ECOSYSTEM SERVICES

(ECOBE 016-R190)

IADC INTERNATIONAL ASSOCIATION OF DREDGING COMPANIES

Ecosystem Management Research Group (Ecobe)
University of Antwerp

Universiteit Antwerpen

SHORT SUMMARY

To enable the design of more sustainable dredging and marine infrastructure works and their efficient and safe implementation and realization in environmentally sensitive areas, the concept of ecosystem services has become increasingly important as a tool for integral evaluation of project effects (whether benefits or impacts) and achieving broad public support. Within an ecosystem service assessment, the main targets of the projects and a wide variety of additional effects on nature and society are identified, quantified and expressed in monetary terms. The main benefits addressed in the five cases in this study are flood protection, shipping opportunities and wind energy.

The cases Polders of Kruibeke and Sand engine are both good examples of designing for the main target (flood protection) with optimization of additional benefits (e.g. recreation, habitat development and biodiversity). Although the additional effects could be small compared to the main target, the sum of all of these effects could nevertheless become substantial (cfr. Polders of Kruibeke).

For the shipping related projects, Western Scheldt Container Terminal and Botany Bay port expansion, the design is dominated by the need to improve the harbour capacity and some nature enhancement work is added to compensate for damage. The Western Scheldt case clearly shows the problem of having a project on a location where compensation is impossible. This is related to the loss of Kaloot beach with its palaeontological importance. By identifying this problem in an early stage of the project, it can be used to foresee and even avoid this kind of problems by letting it be part of the decision about the location (avoid destruction of habitats that could not be replaced). In the case of Botany Bay, a trade-off was made in the habitat enhancement plan to convert mangroves and shrubland to the benefit of creating and improving shorebird habitat (marshes).
This trade-off is indeed beneficial in light of shorebirds, but is not necessarily beneficial when taking into account all ecosystem services (e.g. air quality regulation by removing high vegetation).

The aim of a broad ecosystem services assessment is to identify the consequences of such choices and be able to make a better balanced decision, taking into account the variety of stakeholders. Optimisation for shorebirds could be a valid goal of choice, but it is important to make such choices in a well-informed way. Taking an ecosystem services perspective will not always give a conclusive answer whether a project is overall beneficial or not (in case there are both positive and negative effects), but has an important added value by identifying all consequences and by putting them together in a single assessment.

The last example, the C-power wind farm, affects the least number of ecosystem services. This does not make an ecosystem service assessment less relevant. It identifies trade-offs between habitat types that are converted and habitat types that are created. An ecosystem service assessment cannot give the final answer if that is good or bad, but it is an information tool that can be used to guide project development in the earliest phases of conceptualisation and design.

CONTENT

1. INTRODUCTION

The ongoing need for navigation in the context of a still growing world population and global world trade as well as climate change challenges are major drivers of the dredging sector. Consequently, there is a permanent need for marine infrastructure projects due to growth and this is especially so for people living in low lying delta areas. However, nowadays, dredging companies are operating in an increasingly complex world – not only are projects getting more complicated from a technical point of view but there is also a growing environmental awareness amongst project proponents, legislators and dredging contractors. Companies are taking ownership of their responsibilities (environmental awareness in this case) by promoting the design and implementation of more sustainable solutions. However, developing and designing solutions alone is not good enough. To enable broad implementation and ensure effective realisation, these solutions should be widely accepted by clients, project financers and other stakeholders. To that end, the benefits of these solutions or approaches should be taken into account in the evaluation method that is being utilised. This is where the concept of ecosystem services (ES) comes into play.

To enable the design of more sustainable dredging and marine infrastructure works and their efficient, safe implementation and realisation in environmentally sensitive areas, the concept of ES has become increasingly important as a tool for integral evaluation of project effects (whether benefits or negative impacts) and achieving broad public support. The concept of ES aims at classifying, describing and assessing the value of natural resources and ecosystem services in terms of benefits for society, such as provision of food and other resources and air and water quality regulation. Though these benefits are always delivered, project stakeholders (including developers, financers, governments) do not always perceive them as a full "economic good". An ES assessment can provide quantifiable information and data that can be included in a traditional cost-benefit analysis of projects. Thus, monetary valuation of ES can be utilised to make a full environmental cost-benefit analysis and weigh the investment cost with not only technical profits, but also environmental and socio-economic benefits. An ES assessment also allows for a better comparison between project alternatives – not just scenarios that mitigate negative effects but also the ones that positively contribute to the environment – delivering ecosystem services. Furthermore, qualitative assessment can be done for ES when monetary valuation is not straightforward possible. In this way other considerations can be added to the evaluation such as habitat and biodiversity targets.

This report is not meant as a scientific study to improve the concept and methodology of ES nor is it a monetary quantification of distinct elements in the approach. Instead, the report explores the applicability of the methodology on a range of representative real-world marine works or projects. The intention of the report is not to revaluate projects that were realised or cancelled in the past. The objective of the report is to demonstrate the feasibility and applicability of this approach on a range of environments and marine infrastructure projects. Moreover, the report aims to highlight the successful application of the ES concept and not the importance or relevance of the results gained from it. In this way, the aim is to assess whether the concept of ES can facilitate (positive) evaluation of sustainable approaches towards marine infrastructure development on future projects in the field of dredging.

The report consists of nine chapters. The general concept of ES is introduced in Chapter 2, followed by general considerations on its use in the context of dredging projects in Chapter 3. Chapters 4-8 present the outcomes of ES application to five case studies in highly distinct environments. The case studies are: Wind farms at sea (C-Power) in Belgium; Botany Bay in Sydney, Australia; Western Scheldt Container Terminal and the Sand Engine in the Netherlands; and Polders of Kruibeke in Belgium. The presented results do not evaluate the projects but only assess the feasibility of the ES approach to gain a more integrated insight. The report concludes with general considerations on the governance of ES assessments and their applicability in dredging practice (chapter 9).

The target audience of this report consists of personnel within IADC member companies, particularly those who are in the position to further the ES concept within their own organisations. The report is meant to help them familiarise themselves with the concept and identify opportunities for sustainable development in different stages of project development. The report can also be used to inspire and streamline discussions with third parties involved with decision-making on marine infrastructure projects.

The report was written by authors, Annelies Boerema, Katrien Van der Biest and Patrick Meire of the Ecosystem Management Research Group (ECOBE), University of Antwerp. An expert group consisting of Stefan Aarninkhof (Boskalis), Sander Dekker (Van Oord), Marc Huygens (DEME), Marcel van Parys (Jan De Nul) and Elisabeth Ruijgrok (Witteveen+Bos, a specialist in ES) was actively involved throughout the study to provide input on case studies, discuss intermediate results and maintain close links to daily practice. The study was commissioned by the International Association of Dredging Companies (IADC).

2. THE ECOSYSTEM SERVICES FRAMEWORK

2.1 BACKGROUND

Ecosystem services (ES) are the benefits that humans derive from nature (MEA 2005, TEEB 2010). The ecosystem services framework forms the bridge between ecosystems and human wellbeing (socio-cultural context) (Figure 1). This shows how humans depend on ecosystems and ecosystem services explain the relationships. There are different types of ecosystem services with different benefits for human well-being (e.g. security, basic material for good life, health, good social relations) (Figure 2): 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. This framework helps to analyze the impacts humans have on ecosystems and the feed-back effects these changes have for the ecosystem benefits to humans. Furthermore, the benefits could be translated in monetary terms which stresses the link between ecology and economy.

FIGURE 1.

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

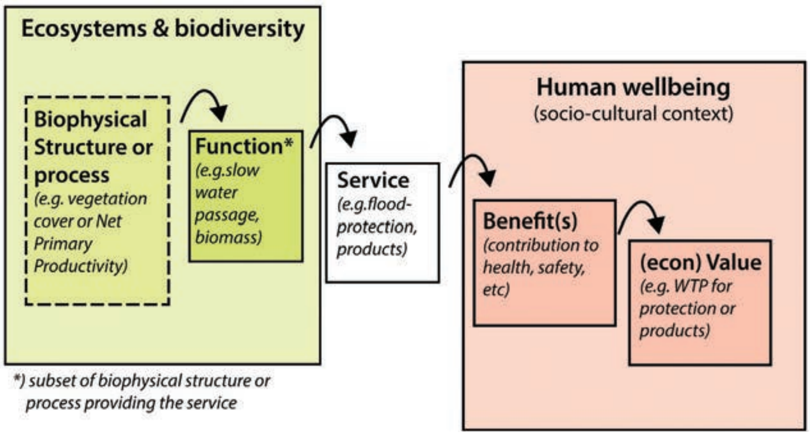
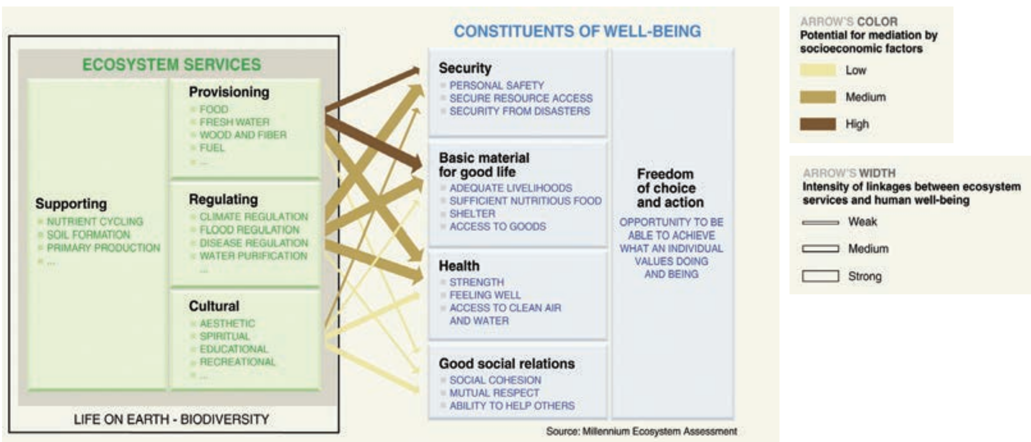


FIGURE 2.

Link between ecosystem services and human well-being (MEA 2005).



