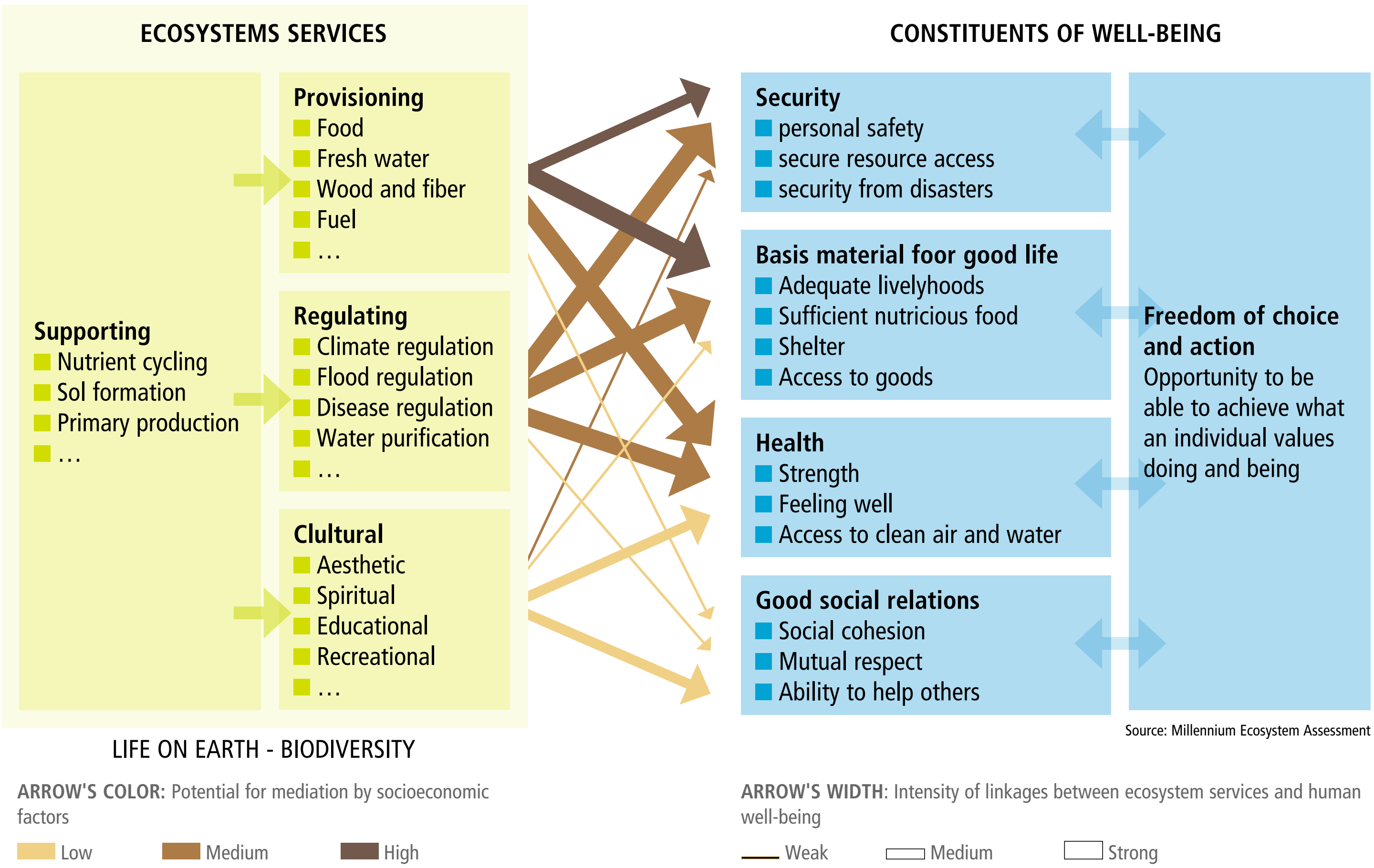

Figure 1. Links between ecosystem services and human well-being (MEA 2005).