2.2 GLOBAL APPLICATION

In the last decade, the ecosystem services concept started to find its way in important international programmes. The ecosystem services concept is integrated in the EU Biodiversity Strategy for 2020 (EC 2011). Action 5 under target 2: "Member States, with the assistance of the Commission, will map and assess the state of ecosystems and their services in their national territory by 2014, assess the economic value of such services, and promote the integration of these values into accounting and reporting systems at EU and national level by 2020". Ecosystem goods and services are also included in the Marine Strategy Framework Directive: "By applying an ecosystem-based approach to the management of human activities while enabling a sustainable use of marine goods and services, priority should be given to achieving or maintaining good environmental status in the Community's marine environment, to continuing its protection and preservation, and to preventing subsequent deterioration."

Also at a global level the concept of ecosystem services is finding its way in important programmes. It is recognised that healthy and sustainable ecosystems are critical for the Millennium Development Goals since they are the ultimate source of natural resources which represent the essential ingredients for human survival, and the 'fuel' and building blocks for human well-being and economic development (MEA 2005, UNEP 2009). Furthermore, the use and restoration of ecosystem services is being recognised by the UN-Water to be "an effective and cost-saving alternative to conventional infrastructure as a solution to water resources management and pollution control" (UN-Water 2014, p.32).

One of the key messages in the Blue Planet synthesis paper from the Millennium Alliance for Humanity and Biosphere (MAHB) also underpins the importance of ecosystem services (MAHB 2012): "Biodiversity has essential social, economic, cultural, spiritual and scientific values and its protection is hugely important for human survival. […] Measures to conserve biodiversity and make a sustainable society possible need to be greatly enhanced and integrated with social, political and economic concerns. There is a need to value biodiversity and ecosystem services and create markets that can appropriate the value for these services as a basis for a 'green' economy" (MAHB, 2012, p.2).

At industry and company level, more attention and effort goes towards the sustainability of their activities, since "all businesses affect ecosystems and rely on the critical provisioning services (freshwater, fiber, food) and regulatory services (climate regulation, flood control, water purification, waste treatment) they provide" (WBCSD 2016). The World Business Council for Sustainable Development (WBCSD) demonstrated in a report several case studies of how business is already responding to the biodiversity challenge (WBCSD 2012). Specifically for the dredging sector, several reports are published to raise awareness about and show good practices related to biodiversity and ecosystem services. Some examples: "Dredging: the environmental facts" (PIANC 2005), "Working with nature" (PIANC 2011), "Ecosystem Services and Dredging and Marine Construction" (CEDA 2013), "Facts about ecosystem services and dredging" (IADC 2013).

3. ECOSYSTEM SERVICES IN THE DREDGING INDUSTRY

Five case-studies from the dredging industry are presented to illustrate how to apply the ecosystem services assessment. These cases give an overview of the diverse activities in the dredging industry: offshore wind power (1. C-power wind farm), container terminal (2. Botany Bay; 3. Western Scheldt Container terminal -WCT), large sand suppletion (4. Sand engine) and tidal marsh restoration (5. Polders of Kruibeke). The main targets of the studied projects are wind energy (C-power wind farm), increasing the harbour capacity to benefit more from the navigation function of the estuary (Botany Bay and Western Scheldt Container Terminal), and flood safety (Sand engine and Polders of Kruibeke). In this study we assess whether the projects generate other ES benefits besides the main target. The aim of this report is to illustrate that these type of projects generate effects on many ecosystem services (apart from the main project target). Depending on the available data, also the calculation of these effects (in biophysical and monetary terms) are illustrated which could be used to include in a cost-benefit benefit analysis. However, making a full cost-benefit analysis for the example projects is not the aim of this report.

The ES assessment is conducted following four steps (Table 1). In step 1 the different habitat types that are affected by the project are identified. Only habitat types that are relevant for the five case studies are included in this report. These habitats range from offshore over shore and estuarine to terrestrial habitats (Table 2). It is important to note that this list of habitats is not exhaustive, but only includes the habitat types that are relevant for the five case studies. In step 2 all ecosystem services delivered by those habitat types are identified and the relevant ES for the specific project selected (Table 2). Each ES as well as the underlying mechanisms driving the delivery are described (step 3). Finally in step 4, all ecosystem services are assessed first in a qualitative review and a quantitative and monetary assessment is added as much as possible depending on available data.

The assessment consists always of the comparison of alternatives: either comparing the situation with or without a project, or the comparison of other scenarios (e.g. case Polders of Kruibeke in chapter 8). For the quantitative assessment, each service has its own unit which is most relevant for that service. Carbon sequestration, for example, is expressed in tons of carbon per hectare per year; wood production is expressed in m³ wood volume increase per hectare per year. For the monetary valuation, each of the quantitative units is translated into € per hectare per year to form a basis for comparison of scenarios.

TABLE 1.

ES assessment in four steps.

Step 1	Changes in habitat and land use (before vs after)
Step 2	ES analysis per habitat • International literature: to select potential ES • Project specific (EIA): to select relevant ES
Step 3	Description of relevant ES (incl. biodiversity) and mechanisms driving the delivery
Step 4	Qualitative, quantitative and/or monetary assessment (depending on available data) • Comparison: with or without project, or other scenarios

The methodologies used to quantify and value the different ecosystem services are summarised in Table 3 and explained in more detail in this chapter. For the quantification, methods differ between offshore systems, intertidal systems and terrestrial systems due to differences in processes that are relevant for ES delivery (e.g. sedimentation in intertidal systems or groundwater in terrestrial systems).

BIOPHYSICAL MODELLING

For terrestrial systems, more advanced biophysical methods are being developed. These are demonstrated for the case Polders in Kruibeke (chapter 8). The biophysical models take into account the multiple biotic and abiotic parameters that affect ecosystem service delivery and potential interactions between different parameters. All of the data is made spatially explicit (in a GIS-environment Geographical Information Systems) and the results can be visualized in maps. In other words, for each area (in the form of a grid cell of 5x5m) a calculation is made for the delivery of each service, based on the parameters characteristic for that area. We provide here a short overview of all of the input parameters needed to assess the different services (applied for the case Polders in Kruibeke, chapter 8):

- **Land use:**
  Land use maps are designed for each scenario (see section 8.2.1 Scenarios, Figure 34). Most common land uses are cropland, pasture, marsh forest (existing, compensation) and tidal area (mudflat, low marsh, high marsh).
  Source: Integraal Plan version 3 (INBO)

- **Soil texture and soil profile development:**
  Soil texture and profile development are derived from the soil map of Flanders (AGIV, 2001).

- **Groundwater depth (cm):**
  The depth of the groundwater table plays a determining role for many of the regulating ecosystem services. In the former agriculture dominated polder, groundwater levels were intensively regulated by a pumping station which farmers used to drain excessive water from the area and increase crop production. The pumping station has only recently (2012) stopped working. The data on groundwater levels available from piezometers installed by INBO date from before 2011 and cannot be used to create maps of the groundwater levels in the present situation. As an alternative, we used the groundwater maps (mean highest and mean lowest groundwater table) that have been developed in the ECOPLAN project (Staes 2015) for the entire region of Flanders. The maps are available on a resolution of 5x5m and are calculated based on a GIS-model that takes into account elevation and relief (digital elevation model of Flanders 2011), the drainage class defined by the soil map of Flanders, the presence of drainage ditches and effects of groundwater abstraction (in case this occurs in the area). For more detailed information on this model we refer to Staes et al. (2014).

- **Digital elevation model (cm TAW):**
  The digital elevation model (AGIV 2011) is used to derive several other parameters that influence ecosystem service delivery:

  o Groundwater depth (see above)
  o Groundwater supply (see Box 1 - Denitrification)
  o Denitrification degree (see Box 1 - Denitrification)

- **Nitrate concentration in groundwater (mg/l):**
  The total amount of nitrate in the groundwater is modelled using information on the amount of leakage of N from agricultural fields (Coppens et al. 2007) and on soil infiltration capacity (Staes et al. 2014).

TABLE 2.

Description of the different habitat types impacted by at least one of the dredging case-studies. Identification of ecosystem services potentially delivered by the different habitat types. Five cases: C (C-power); B: Botany Bay; W (Western Scheldt container terminal); S (Sand engine); K (Kruibeke).

			Cases					Provisioning					Regulating					Cultural			Biodiversity
Category	**Habitat type**	**Description**	1 C-power C	2 Botany Bay B	3 WCT W	4Sand engine S	5 Kruibeke K	Fish production	Agricultural production	Wood production	Water production for potable water	Water provisioning for transportation	Climate regulation	Water quality regulation	Air quality regulation	Flood protection	Sedimentation and erosion regulation	Recreation	Heritage	Cognitive development	Biodiversity
Offshore	Shallow, soft substrate	soft substrate of shallow offshore waters (~6 to 10m below sea level); e.g. sand banks	X		X	X		C,W						C,W			W	W			C,W
Offshore	Open water	water column in the entire offshore zone	X					C										C			C
Shore	Foreshore	seaward extension of beach, subtidal zone between low water mark and depth at which seafloor is no longer stirred by waves		X		X		B						S						S	S
Shore	Beach	between low tide and springtide				X					S					S			S	S	S
Shore	Lagoon, bay	water body along the shoreline, separated from the sea by a barrier, connected to the sea by restricted inlets; e.g. lagoon of the sand engine between the sand suppletion and the beach		X		X		B,S					B,S	B,S		B		B,S		S	B,S
Shore	Sea grass	submerged aquatic vegetation in shallow zones		X				B					B	B		B	B				B
Shore	Mangroves	inundated forest area		X				B		B			B	B	B	B					B
Estuary	Subtidal deep habitat	>5m beneath mean low water (MLW); e.g. gully			X			W					W				W				W
Estuary	Subtidal moderately deep habitat	between 2m and 5m beneath mean low water (MLW)																			
Estuary	Subtidal shallow habitat	between mean low water (MLW) and 2m beneath MLW			X			W													W
Estuary	Bare tidal flat	between mean high water (MHW) and mean low water (MLW)		X	X		X	B					B,W,K	B,W,K	K	K	B,W,K	W,K	W		B,W,K
Estuary	Low tidal marsh	above mean high water (MHW); e.g pioneer vegetation		X	X		X		K				B,K	B,K	B,K	K	B,K	B,K			B,K
Estuary	High tidal marsh	e.g. willow shrub		X			X		K				B,K	B,K	B,K	K	B,K	B,K			B,K
Fresh	Freshwater rivers	Creeks that flow into Penrhyn Estuary (Botany Bay)		X				B													
Hard substrate	Artificial reefs at all depth	concrete, manmade structures; e.g. quay wall, groynes, dikes, jetty	X	X	X			C,B	W			W	W	C,B,W	W	W	W	C,W	B,W		C,W
Terrestrial	Dunes	Above springtide along sandy shores		X	X	X					S		B	B	B	B,S	W	B,S	B	S	W,S
Terrestrial	Dune lake	water body in sandy sediments close to the sea but without connection to the sea, rain or groundwater fed				X														S	S
Terrestrial	Cropland	corn, vegetables, …					X		K				K	K	K	K		K			K
Terrestrial	Grassland	natural grassland, pasture			X		X		K				W,K	W,K	K	K	W	K			K
Terrestrial	Forest	coniferous, deciduous, marsh forest					X			K			K	K	K	K		K			K
Terrestrial	Wetland	e.g. reed			X		X	W	K				W,K	W,K	W,K	K	W	K			W,K

TABLE 3.

Short overview of the methods used for the quantitative and monetary valuation of the studied ecosystem services.

ES	Quantitative assessment			Monetary value (€)
	Offshore habitats	Shore and intertidal system (marsh, mudflat)	Terrestrial system	
Fish production	Biomass production	Biomass production	/	/
Agricultural production	/	/	Expected production losses based on soil suitability. Unit: € Unit	Average agricultural value for cropland and for pastures in Flanders. Unit: €/ha/y
Wood production	/	Meta-analysis for mangrove forests. Unit: kg/ha/y or m³/ha/y	Expected productivity rates per tree species based on soil suitability. Unit: m³/ha/y	Species-specific market prices (Flanders). Unit: €/m³
Water production	/	/	Literature estimate sand engine. Unit: m³/y	Avoided costs related to drought; groundwater abstraction tax (Flanders). Unit: €/m³
Water provision for transportation	Changes in tonne-km	/	/	€/tonne-km
Climate regulation	Literature estimate for North Sea continental shelf. Unit: $tonCO_2$- equivalent/ha/y	Annual sedimentation volume stored × particulate organic carbon content Correction for GHG emissions (CO_2, CH_4, N_2O)[(1)]. Or data from international literature. Unit: $tonCO_2$- equivalent[(2)]/ha/y	Regression model which predicts SOC storage based on soil texture, soil moisture content and land use. Unit: $tonCO_2$- equivalent/ha/y	Avoided reduction cost for emission reduction measures (meta-analysis). Unit: €/$tonCO_2$-equivalent
	[(1)] GHG: CO_2 equivalents/m^2/yr using the ratio 1:25:298 for CO_2:CH_4:N_2O [(2)] 1 ton C = 3.66 ton CO_2-equivalent			
Water quality regulation: denitrification	Literature estimate for North Sea continental shelf. Unit: kg(N)/ha/y	Estimates from other tidal marshes. Unit: kg(N)/ha/y	Maximum denitrification rate under given abiotic soil conditions with the actual supply of nitrogen through groundwater flow and atmospheric deposition. Unit: kg(N)/ha/y	Shadow price for nitrogen. Unit: €/kg(N)
Water quality regulation: N storage	Literature estimate for North Sea continental shelf. Unit: kg(N)/ha/y	Annual sedimentation volume stored × particulate nitrogen content. Unit: kg(N)/ha/y	/	Shadow price for nitrogen. Unit: €/kg(N)
Water quality regulation: P storage	Literature estimate for North Sea continental shelf. Unit: kg(P)/ha/y	Annual sedimentation volume stored × total phosphorous content. Unit: kg(P)/ha/y	/	Shadow price for nitrogen. Unit: €/kg(P)
Air quality regulation	/	Estimate fine dust capture per small/high vegetation. Unit: kg(PM10)/ha/y	Estimate fine dust capture per small/high vegetation. Unit: kg(PM10)/ha/y	Avoided damage to human health. Unit: €/kg(PM10)
Flood protection	Safety benefit from reduced flood damage. Unit: €	Safety benefit from reduced flood damage. Unit: €	Safety benefit from reduced flood damage. Unit: €	Safety benefit from reduced flood damage. Unit: €
Sedimentation and erosion regulation	/	Monitoring data on sediment deposition or erosion before and after the project. or, data from similar habitat types. Unit: m/ha/y	/	/
Recreation	Change in number of visitors	Change in number of visitors	Change in number of visitors	Visitor spends during their visit
Heritage	Presence of items that are part of the cultural heritage	Presence of items that are part of the cultural heritage	Presence of items that are part of the cultural heritage	/
Cognitive development	Number of scientific publications	Number of scientific publications	Number of scientific publications	Shadow price for investment in research. Unit: €
Biodiversity	Biomass and number of species	Biomass and number of species	Biomass and number of species	/

BOX 1.

Modelling denitrification in terrestrial habitats.

Actual denitrification is difficult to quantify and map on the landscape scale as it is strongly variable in space and time. Denitrification depends on many factors such as temperature, soil moisture, carbon supply, structural variation, hydraulic residence time, surface area, temperature and nutrient supply.
To make an estimate of denitrification we compared the maximum denitrification rate under given abiotic soil conditions (1) with the actual supply of nitrogen through groundwater flow and atmospheric deposition (2).

(1) The potentially maximum denitrification rate is calculated based on groundwater level and rate of groundwater supply. Denitrification in soils only occurs when the soil is more than 60% water saturated. High groundwater levels inhibit oxygen diffusion in the soil and thus create a gradient between oxygen poor (groundwater) and oxygen rich (air) conditions. The rate of groundwater supply determines how much nitrogen can potentially enter the denitrification zone. Groundwater velocity is higher in slightly inclined permeable soils (e.g. sand) than in plane, non-permeable areas (e.g. clay), thus increasing the supply of nitrogen rich groundwater.

(2) Denitrification only occurs when a source of nitrogen is available, either through the supply of nitrogen-rich groundwater (leakage of excessive nutrients from agricultural fields), and/or through atmospheric deposition. The amount of nitrogen that leaks from an agricultural field to groundwater reserves is calculated based on the nitrogen residue that remains on the field after harvest. This depends on the total amount of fertilizer used per crop type (Flemish manure standards), the total amount of atmospheric deposition (VMM, 2012) and soil texture (leakage to groundwater is higher in more permeable soils such as sand compared to less permeable soils such as loam and clay). The estimation of N leakage from fertilizer is based on the results of Coppens et al. (2007) and the fertilizer norms of the Flemish government (VLM mestbank aangifte 2011). The amount of N deposited in non-agricultural areas is calculated based on the results from VLOPS-model (VMM, 2012). From the results of Coppens et al. (2007) it can be derived that leakage of N to groundwater varies between 7 and 33% of the total N-input. For soils with a high sensitivity to leakage (Ecodistricten studie 2002), N leakage is assumed 33% of atmospheric deposition, for soils with low sensitivity to leakage this is 7%. Finally, the total amount of N in groundwater is calculated within a radius of 2 km.

3.1 PROVISIONING ECOSYSTEM SERVICES

3.1.1 FISH PRODUCTION

Fish production is directly related to the amount of fish available from open water, from the sea floor (crab, shrimp, flatfish, …) or from hard substrata present in the sea, estuary, harbor (oyster, mussel, …). The potential for fish production is indirectly regulated by several other ecosystem functions and services such as the amount of food available for fish to feed on, or else biomass production, water quality regulation, nursery function and biodiversity. Fish production also depends, besides the availability of fish, on the capability of catching fish. If fish stocks are out of reach or if catch restrictions or no-fishing zones are imposed, such as in wind farm concession areas, fish production may decrease in case no alternative qualitative fishing grounds are available. Catch restrictions however may also have positive effects on fish production if fish are not restricted to the no-fishing zone. The reduced disturbance of benthic habitats also positively influences production and biomass as stirred up sediments result in increased mortality of benthic species.

On the other hand, sand extraction temporarily enriches the water column with organic matter and may attract suspension-feeders, omnivorous, and/or scavenging species and also fish such as common sole, black seabream, and cod (Marchal et al. 2014). Biodiversity in itself is also positively influenced as vulnerable species are not disturbed by trawling. Both mechanisms strengthen the food chain for fish.

The impact of dredging projects on fish production can be assessed in different ways depending on the availability of data. In the ideal situation, research is carried out to quantify annual fish catch as a result of dredging projects. Such research would require monitoring on medium to long term as fish stock and catch rates may take a while to stabilize. Fish populations and catch rates can also be influenced by many other events, e.g. pollution incidents, changes in quota, etc. In reality it will therefore be very complex to quantify the impact of the project. Alternatively, the expected trend can be predicted based on changes in total surface area of feeding grounds and related biomass production (e.g. mussel production on concrete walls in the harbor; WCT), or changes in biomass of fish (C-power wind farm). Data from a meta-analysis on mangrove forests is summarized in Table 4.

TABLE 4.
Data for the fish production in mangrove forests (Salem and Mercer, 2012).

Habitat	Production (kg/ha/y)		Economic value (US$/ha/y)
	Fish, shellfish, molluscs	Shrimps	
Mangrove forests	Mean: 539 Range: 10-2,500	Mean: 146 Range: 6-349	Mean: 23,613 Range: 10 – 555,168

3.1.2 AGRICULTURAL PRODUCTION

Agricultural production (not fish) depends on biophysical suitability of the soil and land use. Four different types of agricultural land use are accounted for: conventional cropland (with use of fertilizers, herbicides and pesticides), conventional grassland (intensively grazed pastures – 5 head/ha – with use of fertilizers, herbicides and pesticides), grassland with extensive grazing (such as grazing to maintain dikes – 2 head/ha – without input of additional fertilizers, herbicides and pesticides is allowed) and natural grassland with very extensive grazing (pastures in areas with nature protection where no input of additional fertilizers, herbicides and pesticides is allowed – 0.5 head/ha). This allows us to take into account the different intensities of agricultural production. Based on recent data on agricultural productivity in Flanders, we derived the potential productivity of conventional cropland and grassland (expected value, expressed in €/ha/year, and standard deviation) (Van Broekhoven et al., 2012), Table 5.