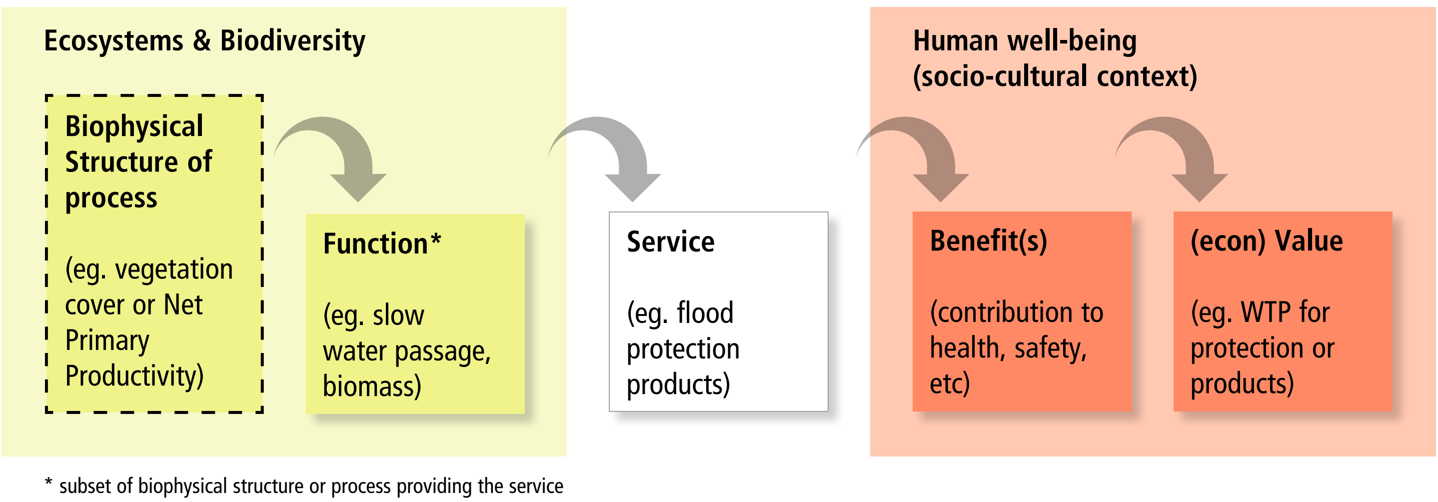

Figure 2. Ecosystem services cascade: From ecosystem to human well-being (TEEB 2010).

- In step 3, each ES as well as the underlying mechanisms driving the delivery are described.
- Finally, in step 4, the impact on all relevant ES are calculated in a quantitative and monetary way as much as possible.

For the quantitative assessment, each ES has its own unit which is most relevant for that service. Carbon sequestration (that is the long-term storage of carbon dioxide or other forms of carbon), for example, is expressed in tonnes of carbon per hectare per year; wood production is expressed in m^3 wood volume increase per hectare per year.

For the quantification, methods differ between intertidal systems and terrestrial systems owing to differences in the processes that are relevant for ES delivery (e.g., sedimentation in intertidal systems or groundwater in terrestrial systems). For the monetary valuation, each of the quantitative

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Table I. ES evaluation in four steps.

Step 1	Changes in habitat and land use/land cover (before vs after)
Step 2	ES analysis per habitat type • International literature: to select potential ES • Project specific literature (e.g., Environmental Impact Assessment): to select project relevant ES
Step 3	Description of relevant ES and important underlying mechanisms
Step 4	Quantitative and/or monetary assessment (depending on available data)

units is translated into euros (€) per hectare per year to form a basis for comparison of scenarios or project alternatives.

CASE STUDY: POLDERS OF KRUIBEKE

The presented method of ES evaluation is applied on a dredging-related case study: tidal marsh restoration in the Polders of Kruibeke, located in the Zeeschelde, the Belgian part of the tidal River Scheldt (Figure 3A). The main development targets of this project are flood prevention and nature development linked to the European habitat and bird directives. This is one of the projects of the Sigma Plan, the Flemish management agreement for the Scheldt estuary which focusses on safety, navigation and nature.

Within this project two techniques are used to create an area for flood safety and nature development. Both techniques (Flood Control Area [FCA] and Flood Control Area with Controlled Reduced Tide [FCA-CRT]) are illustrated in Figure 4. The project – expected to be finished by the end of 2015 – uses a combination of both techniques and the result is mixed habitat configuration of wetland, bird area, alder brook forest and tidal marsh (Figure 3B).

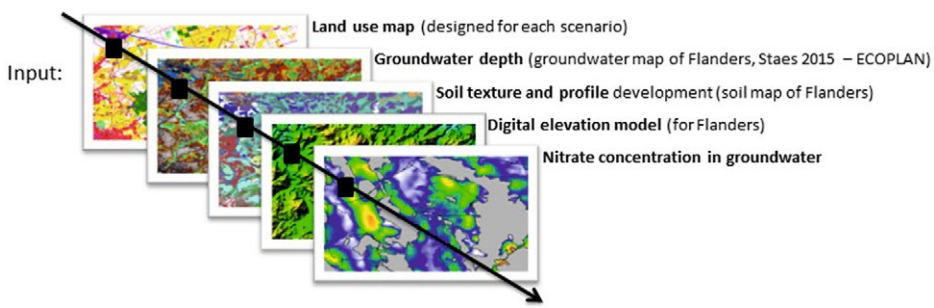
To assess the beneficial value of the project, a comparison is made with the situation (agricultural area) before the project. For the first scenario – the agricultural area without the project – only maintenance costs are taken into consideration (no further investment costs). The maintenance cost amounts to € 140,000 per year (or € 3.5 million for 100 years with 4% annuity rate).

For the second scenario, the investment cost for the project consists of a construction cost of about € 75 million and an expropriation cost of about € 25 million. Furthermore an annual maintenance cost (e.g., for mowing of dikes) is accounted for (€ 170,000 per year, or € 4 million for 100 years). This gives a total investment over 100 years of € 3.5 million without the project and € 104 million with the project (Stabo, 1998; Triple E Trust & Natuur en Economie, 2015; W&Z, 2015; Polderbestuur, 2015).