TABLE 5.

Estimated potential maximum productivity (given optimal soil conditions) for different types of agricultural land use.

Agricultural land use type	Potential maximum productivity (€/ha/year)
Conventional cropland	2,500 – 3,000
Conventional grassland	2,000 – 2,500
Grassland, extensive grazing	1,000 – 1,500
Natural grassland, very extensive grazing	500 – 1,000

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; Wint and Robinson 2014) and taking into account a higher meat price for organic meat compared to regular meat.

Biophysical suitability for agriculture depends on soil type, soil moisture content and profile development. Agricultural productivity is highest under most optimal soil conditions (loamy, organic soils with average groundwater depth) and corresponds to the values given in Table 5. Productivity will be lower on less fertile soils (e.g. dry, sandy soils). 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). Five different classes of productivity loss are distinguished: 0-10% (highly fertile soils), 10-25%, 25-45%, 45-70% and 70-100% (low fertile soils).

3.1.3 WOOD PRODUCTION

Wood production depends on the 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 (Verheyen, unpublished data).

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. The harvest factors were derived from recent data on timber selling (2009-2012) and were set to 0.15 and 0.54 for private and state-owned forest, respectively. Production data from a meta-analysis on mangrove forests is summarized in Table 6. It is however not clear whether sustainable harvest is taken into account.

Monetary valuation: 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). This service appears in the case polders of Kruibeke for which the required details on soil type is available. Economic value data from a meta-analysis on mangrove forests is summarized in Table 6.

Monetary valuation: Different methods exist to value the production of potable water. The actual price consumers pay for per m³ of potable water is €1.6. This value however includes the costs of pumping up the water, additional purifying and distribution of the water, and is thus not representative for the actual value of the water. An alternative method uses the avoided costs for drinking water companies if insufficient groundwater can be extracted and needs to be compensated for by buying in water from, for example, neighboring regions. This cost is estimated to be 0.2 €/m³ in Flanders (Broekx et al. 2014). Another method is the revealed preferences method and uses the costs a company pays to sustain groundwater reserves. Companies can for example pay forest owners to convert coniferous forest, which have a much higher evapotranspiration rate, into deciduous forests (e.g. soda company Bionade in Germany). The costs companies actually pay vary between 0.05 €/m³ and 0.17 €/m³ (Broekx et al. 2014). Another method uses the taxes water companies pay for the abstraction of groundwater (0.075 €/m³) and can be seen as a compensation of the costs to comply with the criteria of the Water Framework Directive. In this study we use a minimum value of 0.075 €/m³ and a maximum value of 0.2 €/m³ (Broekx et al. 2014).

TABLE 6.
Data for the wood production in mangrove forests (Salem and Mercer, 2012).

Habitat	Production (kg/ha/y)		Economic value (US$/ha/y)
	Timber	Fuel wood and charcoal	
Mangrove forests	Mean: 5,976 Range: 289 – 13,300	Mean: 5,140 Range: 6 – 28,370	Mean: 38,115 Range: 18 - 1,287,701

3.1.4 FRESH WATER PRODUCTION

The delivery of clean potable water from natural ecosystems is regulated by water purification processes (see water quality regulation) and infiltration. Water production in coastal areas today is confined to the exploitation of the freshwater lens in dunes. Dunes are particularly suitable for groundwater abstraction as the very coarse sand allows for fast replenishment of the phreatic water reserve and water infiltrating through the sand is naturally purified. Additionally, dunes are very easily exploited. Dredging projects can have an impact on this service in different ways. First, the freshwater lens disappears together with the removal of dunes. Second, excavations in areas close to the dunes may reduce groundwater levels and thus total volume of available water within the dunes. When impermeable layers on which the freshwater lens rests are disrupted due to excavation works this may also lead to desiccation of existing water bodies in the dunes. Third, accretion of dunes and embryonic dune formation (e.g. sand engine) or erosion of dunes increase or decrease the total surface area of dunes and thus potentially the volume of the dune aquifer. The impact of projects on this service are assessed based on changes in the total surface area of dunes.

3.1.5 WATER PROVISIONING FOR TRANSPORTATION

Surface water bodies are used for transportation by ships. Capital and maintenance dredging aims to improve the navigation depth and width to improve its function for transportation (bigger ships, more tonne per km transport). Other

projects such as the building of a new container terminal are also related to this service. It increases the facility to gain more from the existing presence of the ecosystem service water provisioning for transportation.
For the quantification of this service, estimated changes in the number of ships, number of containers (TEU), tonnage of transported goods (tonne-km) could be used. For the monetary valuation five different types of costs can be estimated (Liekens et al. 2013): efficiency gains or losses (due to more or less tons/ships), time gains or losses due to faster or slower trajectories for shipping and or time required to enter the port, additional costs or benefits due to longer or shorter trajectories, modal shift benefits or costs if goods are transported by other modes of transportation being less or more expensive, environmental benefits or costs linked to shorter or longer trajectories and modal shifts, and costs of additional measures (e.g. dredging) to prevent the previous cost categories.
Indicative data on the cost to transport by road (0.14 €/ton-km), rail (0.09 €/ton-km), water (0.009 €/ton-km) and air (0.75 €/ton-km), illustrate that the cost advantage for shipping is very important (data for 2005) (Liekens et al. 2013).

3.2 REGULATING ECOSYSTEM SERVICES

3.2.1 CLIMATE REGULATION

The capacity of an ecosystem to regulate the climate is to a large extent determined by its capacity to store organic carbon, both in above and below ground biomass and in the soil. As only the soil component can be seen as permanent storage, we focus on this type of organic carbon storage (soil organic carbon or SOC). Climate regulation through carbon storage can be realized by burial of organic matter during sedimentation and by anoxic accumulation of organic matter in the soil. 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.

The average carbon burial in sediments on the North Sea shelf is 0.0019 ton C/ha/y (Thomas et al. 2005). We consider this value representative for burial in offshore habitats, as they constitute the largest part of the North Sea shelf. This value is negligible small to play a role in climate regulation (O'Higgins and Gilbert 2014), even with an increased biomass production as a side effect of artificial reefs (e.g. wind turbine foundations, quay wall). Carbon burial on the sea floor depends on primary production rates, export, resuspension and transfer to top trophic levels (Mangi et al. 2013). The North Sea is characterized by a low density of phytoplankton and absence of seaweeds (Beaumont et al. 2007). Most of the primary production is recycled within the system (Liquete et al. 2013), as is the case for similar soft substrate habitats without subaquatic vegetation in other marine areas outside of the North Sea. This explains the low amount of carbon burial in offshore habitats in the North Sea.

For seagrasses an average value of 138 gC/m²/y (= 1.38 tonC/ha/y = 5 ton CO2-eq./ha/y) was found (Duarte et al. 2013).
For mangroves, several numbers on carbon burial are found in literature indicating the high variability depending on local conditions. Average values indicate a range from 0.83 to 3 tonC/ha/y (Alongi et al. 2001; Bouillon et al. 2008; McLeod et al. 2011; Lee et al. 2014). The meta-analysis of Salem and Mercer (2012) revealed a range from 0.02 to 90.5 tonC/ha/y. The first, lower, range is applied in this report.

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 CO2-eq./ha/y) can be calculated based on sedimentation volume (i.e. annual sedimentation rate in m/y, bulk density in g/m³, area unit m²/ha), particulate organic carbon content (i.e. suspended particulate matter in g/L, particulate organic carbon in the river in mol/L, molar mass of carbon in g/mol). An example of this calculation can be found in the case Polders of Kruibeke (chapter 8). When data is not available to make this calculation, data presented in Table 7 could be used.

For C burial in lagoons, a similar calculation can be performed. Since the only case in this project where a lagoon is found is the sand engine, we use parameter values from the North Sea (based on IDOD database for the Belgian part of the North Sea, MUMM 2015): bulk density 1.37 g/cm³, C concentration 1.84%. The average sedimentation rate in the lagoon is calculated based on the change of the dimension of the lagoon from 2011 to 2031 (17 to 8 ha) and the average depth (0.4 – 1.7m, van der Moolen et al. 2015): 2.8 cm/y. The burial of C is calculated as follows:

$(0.028 \text{ m/y} \times 10000 \text{ m}^2 \times 1370 \text{ kg/m}^3) \times 0.0184 = 7.06 \text{ tonC/ha/y}$.

Marshes and mudflats are furthermore characterized by important amounts of greenhouse gas emissions (CO_2, CH_4 and N_2O). These were taken into account by subtracting it from the estimated amount of burial. Data measured in the intertidal sediment at Doel (close to the polders of Kruibeke) was used (Middelburg et al. 1995a,b): 7 - 11 ton CO_2-eq. ha^{-1} y^{-1} for CO_2, 18 - 51 ton CO_2-eq. ha^{-1} y^{-1} for CH_4, 0.87 ton CO_2-eq. ha^{-1} y^{-1} for N_2O.

To model terrestrial SOC sequestration by accumulation of plant material, we based ourselves on the method applied in Evaluation of the benefits of NATURA2000 (Broekx et al. 2014). Although many mechanistic SOC models have been developed in the past (Skjemstad et al., 2004; Byun and Schere, 2006), their extensive data requirements makes them only applicable in small, field scale studies. To obtain a regionally applicable model, SOC sequestration by accumulation of plant material is based on an empirical study on SOC storage conducted in Flanders (Meersmans et al., 2011). In this study, a regression model has been developed which predicts SOC storage 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 we refer to Meersmans et al. 2011. This modelling method is applied for the case Polders of Kruibeke. When data is not available to apply this model, numbers given in Table 7 could be used.

Monetary valuation: 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 (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). A monetary value of 220 €/ton C or 60 €/ton CO_2-equivalent was used to calculate the economic value of carbon sequestration (Mint and Rebel 2013). This is the same value as used in the Environmental Cost-Benefit Analysis of the WCT project: 59.96 €/ton CO_2 (Ecorys 2006a).

TABLE 7.

Summary data carbon sequestration in different habitat types, in tonC/ha/y and tonCO2-equivalent/ha/y (1 ton C = 3.66 ton CO2-equivalent).