ES EVALUATION OF THE POLDERS OF KRUIBEKE

For terrestrial systems, advanced biophysical methods are being developed. The biophysical models take into account the multiple biotic

Table II. Schematic overview the required data from the different biophysical maps are combined. For each raster cell of 5x5m data from the different layers are combined and used to estimate the different ecosystem services.



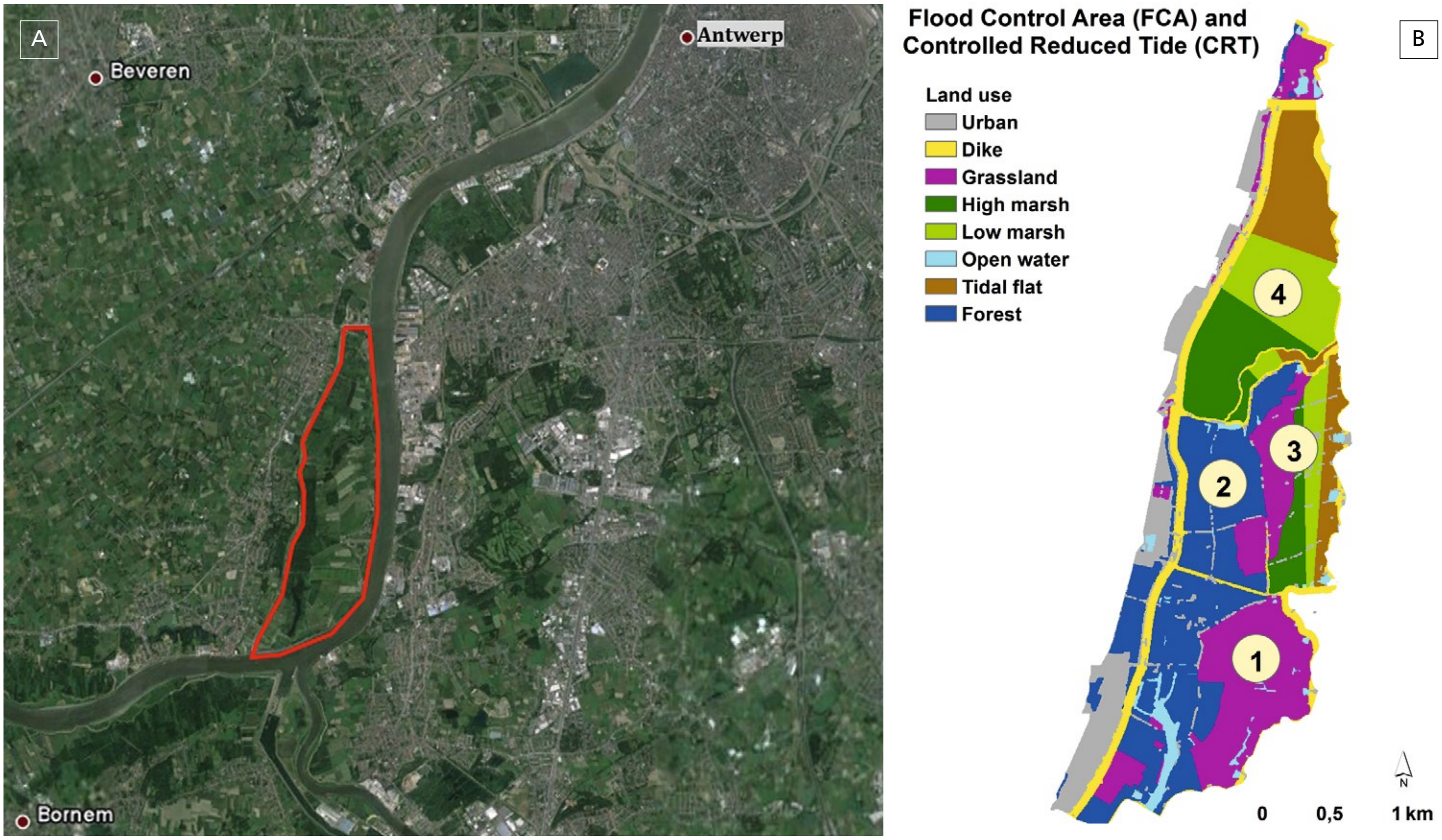


Figure 3. A) Study area the Polders of Kruibeke in the Zeeschelde, the Belgian part of the tidal River Scheldt. B) Integrated Plan for the Flood Control Area (FCA) Polders of Kruibeke with four different zones: (1) bird area, (2) alder brook forest, (3) tidal marsh combined with bird area (FCA-CRT), (4) tidal marsh (FCA-CRT).

(living) and abiotic (non-living, physical) parameters that affect ES delivery and potential interactions between different parameters. All of the data are made spatially explicit in a Geographical Information Systems (GIS) environment and the results can be visualised in maps. The aerial photographs in Figures 5 and 6 show the northern and southern parts of the project site. Figure 5 was taken before the project; Figure 6 after the project.

In other words, for each area (in the form of a raster cell of 5 m x 5 m) a calculation is made for the delivery of each service, based on the parameters characteristic for that area (Table II).

A short overview of all of the input parameters needed to assess the different services is provided:

- *Land use:* before and after realisation of the Integrated Plan Version 3 for the Polders of Kruibeke (INBO) (Instituut voor Natuur en Bos Onderzoek/Institute for Nature and Forest Research) (Figure 3B)
- *Soil texture:* Soil map of Flanders (AGIV, 2001)
- *Soil profile development:* Soil map of Flanders (AGIV, 2001)
- Groundwater depth (cm): modelled groundwater levels for Flanders (ECOPLAN project, 2015)
- *Elevation (cm TAW):* digital elevation model Flanders (AGIV, 2011). TAW (Tweede Algemene Waterpassing) is the reference height used to express elevation measures in Belgium. This is similar to the Dutch Normaal Amsterdams Peil (NAP), which is 2.33 metre higher than TAW and the average sea level in Marseille (used in France), which is 1.82 metre higher than TAW.
- *Groundwater supply (l/day):* modelled data for Flanders (ECOPLAN Project, 2015)
- *Nitrate concentration in groundwater (mg/l):* modelled data for Flanders (ECOPLAN Project, 2015)

Wood provisioning

Wood production depends on biophysical suitability of the soil and on land use and related management practices. Biophysical potential of the soil was modelled based on a suitability scoring approach, carried out for all frequently occurring tree species in Flanders (De Vos, 2000). The species-specific suitability scores, dependent on soil texture, soil moisture content and profile development, were devised by experts, who based their knowledge on existing literature and field studies on forest productivity (Landuyt et al., 2015).

These suitability scores were used to derive expected productivity rates (m^3/ha/year) for each tree species. To account for the effect of management, harvest factors were used to differentiate between state-owned forests and private forests, where state-owned forests are more frequently harvested than private forests. Based on species-specific market prices, derived from a statistical analysis on a database of actual selling prices in Flanders (Demey et al., 2013), production rates were converted into monetary values (€/ha/year).

Food production (crops and livestock grazing)

Agricultural production depends on land use and biophysical suitability of the soil. Four different types of agricultural land use are accounted for:

- conventional cropland (with use of fertilizers),
- conventional grassland (intensively grazed pastures with use of fertilizers),
- grassland with extensive grazing (such as grazing to maintain dikes without input of additional fertilizers) and
- natural grassland with very extensive grazing (pastures in areas with nature protection where no input of additional fertilizers is allowed).

Biophysical suitability for agriculture depends on soil type, soil moisture content and profile development. Agricultural productivity is highest under the most optimal soil conditions (loamy, organic soils with average groundwater depth) and lower on less fertile soils (dry, sandy soils).

Based on recent data on agricultural productivity in Flanders, the potential productivity of conventional cropland and grassland (expected value, expressed in €/ha/year, and standard deviation) (Van Broekhoven et al., 2012) were derived. The expected production for the more extensive grasslands is estimated based on values of livestock density in head per hectare (Wint and Robinson, 2007; Nolte et al., 2013) and taking into account a higher meat price for organic meat compared to regular meat. For each combination of soil characteristics, a certain reduction of the maximum productivity is determined based on data used by the Flemish government (Bollen, 2012).

Air quality regulation (fine dust removal)

Plants are capable of reducing the amount of fine dust (PM2.5 and PM10) in the air originating from urban and industrial activities. Fine dust particles precipitate on leaves, stems and branches and are then washed away by rain to accumulate on the soil. The type of vegetation and the presence of understories are major factors determining the capacity of an ecosystem to improve air quality. This service is only relevant in a region with air pollution, for example close to cities, harbours or busy roads, and should be evaluated per case study. From the average daily concentration of fine particles (PM2.5 and PM10) in Belgium (website ATMOSYS, March 2015), the area of Kruibeke clearly receives large amounts of fine dust particles, caused by the presence of a busy highway and industrial activity on the other side of the Scheldt estuary.

The quantitative values used for the evaluation of air quality in this study are based on the values used in the Nature Value Explorer (digital and continuously updated version, March 2015), which are derived from Oosterbaan et al. (2006). The monetary value of air quality regulation (fine dust removal) is calculated as the avoided damage to human health caused by fine dust emission (€/kg PM10) (Liekens et al. 2013).

Climate regulation (carbon sequestration)

Climate regulation through carbon sequestration can be realised by burial of organic matter during sedimentation and by anoxic accumulation of organic matter both in above and below ground biomass and in the soil. As only the soil component can be seen as permanent storage, the focus here is on this type of organic carbon storage (soil organic carbon or SOC). Storage by burial only occurs in case of regular flooding, such as on marshes and mudflats. Storage through accumulation of organic matter can only occur in the presence of vegetation, either on terrestrial land or on transitional grounds such as vegetated marshes.