Habitat		Carbon sequestration (tonC/ha/y)	ton CO_2-eq./ha/y
Offshore	Shallow, soft substrate	0.0019	0.007
Shore	Lagoon	7.06	25.6
	Seagrass	1.38	5
	Mangroves	0.83 - 3	3-11
Estuary	Subtidal deep habitat	0.07	0.3
	Tidal flat (1)	0.55-2.46	2-9
	Marsh (1)	0.55-2.46	2-9
Terrestrial	Dunes -unvegetated	0	0
	Dunes -vegetated	0.90	3.3
	Grassland (2)	2	7.3
	Wetland, reed, shrub (2)	6.80	25

(1) References: Middelburg et al. 1995, Soresma et al. 2007, Böhnke-Henrichs and de Groot 2010, Mcleod et al. 2011, Adams et al. 2012, Duarte et al. 2013
(2) Reference: Ruijgrok et al. 2006b

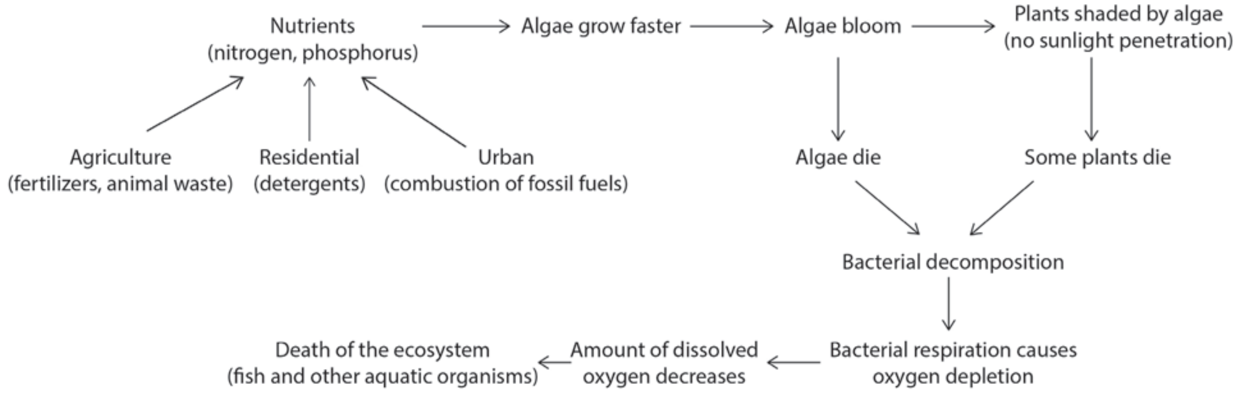
3.2.2 WATER QUALITY REGULATION

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 (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 ecosystem service delivery such as fish production, an excessive supply leads to eutrophication (Figure 3) 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).

FIGURE 3.

Causes and consequences of eutrophication in marine ecosystems (www.marbef.org).



A healthy marine ecosystem requires that there is 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.

Among 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 and prevention of fish mortality and decrease in recreational amenity value.

We only take into account the benefits from denitrification and nutrient burial (nitrogen and phosphorous) as these processes have long-term storage capacities. Removal by transfer to higher trophic levels is temporary, except if biomass is harvested (e.g. through fishing), and is therefore not considered in this research.

Denitrification (Den)

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 ecosystem service 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 and anoxic waters. Denitrification is thus rather marginally influenced by vegetation.

Based on a review by Brion et al. (2004), the average annual denitrification rate of the sediments in the southern part of the North Sea (offshore habitats) is 21.9 kg N/ha.y-1 (Table 8). Bivalves are known to have important effects on water quality by removal of excessive nutrients. They are so-called filter-feeders that feed themselves by straining suspended matter and food particles from water using a specialized filtering structure over which water passes. The nutrients they use for the growth of their shells can be accumulated for years, decades or even centuries when the shells get buried (Waldbusser et al. 2011). They grow both on soft and hard substrate. Bivalves growing in reefs furthermore increase denitrification as the physical structure of a reef provides numerous microhabitats that facilitate the processes of nitrification and denitrification (Kellogg et al. 2013). Kellogg et al. (2013) found that oyster reefs (consisting of oysters and mussels) at ~4m depth in Chesapeake bay (USA) remove on average 610 kg N/ha.y-1 by denitrification. Piehler and Smyth (2011) and Smyth (2013) found an average denitrification rate of ~114 kg N/ha.y-1 and ~57 kg N/ha.y-1, respectively, in estuarine oyster reefs. In this research, the average of the values of the different studies is used (Table 8).

Lagoons with benthic macrofauna (such as shrimps, burrowing worms, …) have been reported to remove on average 61.32 kg N/ha/y (Eyre et al. 2011). Similar results are found for denitrification in shallow parts of coastal bays in the German Wadden Sea, where an average removal of 63.16 kg N/ha/y was measured (Deek et al. 2012).

The role that sea grasses in temperate habitats play in denitrification is less clear. Several studies indicate low denitrification rates (review by McGlathery et al. 2007) while others show results comparable with that of oyster reefs (Smyth 2013). Smyth (2013) found a value of 104.9 kg N/ha/y, while the average rate of removal from the different studies in McGlathery et al. (2007) is 10.6 kg N/ha/y. Here, we use the average of the values from the different literature studies, 29.45 kg N/ha/y.

For mangroves, no useful data was found (not in kgN/ha/y).

Fouling communities of the subtidal zone consisting of amphipods, polyps, anemones, echinoderms, … are expected to have much lower denitrification rates as they do not form reefs with microhabitats. Due to the lack of literature we used the lowest estimate of denitrification (shallow substrate).

For denitrification in estuaries (Table 8), we used data from the Scheldt estuary. Middelburg et al. (1995) found a range between 0 and 437 kg(N)/ha/y with an average value of 140 kg(N)/ha/y at Doel. This range includes frequently and occasionally flooded areas, with denitrification being higher in frequently inundated zones and hence in frequently alterating oxic/anoxic conditions. For fresh water marshes Broekx et al. (2011) apply a value of 176 kg(N)/ha/y and for salt water marshes 107 kg(N)/ha/y. For brackish marshes, the average value of salt and fresh water (140 kg(N)/ha/y) is applied. For the more frequently inundated mudflats a conservative value of 200 kg(N)/ha/y was used.

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 nitrate through fertilizing compared to the concentration of nitrates in the Scheldt water. 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 by subtracting it from the removal by denitrification. In Flanders, roughly half of the total amount of nitrate fertilizer is allowed to be of animal origin (VLM Manuring Standards 2014). In case the fertilizer is synthetic, denitrification on the field where the fertilizer is applied cannot be accounted for as a benefit. The total amount of synthetic nitrates that is not taken up by the crop and that stays on the field after harvest to be either denitrified or leaking to water reserves (nitrate residue), needs to be subtracted from the denitrification. In case the fertilizer is of animal origin, denitrification provides a service of waste treatment because the manure does not need to be processed industrially. The amount of nutrients of animal origin that is not denitrified and leaks to water reserves however needs to be corrected for as it causes additional costs for water treatment. The total amount of denitrification on the field thus needs to be reduced by the total nitrate leakage and by the synthetic half of the denitrified nitrate (difference between N residue and N leakage divided by 2). Calculations for denitrification in agricultural environments are based on the assumption that farmers consume the maximum allowed
fertilization standard (VLM 2014) and that half of the fertilizer is from animal origin.
For the input data on leakage from agricultural fields, three different types of agricultural land use were considered, that is conventional grassland, conventional cropland (assumed to be corn, which was the most dominant former crop grown in the area (case Polders of Kruibeke)) and natural grassland. This distinction allows to take into account the different manure standards as defined by the Flemish government (VLM 2014) and thus the different amounts of leakage to groundwater reserves. For natural grasslands, the manure standards are restricted to a total of 2 head per ha and no additional application of fertilizers. Since natural grasslands are grasslands lying in areas with nature protection status, it is assumed that the total leakage of nitrates to groundwater is 0.
For more detailed information on the modelling methodology applied for terrestrial habitats we refer to Box 1.

Monetary valuation: 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 (other) technical investments. A monetary value of 40 €/kg(N) was used, this is the average from the range found in literature (5 – 74 €/kg(N), Liekens et al. 2012).

Nitrogen burial

Based on a review by Brion et al. (2004), the average annual burial of N in the soft sediments in the southern part of the North Sea (offshore habitats) is 0.7-0.8 kg N/ha.y-1 (Table 8). Kellogg et al. (2013) found that oyster reefs at ~4m depth in Chesapeake bay (USA) assimilate on average 950 kg N/ha.y-1, of which 47% is used for the construction of their shell and can be accounted for as long term storage (Table 8).
The biomass produced in the subtidal zone contributes to organic enrichment of the sediments on the sea floor as a result of the deposition of (pseudo)faeces and other organic material. No information was found on this so the minimum estimate of nitrogen burial on

shallow, soft substrate was used as reference. Nitrogen burial in estuaries was calculated by taking into account the annual sedimentation volume (i.e. annual sedimentation rate in m/y, bulk density in g/m³, area unit m²/ha) and the particulate nitrogen content (i.e. suspended particulate matter in g/L, particulate nitrogen in the river in mol/L, molar mass of nitrogen in g/mol). This calculation is similar as for the carbon burial. An example of this calculation can be found in the case Polders of Kruibeke (Chapter 8).
For N burial in lagoons, a similar calculation can be performed. Average N concentration in the North Sea is 0.31% (MUMM 2015). N burial is calculated as follows:
(0.028 m/y x 10000 m² x 1370 kg/m³) x 0.0031
Nitrogen burial in sea grass is estimated at 134 kgN/ha/y (Gacia et al. 2002)

When data is not available to make calculations, data presented in Table 8 could be applied.

Monetary valuation: idem as for denitrification.

Phosphorous burial

Based on a review by Brion et al. (2004), the average annual burial of P of the soft sediments in the southern part of the North Sea (offshore habitats) is 0.03-0.07 kg P/ha.y-1. Kellogg et al. (2013) found that oyster reefs at ~4m depth in Chesapeake bay (USA) assimilate on average 150 kg P/ha.y-1 , of which 48% is used for the construction of their shell and can be accounted for as long term storage (Table 8).
The biomass produced in the subtidal zone contributes to organic enrichment of the sediments on the sea floor as a result of the deposition of (pseudo)faeces and other organic material. No information was found on this so the minimum estimate of phosphate burial on shallow, soft substrate was used as reference. The calculation of phosphorous burial in estuaries is equal to carbon and nitrogen burial: the annual sedimentation volume (i.e. annual sedimentation rate in m/y, bulk density in g/m³, area unit m²/ha) multiplied with the total phosphorous content (i.e. suspended particulate matter in mg/L, total phosphorous in the river in mg/L). We do not take into consideration that in the first years (after converting agricultural land into the flood control area), phosphorous is being released instead of buried (based on field measurements in the pilot project Lippenbroek). An example of this calculation can be found in the case Polders of Kruibeke (Chapter 0).
For P burial in lagoons, a similar calculation can be performed. Average P concentration in the North Sea is 0.02%. P burial is calculated as follows:
(0.028 m/y x 10000 m² x 1370 kg/m³) x 0.0002
Phosphorous burial in seagrass is estimated at 20.1 kgP/ha/y (Gacia et al. 2002).

When data is not available to make this calculation, data presented in Table 8 could be applied.

Monetary valuation: 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 (other) technical investments. A monetary value of 55 €/kg(P) was used, this is the average from the range found in literature (8 - 103 €/kg(N), Liekens et al. 2012).

TABLE 8.

Estimated average values for removal of N and P by denitrification and burial.

Habitat	Denitrification (kg N/ha.y^{-1})	N burial (kg N/ha.y^{-1})	P burial (kg P/ha.y^{-1})
Shallow, soft substrate: Soft sediment sea floor	21.9	0.51	0.10
Oyster reef	260.3	446.5	72
Lagoon (1)	63.16	1189	77
Seagrass (2)	57.8	134	20.1
Mangrove	*No data found*	*No data found*	*No data found*
Estuary – Bare flat (3)	200	56.9 – 252	3.64 – 40
Estuary – Marsh (3)	140	14.2 – 252	0.91 – 40
Artificial reef (Subtidal zone)	21.9	0.51	0.10
Grassland (4)		35	1.3
Reed, shrub (5)		277	20

(1) calculated in the case Sand Engine (chapter 7)
(2) Reference: Gacia et al. 2002
(3) References data N burial: Middelburg et al. 1995, Dettmann 2001, Broekx et al. 2011, Ruijgrok 2006b. references data P burial: Broekx et al. 2011; De Nocker et al. 2004; Ruijgrok 2004; Nixon et al 1996; Andrews et al. 2006; Andrews et al. 2008; Sousa et al. 2010; Grossmann 2012; Vymazal, J. 2007
(4) References: Ruijgrok 2004, Ruijgrok 2006b, Billen et al. 2009
(5) References: Ruijgrok 2004, Ruijgrok 2006b

(4) Other aspects related to water quality regulation

Besides nitrogen and phosphorous also other aspects such as metals and carbon in the water do influence water quality regulation. For the WCT case two additional services were added:

- Metal binding (Cd, Pc, etc.):
- Intertidal area (bare tidal flat and marshes): 7686 kgCd, Pc etc/ha/y (Ruijgrok 2006b)
- Wetland, reed, shrub: 109 kgCd, Pc etc/ha/y (Ruijgrok 2006b)
- Monetary value: 0.31 €/kgCd, Pc etc (Ruijgrok 2006b)

- Carbon burial:
- Subtidal deep habitat (gully): 68 kgC/ha/y (Ruijgrok 2006b)
- Intertidal area (bare tidal flat and marshes): 1500 kgC/ha/y (Ruijgrok 2006b)
- Wetland, reed, shrub: 1222 kgC/ha/y (Ruijgrok 2006b)
- Monetary value: 0.148€/kgC (Ruijgrok 2006b)

3.2.3 AIR QUALITY REGULATION

Plants are capable of reducing the amount of fine dust (PM 2.5 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, harbors or busy roads, and should be evaluated per case-study.
The quantitative values used for the assessment of air quality in this study are based on the values used in the Nature Value Explorer (digital and continuously updated version, March 2015). These values are derived from Oosterbaan et al. 2011 (Table 9).
Monetary valuation: The monetary value of air quality regulation (fine dust removal) is calculated as the avoided damage to human health (€/kg PM10). This is based on studies on

the damage to human health due to fine dust emission, with an average of 54 €/kg (Liekens et al. 2013).

depends on local conditions (water currents, sediment type, etc.). Monitoring sedimentation and erosion rates before and after the project will be necessary to get a good idea of the impact.

TABLE 9.
Quantitative values used for the assessment of air quality (Oosterbaan et al. 2011).
Minimum and maximum values of fine dust removal (kg/ha).

Habitat	Minimum (kg/ha)	Maximum (kg/ha)
Open water	0	0
Dunes	18	36
Bare tidal flat	0	0
Marsh	18	36
Wetland	18	36
Forest	44	88
Grassland	18	36
Cropland	6,4	12

3.2.4 FLOOD PROTECTION

Flood protection as ecosystem service along sandy shores can be mediated through shallow sandbanks, islands, foreshore deposits, beaches and dunes. Along estuaries, also tidal flats and marshes contribute to flood protection. These different geomorphological features act as buffers that reduce wave and tidal energy, hence erosion of other protective structures, and/or as physical barriers (mostly dunes or grassed dikes) that prevent the hinterland from flooding. Estuaries additionally can protect against flooding by temporarily storing of flood water during storm events in so-called flood control areas.

Monetary valuation: The value of the ecosystem service flood protection is calculated as the avoided damage costs and/or casualties. For both cases where this service is affected (sand engine and polders of Kruibeke), we used data from existing flood reduction calculations in the area itself (see chapter 7.3.2 for the sand engine case and 8.3.2 for the polders of Kruibeke case).

3.2.5 SEDIMENTATION AND EROSION REGULATION

Different habitat types contribute differently to sedimentation and erosion regulation, and this

Some of the effects observed in the case studies are summarised here and some key data is presented to use in case no monitoring data is available.

- Sand extraction (Shallow, soft substrate) affects the morphology of the seabed. The effects are in general limited to the extraction area and refilling of the area takes place after extraction (Kubicki et al. 2007; Uścinowicz et al. 2014; Gonçalves et al. 2014). Long-term sediment transport could be affected from changing tidal ranges, phases and currents at near but also far distance from the extraction area (de Boer et al. 2011). Furthermore, local morphologic changes have potential consequences for benthic species and primary production in case of increased turbidity and changes in sediment composition (see 3.4 Biodiversity). More recent, ecosystem-based landscaping techniques are promising to reduce negative effects and influence fish assemblages (de Jong et al. 2014).
- Subtidal habitat: important role for sediment flows (import and export).
- Seagrass is highly sensitive to sedimentation and will not survive with certain sedimentation thresholds (depending on species, local conditions).

- Intertidal habitat (bare tidal flats and marshes) have the capacity to store sediments (in case of net sedimentation) which could be beneficial to reduce sedimentation in the navigation channel and at the harbor entrance. Sediment storage is calculated based on the sedimentation rate in the project area (= sedimentation rate in m/y x area unit 10,000 m²/ha x bulk density in g/m³). An average value for sediment storage in tidal habitat is 200 m³/ha/y (Ruijgrok 2006b).
- Artificial structures such as quay walls function as a barrier and affect sedimentation and erosion processes.
- Dunes depend on sediment supply for their development and sustenance.

Monetary valuation: The monetary value of sediment storage is retrieved from the cost of dredging (alternative to remove sediment) and ranges between 4 and 10 €/m³ (Ruijgrok 2006b, Broekx et al. 2008).

3.3 CULTURAL ECOSYSTEM SERVICES

3.3.1 RECREATION

Benefits from recreation resulting from changes in the landscape by dredging projects are difficult to assess because of 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. Only if the trend of recreation is apparent and clearly results from habitat changes related to the project, the impact on recreation will be evaluated.

The benefits and the type of recreation are very site-specific. The evaluation method therefore strongly depends on the case-study and requires analysis of existing literature on the project site itself.

Monetary valuation: If information on the number of visitors before and after the project is available, it is possible to make a prognosis on the impact on recreation by using values on the estimated amount a visitor spend during their visit and the added value created by this. The profit generated by recreation in The Netherlands is estimated to be ~10% of the total amount spent (Wijnen et al. 2002), where profit is calculated as gross value added minus depreciation, interest, rent and wages (Ruijgrok 2006a).

3.3.2 HERITAGE

In the context of this research, heritage comprises both cultural and natural heritage. The Millenium Ecosystem Assessment defines cultural heritage as 'memories' in the landscape from past cultural ties. This may refer to a longstanding tradition of local fisheries, traditional fishing methods such as horseback shrimp fishing, archaeological sites, authentic landscapes, … Natural heritage refers to paleontological remains or fossils.

The ecosystem service heritage depends on societal aspects which cannot be predicted based on knowledge of environmental conditions or habitat type solely. The importance of this service can only be assessed by consulting literature, local stakeholders or specialists of each case study separately. The service can potentially be delivered in any kind of habitat. Dredging related projects can have both negative and positive effects on this service. While the destruction of archeological or paleontological sites is an important negative effect, the fact that dredging activities may uncover previously unknown sites can be seen as positive, on the condition that the site is preserved.

Monetary valuation: Heritage is an ecosystem service which is difficult to express in monetary terms. It does not have a real market price, and the loss of heritage does not necessarily result in costs for society or for companies. There is however an important intrinsic value attached to natural and cultural heritage. Methods exist which try to put a price on this intrinsic value, for example by asking people for their willingness-to-pay to preserve their heritage. This method however is often contested and in this study we will assess the impact of dredging projects on heritage in a qualitative way. Only for the WCT project, willingness-to-pay values for open landscape and fossil recreation were collected (Ecorys 2006a Attachment F) and presented here.

3.3.3 COGNITIVE DEVELOPMENT

The benefits of knowledge of ecosystems are highlighted in increased delivery of other ecosystem services (Gómez-Baggethun et al. 2013), within the study area itself or in other areas. It is expected that more informed decision making results in more sustainable management of the environment and thus higher ES delivery. Sharing of knowledge through media, information panels, excursions etc. also increases value people attach to a place (recreation, sense of place, …) and stronger recognition of the value of ecosystems (Gómez-Baggethun et al. 2013). Indirect benefits of cognitive development result from the establishment of an expert reputation and application of the knowledge in other areas and/or domains (knowledge economy).