In estuaries, carbon regulation consists of sequestration through litter accumulation (vegetated marshes) and burial through sedimentation (subtidal habitat, seagrass, tidal flats, marshes). Annual carbon burial (ton C/ha/y, or ton CO_2-eq./ha/y) is calculated based on:

- the annual sediment volume increase (with annual sedimentation rates being lower for high marshes compared to mudflats and

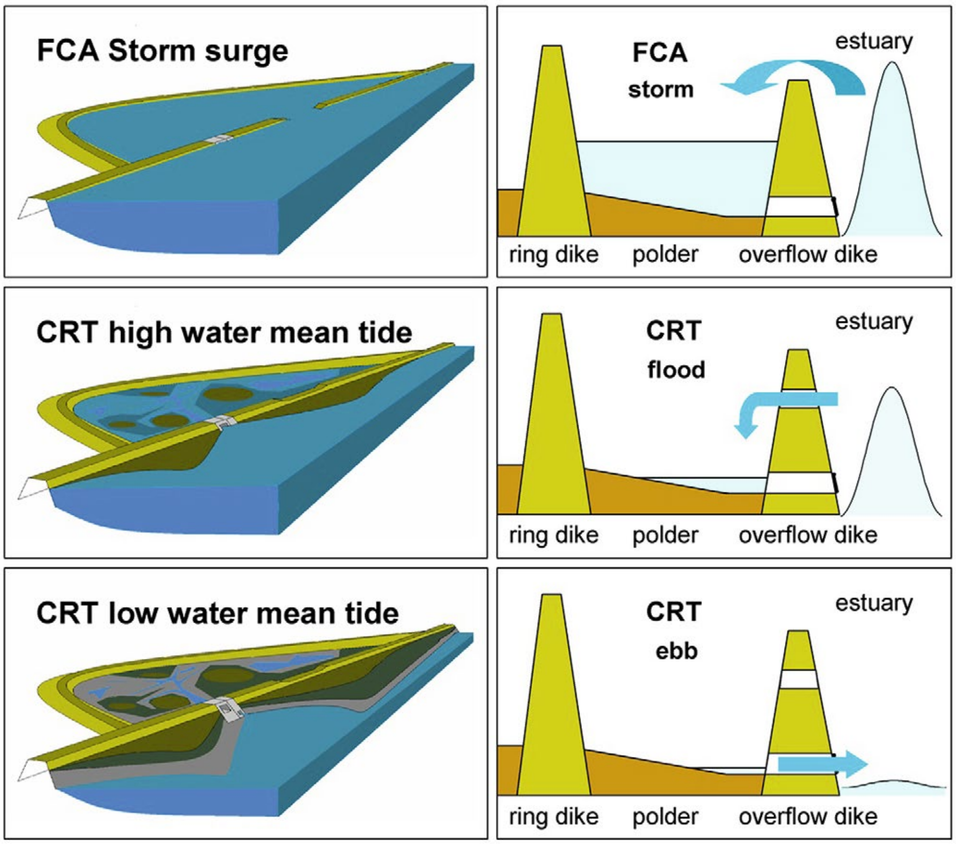
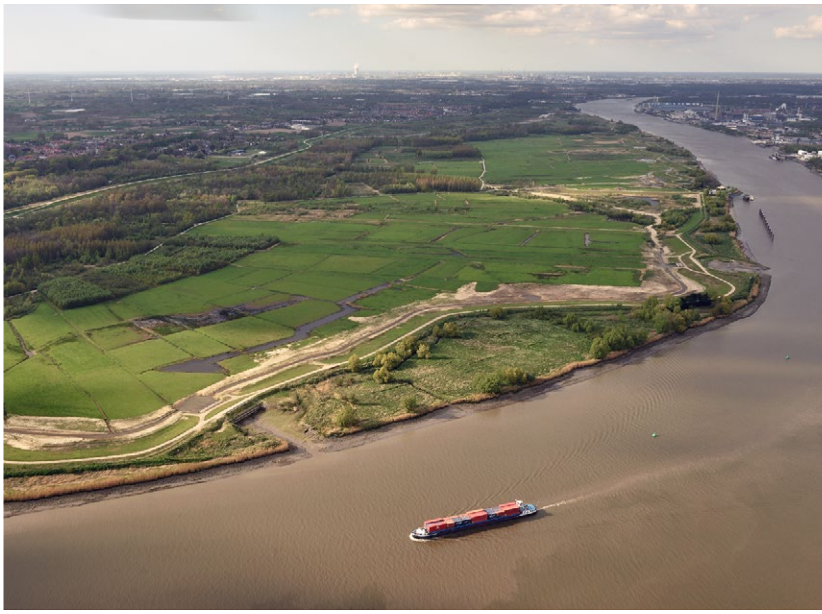


Figure 4. Concept of a Flood Control Area (FCA) and Controlled Reduced Tide (CRT). References for more details on the FCA-CRT technique: Meire et al., 2005; Cox et al., 2006; Maris et al., 2007.