Monetary valuation: The benefits of cognitive development are difficult to express in monetary terms and literature on this matter is nearly inexistent. The few studies that were found on this matter use the investment costs for research and monitoring to value this service, assuming that this is the price institutes want to pay to be able to make more appropriate choices on the management of the ecosystem. This valuation method however does not reflect real economic benefits from the investments, such as payments for applying knowledge in similar cases abroad. In lack of such information, the importance of a project for cognitive development is described qualitatively and not added to the total sum of economic benefits from a project. Non-monetary valuation methods such as the number of citations of scientific publications may provide additional information on the value of a place for cognitive development.

3.4 BIODIVERSITY

Biodiversity is not considered an ecosystem service in itself but for several ecosystem services 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 on 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 due to trampling or repeated disturbance. Recreational attraction on the other hand may be higher if a higher diversity of species is present.

Although the relationships between biodiversity and ecosystem services are complex and service dependent, it is believed that the creation of new (e.g. sand engine, artificial reefs, …) or more natural (e.g. depoldering) habitat increases both biodiversity and service delivery. Biodiversity is relevant in each of the habitat types.

An important objective of habitat enhancement projects is the contribution to the Habitat and Bird Directive targets (e.g. creation of estuarine nature and bird area). However, societal benefits from habitat creation and an increase/shift in biodiversity are not included in the monetary assessment due to a lack of scientifically sound methods. However, the contribution of the project towards targets in the Habitat- and Bird Directive (HD and BD) is crucial for decision makers and managers. Therefore, a qualitative assessment will be executed to indicate which scenario is contributing to which of the HD and BD targets. This information can be used in addition to the monetary ES assessment to make a more objective decision.

Monetary valuation: As for heritage, biodiversity rather has an intrinsic than a monetary value. Biodiversity can be expressed either in quantitative terms (number of different species) or in qualitative terms (valuation score) which has the advantage that rareness of species can be taken into account besides number of species.

4. C-POWER WIND FARM

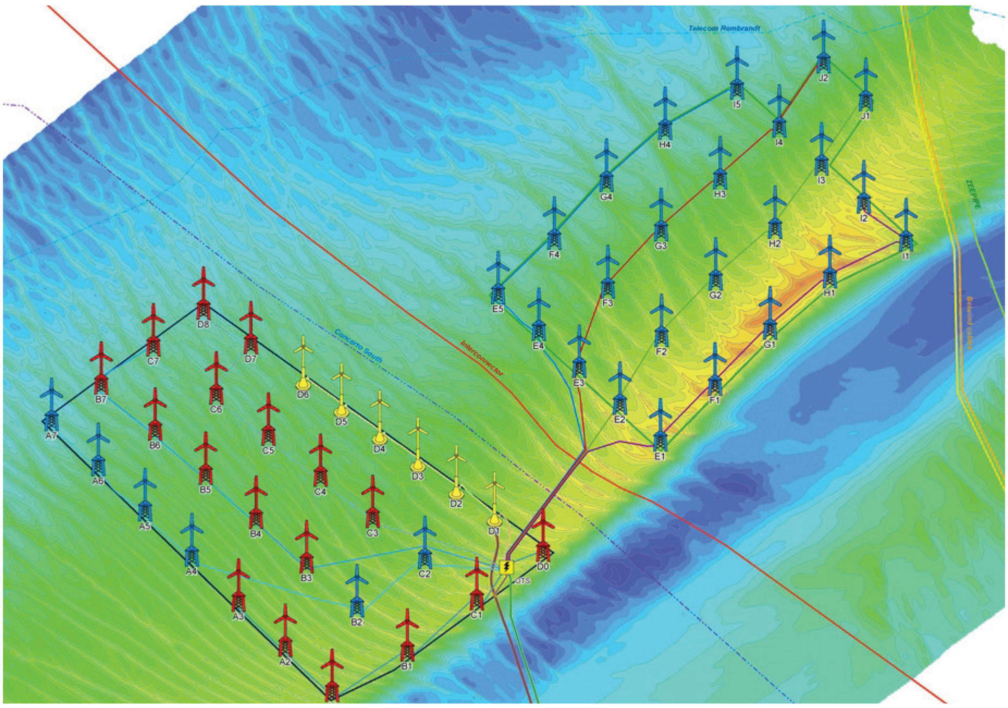
4.1 INTRODUCTION

The C-Power wind farm has two different types of wind turbine foundations (6 gravity based foundations supporting 5MW turbines and 48 steel jacket foundations supporting 6MW turbines), and one further jacket foundation for the offshore transformer station (Figure 4). They are implanted on the Thornton sand bank in the Belgian part of the North Sea, at 30 km off the shore. The offshore construction started in 2008 and the wind farm is fully operational since July 2013. Wind turbines and offshore transformer station are inter connected by means of submarine high voltage cables to transport the energy produced by the turbines.

An important source for the knowledge and findings used in this ecosystem service analysis is the set of reports of the six year monitoring campaign on the environmental impacts of offshore wind farms in the Belgian part of the North Sea (Degraer et al. 2013). These reports provided us with the most site-specific and recent information as the C-Power wind farm, amongst other wind farms on the North Sea sandbanks, was object of the study.

FIGURE 4.

C-power wind farm layout. Yellow: 6 GBF wind turbine, blue and red: 48 jacket foundations, lightening symbol: transformer station (www.c-power.be).



The main target of the wind farm is creating the benefit of energy production from wind energy. In the ecosystem services assessment, as presented in this report, additional benefits from other ecosystem services will be assessed.

In a first pilot phase of the project, 6 wind turbines with gravity based foundations (GBF) were constructed (Figure 5). After this phase it was opted to use metal jacket foundations instead of GBF's. The ecosystem services

delivered by both types of wind turbine foundations differ substantially.
"A gravity based foundation (GBF) is a hollow, concrete structure that is filled with sand once it is placed on the seabed. Due to its weight, it remains stable. Before the GBF can be placed, the seabed needs to be prepared to create a flat surface on dense sand." (Degraer et al. 2013a). Erosion at the foot of the foundation is prevented by an erosion protection layer consisting of stones. The jacket foundations consist of a steel jacket with four legs, each leg grouted on a pin-pile that was driven before into the seabed (Degraer et al. 2013a).

sandbank) as the distance to the shoreline is too large and the footprint of the wind turbine foundations too small to have an impact on beach habitats through changes in hydrodynamics and sediment/erosion processes. All of the changes in ecosystem service delivery resulting from the installation of offshore wind turbine foundations are directly related to changes in certain species or communities. In the discussion on the impact of wind turbine foundations on the different habitats we will therefore also indicate which types of species or communities may be affected.

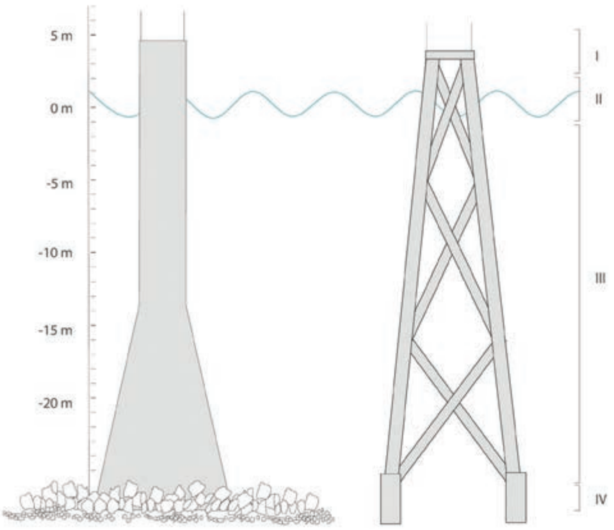
FIGURE 5.
Jacket foundation and gravity based foundation (GBF) (www.redwave.nl).

4.2 HABITAT CHANGES RELATED TO C-POWER PROJECT

The wind farm of C-Power is located at 30 km from the Belgian shoreline. The changes in habitat are all on-site changes (on the Thornton

Figure 6 gives a schematic representation of the different zones and fauna community types associated with the two types of foundations. Table 10 gives quantitative information on the affected surface area per habitat type.

FIGURE 6.
Indication of the different zones with hard substrata communities of a gravity based foundations and a jacket foundation (I splash zone dominated by non-indigenous midge Telmatogeton japonicus, II intertidal zone with blue mussels, III subtidal zone and IV erosion protection layer with anemones and hydroids (Rumes et al. 2013).



Shallow, soft substrate – changes due to dredging and dumping activities

Prior to the placement of a GBF, the seabed needs to be levelled off, requiring important amounts of sand that need to be dredged. At other locations, sand is extracted to compensate for losses during the dredging and dumping activities. The dredging pits and associated disposal sites, that were defined with the perspective of natural replenishment of the pits, remain unexpectedly stable. These dredging and dumping activities result in a temporary destruction of the sea floor habitat which may potentially lead to the permanent loss of the habitat type concerned, the specific fauna and flora dependent of it (e.g. nursery grounds for fish, feeding grounds for birds), and the ecosystem services they may deliver (fish production, carbon sequestration). The huge surface of similar habitat (sand banks) surrounding the impacted area however allows us to assume that biodiversity impacts are reduced to a minimum, unless if important shallow feeding or nursery grounds are permanently lost (Vanermen et al. 2013). On this topic however no information is available.

Shallow, soft substrate – loss due to permanent burial underneath foundations

The placement of a GBF results in the permanent burial of seafloor habitat beneath the foundation and the erosion protection layer, in contrary to the placement of jacket foundations which does not result in habitat loss through burial. For burial the same applies as for dredging and dumping, which is that the large surface of similar habitat in the surroundings is expected to reduce the biodiversity impacts to a minimum.

Shallow, soft substrate – changes in sediment characteristics around wind turbines

The presence of a GBF results in a reduction of current flows and grain size of the sediment in the wake of the GBF. The colonization of the concrete foundations by fouling communities in the vicinity of the turbines additionally causes organic enrichment of the soft substrate surrounding the GBF due to the sinking of faeces and other organic material. These changes in the soft substrate result in increased abundance and alteration of benthic communities on the soft substrate surrounding the GBF up to a distance

TABLE 10.