Left, Figure 5. Before: Aerial photograph of the northern part of the project site along the River Scheldt shows the situation with agricultural land before the start of the project. This part is being converted into a tidal marsh by the creation of a Flood Control Area with a Controlled Reduced Tide (FCA-CRT) (see Zone 4 in Figure 3B and Figure 4 for more details about the FCA-CRT concept). Right, Figure 6. After: Aerial photograph of the southern part of the project site along the River Scheldt: wetland as bird area (Zone 1 in Figure 3B) and alder brook forest (Zone 2 in Figure 3B).

low marshes),
- bulk density of the sediment and
- particulate organic carbon content in the river water.

Marshes and mudflats are furthermore characterised by important amounts of greenhouse gas emissions (CO_2, CH_4 and N_2O). These emissions were taken into account by subtracting them from the estimated amount of carbon burial. Data for the three greenhouse gas emissions are derived from measurements in the intertidal sediment at Doel near the Polders of Kruibeke (Middelburg et al.,1995a,b).

Terrestrial SOC sequestration by accumulation of plant material in soils was estimated using an existing multiple regression model for carbon storage in soils in Flanders (Meersmans et al., 2011). This model predicts the total SOC stock based on soil texture, soil moisture content and land use (grassland, heathland, cropland and forest). The thus predicted SOC is divided by 100, assuming that soils reach their equilibrium SOC concentration after a period of 100 years. For more detailed information on the modelling methodology applied for terrestrial habitats see Meersmans et al. (2011) and Broekx et al. (2014).

The monetary value of climate regulation (carbon sequestration) is calculated as the avoided reduction cost, i.e., the costs for emission reduction measures that can be avoided in other areas to reach the environmental targets, which are related to the worldwide max. 2°C temperature increase relative to the pre-industrial level of 1780. Data is based on a meta-analysis of several climate model studies (Kuik et al. 2009).

Water quality regulation

Water quality regulation refers to the removal of excessive nutrients (nitrate and phosphate) from water bodies (soil pore water, groundwater, surface water and sea). This service is especially important close to agricultural areas regarding the use of fertilizers or in coastal areas with a high discharge of nutrient rich freshwater. Denitrification is one of the main processes by which nutrients are permanently removed from an ecosystem. Nutrients can additionally be removed through transfer of primary production to higher trophic levels (nutrient cycling) and burial through sedimentation of organic material (especially in estuaries). While nutrients form the basis of marine life (primary production) and increase ES delivery such as fish production, an excessive supply leads to eutrophication and may cause proliferation of (toxic) algae, oxygen depletion, light limitation, mortality of fish and benthic organisms and reduced recreation amenity value (O'Higgins and Gilbert, 2014).

A healthy marine ecosystem requires a balance between primary production and consumption by higher trophic levels (bivalves, fish, …). Marine ecosystems with high nutrient loads and intensive fishing, such as the coastal zone of the North Sea, may thus benefit from developments that increase habitat surface or quality for higher trophic levels feeding on excessive algae growth.

Amongst the main benefits of the removal of excessive nutrients by plants and natural ecosystems are:
- reduction of the costs for mechanical purification of drinking water,
- increase of biodiversity,
- prevention of fish mortality and
- decrease in recreational amenity value.

Only the benefits from denitrification and nutrient burial (nitrogen and phosphorous) have been taken into account here as these processes have long-term storage capacities. Removal by transfer to higher trophic levels is

Figure 7. Close up view of the sluice system in the northern part of the project connects the project site with the River Scheldt. The sluice will reduce the tidal range that comes into the area, thus creating a Controlled Reduced Tide. Making the sluices, lowering the dike next to the river and building the new ring dike land inwards are the main dredging operations in this project.

temporary, except if biomass is harvested (e.g., through fishing), and is therefore not considered in this research.

i. Denitrification

Denitrification is the biochemical process in which bacteria convert biologically available nitrogen into nitrogen gas. Denitrification can occur in all ecosystem types, natural and equilibrated as well as more disturbed and eutrophic systems, but it only becomes an ES when it prevents leakage of nitrogen to ground- and surface water reserves or when it removes excessive nitrogen from water reserves. Denitrification typically occurs in water saturated soils (wetlands, rivers, river banks, …) where oxygen-poor groundwater meets oxygen-rich conditions. Denitrification is thus rather marginally influenced by vegetation.

For denitrification in estuaries, the focus here has been on measurements in flood areas in the Scheldt estuary (Middelburg et al., 1995a; Broekx et al., 2011). A distinction is made between frequently and occasionally flooded areas, with denitrification being higher in frequently inundated zones and hence in frequently alternating oxic/anoxic conditions.

Denitrification in terrestrial habitats is especially important under conditions of high nutrient supply such as in the vicinity of agricultural sites that apply fertilizers.

A scenario with a large amount of agricultural fields may thus have higher denitrification rates than marshes and mudflats, because of the higher input of nitrates through fertilizing compared to the concentration of nitrates in the Scheldt water. The high denitrification rates result from the addition of fertilizer on fields. As fertilizers cause leakage of nutrients to water reserves, the negative impacts of the use of synthetic fertilizer on water quality is taken into account.

When animal manure is being used as fertilizer, nutrient uptake by crops and denitrification could be considered as an additional benefit (avoiding expensive animal manure treatment). This is not included in the analysis since no information is available on the proportion of animal manure used and the cost of animal manure treatment.

For the monetary value, the shadow price for nitrogen removal (€/kg N) is used which is the cost for an equal removal of nitrogen using technical investments. An average value based on a literature review is used (Liekens et al. 2013).

ii. Nitrogen burial

Nitrogen burial in estuaries was calculated by taking into account the annual sediment volume increase (idem as for carbon burial) and the particulate nitrogen content of river water. For the monetary valuation, the same method as for denitrification is used.

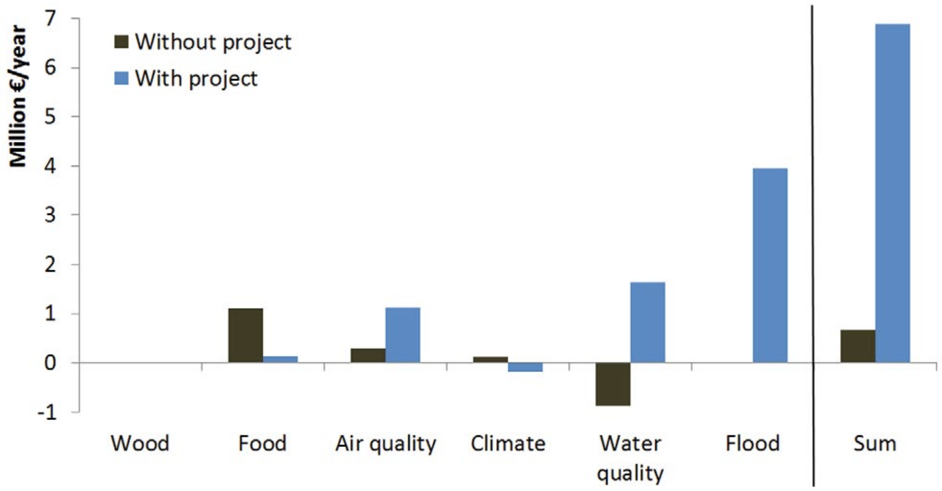


Figure 8. Annual benefits per ES and total sum for both scenarios: without or with the project (million €/year).

iii. Phosphorous burial
The calculation of phosphorous burial in estuaries is equal to carbon and nitrogen burial: the annual sediment volume increase multiplied with the total phosphorous content of river water. No consideration was given to the fact that in the first years (after converting agricultural land into a flood control area), phosphorous is being released instead of buried (based on field measurements and mass balance calculations for the pilot project Lippenbroek in the Scheldt estuary, Maris et al. 2010).

For the monetary value, the shadow price for phosphorus removal (€/kg P) is used, which is the cost for an equal removal of phosphorus using technical investments. An average value based on a literature review is used (Liekens et al. 2013).

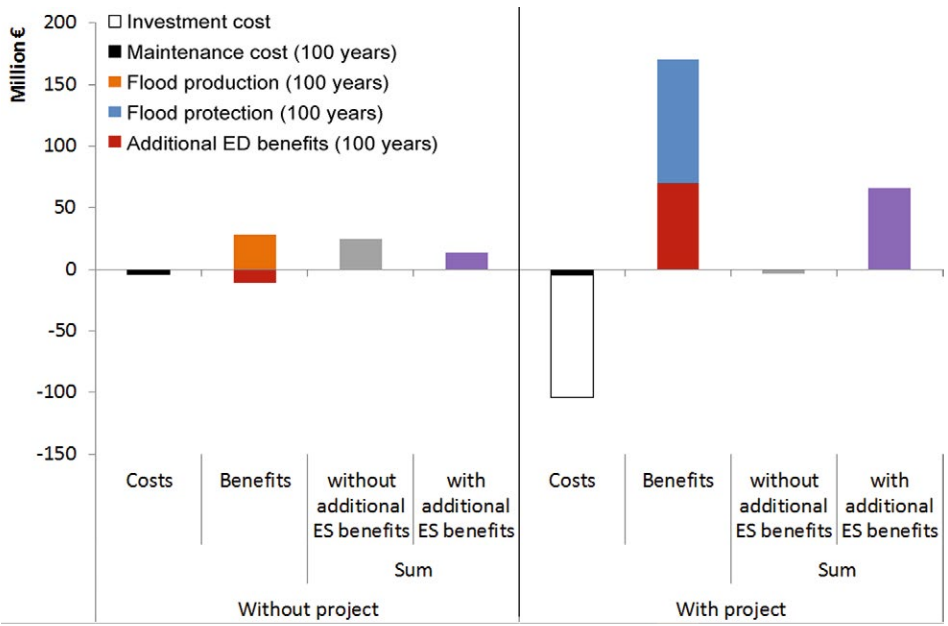


Figure 9. The total costs and benefits and the total sum are given for the situation without and with the project (million €, for 100 years with 4% annuity rate). The benefits of the situation without the project consist of benefits from food production and additional ES benefits. The benefits of the project consist of safety benefits and additional ES benefits. For both, the total sum is presented with and without the additional ES benefits to see the difference of a full ES evaluation.

Flood protection
Flood control areas contribute to flood safety through water storage during storm surges (Figure 7). The monetary value of the ES flood protection is usually calculated as the avoided damage costs and/or casualties. This method requires the use of hydrodynamic models to predict water flow and flood levels. In the frame of the Sigma Plan, the safety benefit of the different projects is estimated using such hydrodynamic models (Gauderis et al. 2005).

Recreation
Benefits from recreation resulting from new projects are difficult to assess for two reasons: First, it is difficult to distinguish between the effects of changes in the ecosystem and the effects resulting from additional efforts to stimulate recreation (walking trails, promotion campaigns, …). Second, it is difficult to estimate differences between habitat types, where in some cases agricultural sites may attract a similar amount of visitors as natural habitat types. The monetary value is estimated as the amount all visitors spend during their visits. Therefore data is needed on the number of visitors before and after the project.
For the Polders of Kruibeke the number of visitors was estimated in a study about the tourist and recreational potential of the project (ANTEA group and IDEA Consult, 2012). However, recreational benefits were not included in the ES evaluation, because the added value of the landscape changes is not clear (difference between before and after the project, both in number of visitors and in added value to the recreants).

Biodiversity
An important objective of the Polders of Kruibeke project is the contribution to the European Habitat and Bird Directive targets (e.g., creation of estuarine nature and bird area). Biodiversity is not considered an ES in itself but for several ES there is a strong positive feedback mechanism between biodiversity and service delivery. Biodiversity for example will be higher under good water quality conditions. A higher biodiversity in its turn may increase removal of excessive nutrients as a result of niche partitioning within a certain habitat. Other services

however may have negative feedback mechanisms with biodiversity. Recreation for example may result in a decline of species richness caused by trampling or repeated disturbance. Recreational attractiveness on the other hand may be higher if a higher diversity of species is present.

Although the relationships between biodiversity and ES are complex and service dependent, it is believed that the creation of more natural habitat increases both biodiversity and service delivery. Biodiversity is relevant in each of the habitat types.

Monetary valuation: Societal benefits from habitat creation and an increase/shift in biodiversity are not included in the monetary assessment because of a lack of scientifically sound measurement methods. Furthermore, biodiversity has an intrinsic rather than a monetary value. Only a qualitative or quantitative (e.g., number of different species) assessment could be used to specify the contribution of the project. Habitat types that are created are estuary (tidal habitat), meadows and alder brook forest. Relevant species groups are macrobenthos, nematode communities, fish, shellfish, tidal marsh vegetation and birds.

OVERALL NET BENEFIT FOR BOTH SCENARIOS: WITH OR WITHOUT THE PROJECT

With the ES evaluation the external effects of the alternatives without or with the project and its relevance for society have been investigated and compared. The project gives much higher annual benefits compared to the situation without the project (Figure 8). The situation without the project provides the ES food production but creates negative effects for water quality (nitrogen leaching).

On the other hand, the project provides not only safety benefits (flood prevention) but also positive effects for air quality and water quality regulation. In addition, the benefits are compared with the investment and maintenance costs.

To understand the impact of including an ES evaluation, the sum with and without the additional ES benefits is shown in Figure 9. Without the ES evaluation, only the benefit of food production (without project) and of flood safety (with project) would be compared. As a result of the high investment cost for the project, the conclusion would be a negative result for the project compared to the situation without the project.
However, by taking into consideration the ES evaluation and including additional ES benefits, the situation with the project turns out to be more beneficial to society than without the project.

The difference with and without additional ES benefits is minimal for the situation without the project, but highly important for the project to show its overall societal benefit.

CONCLUSIONS

An ES evaluation enables an integrated and balanced comparison of human actions or project alternatives. This will help to assess whether one human action has more or less positive effects for the ecosystem, for different stakeholders and the broad society. Monetary valuation of ES is useful to make a full environmental cost-benefit analysis and weigh the investment costs with environmental and socio-economic benefits. This has been applied to a maritime project at the Polders of Kruibeke in Belgium.

The ES evaluation of the Polders of Kruibeke project shows that the project is more beneficial for society than the situation without the project. What is remarkable is that this conclusion is the opposite of what would have been decided had the additional ES benefits not been included. Without ES, the project gave an overall negative effect for society.

Interpreting this result in the wider context is important, for example by looking at the ES that are actually needed in the area (e.g., is there a local demand for the ES benefits?). Furthermore an assessment is also useful as to which ES are really dependent on the project or the location (e.g., flood prevention at a flood control area along the estuary river) and which ES could also be delivered elsewhere (e.g., fine dust capture by vegetation or food production). Lastly, making a full ES evaluation is rather impossible since knowledge gaps and data availability limit the inclusion of all effects.

Ecosystem services that are not included in the assessment of the Polders of Kruibeke are, for example, the contribution to the silica cycling, turbidity reduction in the River Scheldt (linked to primary production), nursery function and the contribution to the bird communities as feeding or resting areas.

Nevertheless, the ES evaluation is a useful tool to include external effects – as much as possible – in the decision-making process and can hence contribute towards more integrated maritime infrastructure project assessments.

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