Permanent changes in total surface area (m²) per habitat type as a result of the construction of 6 gravity based foundation (GBF) and 49 jackets (based on Rumes et al. 2013).

Habitat type	6 gravity based foundations (GBF)		49 jacket foundations	
	m²	Type of impact	m²	Type of impact
Shallow, soft substrate	6 x 2,419	Burial underneath foundation and erosion protection	49 x 10	Loss of surface area at anchoring points (in case no erosion protection is used)
Shallow, soft substrate	6 x 16,548 (surface circle with radius 77.7, minus circle surface 2419 m²)	Changes in current flows and sediment characteristics around GBF	-	-
Shallow, soft substrate	~2 km2	No-fishing zone (no trawling)	~18 km²	No-fishing zone (no trawling)
Hard substrate	6 x 62	Foundation as artificial reef – splash zone	-	-
Hard substrate	6 x 75	Foundation as artificial reef – intertidal zone	49 x 51	Foundation as artificial reef – intertidal zone
Hard substrate	6 x 671	Foundation as artificial reef – subtidal zone	49 x 1,280	Foundation as artificial reef – subtidal zone
Hard substrate	6 x 2,242	Erosion protection layer as artificial reef	-	-
Open water	~2 km2	No-fishing zone (refugium effect)	~18 km²	No-fishing zone (refugium effect)

of 50m (Coates et al. 2014), with species such as sea stars and hermit crabs (Vandendriessche et al. 2013).

Shallow, soft substrate – changes due to no fishing zone

Inside the wind farm, all fishing activity is prohibited. This results in reduced disturbance of the sea floor caused by trawl fishing, on its turn increasing the production of benthic communities living on the sea floor and providing opportunities for the recovery of long living species vulnerable to trawling such as oysters (Vandendriessche et al. 2013). Increased production of benthic communities is not only the result of the absence of fisheries but also of the presence of nearby hard substrate and their fouling communities.

Hard substrate – new habitat on concrete foundation and erosion protection layer

Wind turbines bring a different type of substrata into a mainly sandy environment, resulting in the colonization of new types of communities. Three different zones can be distinguished in which communities will differ from each other, that is the splash zone above high tide (dominated by an invasive midge species Telmatogeton japonicus), the intertidal zone between high and low tide (barnacles, blue mussel and invasive oyster Crassostrea gigas) and the subtidal zone below the low water line (with anemones and hydroids). Communities on the foundation itself differ from communities on the erosion protection layer (only present at the GBF), with highest species diversity on the erosion protection layer. This might be due to the higher complexity of the stony erosion protection and the formation of microhabitats (De Mesel et al. 2013).

Open water – temporary changes in turbidity and noise level

Intensive dredging activities took place during the construction phase of the project (in the wind farm itself for the wind turbines and between the wind farm and the coast for placements of the high tension cables), resulting in temporary higher turbidity and reduced primary production due to less light penetration. The impact on turbidity however is local and temporary, with no significant difference between the before and after situation (Van den Eynde et al. 2013). During the construction phase of the wind farm there was a relatively high noise disturbance from drilling the pin-piles of the jacket foundations into the sea floor. This noise resulted in a decreased occurrence of marine mammals near and up to a distance of 20 km from the wind farm (Degraer et al. 2013a). This effect however is temporary.

Open water – changes due to no fishing zone

The prohibition of all fishing activity inside the wind farm may result in a refugium effect, increasing the density and size of certain fish species in the zone between the turbines. This refugium effect however may be limited for larger fish species (such as sole) that do not stay within the limits of the no-fishing zone for long periods of time (Vandendriessche et al. 2013).

4.3 ECOSYSTEM SERVICES OF THE C-POWER PROJECT

4.3.1 PROVISIONING ECOSYSTEM SERVICES

Fisheries production

The presence of wind farms may influence the number and size distribution of commercially and recreationally important fish, crustaceans and bivalves as a result of two main factors:

(1) biomass on which fish and crustaceans feed themselves is higher as a result of the availability of new, hard substrate in a soft-sediment environment.

(2) all fishing activity is prohibited within the concession zone, resulting in a refugium effect and/or recovery of benthic habitat (no trawling) and associated benthic invertebrates

The introduction of hard substrate in a sediment dominated environment increases biomass significantly (Figure 7). Not only biomass of the fouling communities which colonize the foundations and erosion protection layer increases but also communities living in the vicinity of the turbines benefit from the organic enrichment caused by fouling communities. Fish and crustaceans that feed on these communities and on the produced organic material are also expected to benefit from the increased biomass. To evaluate the impact of the C-Power wind farm on biomass production and potential effects on fish production, we compare the total autumn biomass of the Belgian Part of the North Sea (BPNS) before and after construction of the wind farm. The average autumn biomass production of the BPNS prior to construction of the C-Power wind farm is 10 g ash free dry weight per m² (Heip et al. 1992). For the entire BPNS of 3454 km² (www.mumm.ac.be), this results in a total autumn biomass of 34540 ton. To calculate the biomass after construction of the wind farm (6 GBF, 49 jacket foundations), we first subtract from the total autumn biomass of the BPNS the biomass which is lost due to the disappearance of soft substrate underneath the different types of foundations (1). To this we add the estimated amounts of biomass for the different types of foundations (2).

Autumn biomass loss soft sediment = (1)
[(lost surface area 6 GBF) + (lost surface area 49 jackets)] x average autumn biomass production BNPS per m² =
[(6 x 2,419 m²) + (49 x 10 m²)] x 10 g/m² = 0.15 ton

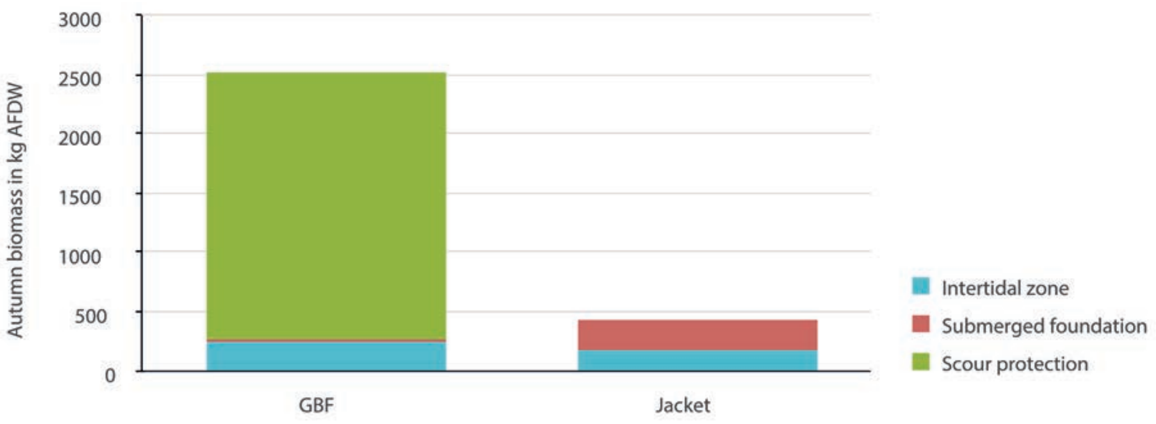
Autumn biomass increase hard substrate (numbers derived from Figure 7) = (2)
(6 x 2,500 kg) + (49 x 450 kg) = 37.05 ton

Total autumn biomass after construction = (3)
Autumn biomass before construction – loss of autumn biomass soft sediment + increase

autumn biomass hard substrate
34,540 ton – 0.15 ton + 37.05 ton = 34,576.90 ton

This sums up to a total autumn biomass of 34,576.90 ash free dry weight after construction of the C-Power wind farm (3), or else an increase of 0.11 % compared to the pre-construction situation. If we suppose all of the wind turbine foundations are GBF's, this would result in an increase of 0.39 %. If all foundations would be jacket (without scour protection layer), the increase would be 0.07 %. It is not possible to make predictions on how much more fish production the increase in autumn biomass could lead to, but it is proven that an increased number of commercially and recreationally important species and an increased body size of the fish are observed within the concession zone, both of which are known to feed on species associated with the hard substrata of the wind turbine foundations (Reubens et al. 2013). It is however expected that the effect is negligible in terms of fish production in the entire BPNS, as only a small amount of fish will feed itself near the wind turbines.

FIGURE 7.
Calculated total autumn biomass for a single gravity based foundation (GBF) and steel jacket foundation in the Belgian part of the North 3Sea (Rumes et al. 2013).



The prohibition of all fishing activity within the wind farm may have a negative impact on fish production in case the concession zone covers suitable fishing grounds that may not be found anywhere else. If we assume that the larger, commercial fish species do not permanently stay within the boundaries of the concession area, we can expect an overall positive effect of the wind farm on fish production. During a monitoring campaign to study the effect of wind farms on fish, it was observed that 4 out of 13 specimens of turbot caught in the BPNS originated from within the Bligh Bank where a similar wind farm is established as on the Thornton bank. These 4 turbots had an average length of 34 cm, while the average length of turbot in the BNPS is 23 cm (Vandendriessche et al. 2013). The installation of a wind farm may thus potentially increase fish production.

A moderate increase in the number of fishing vessels in the zone surrounding the wind farm concession area (Figure 8) may confirm a positive effect of the wind farm on fish production, although a redistribution effect resulting from the no-fishing zone may also play a role in this (Vandendriessche et al. 2013). When summing the amount of kilometers sailed in each grid cell of the entire BPNS (based on the lowest value of the given interval and value 5 for the first interval 0-10 of Figure 8), an increase of 10% can be noticed by 2011, when the installation of the 6 GBF wind turbines was completed. Since we do not know how fruitful the fishing trips were, we cannot make predictions on the potential extra amount of fish which has been caught as a result of the wind farm.

FIGURE 8.

Number of fishing vessel (commercial and recreational) registrations per 3 km2 near the wind farms on the BPNS. Circles represent areas with an increase (zones 1, 2, 3) or a decrease (zone 4) in number of registrations (Vandenderiessche et al. 2013).

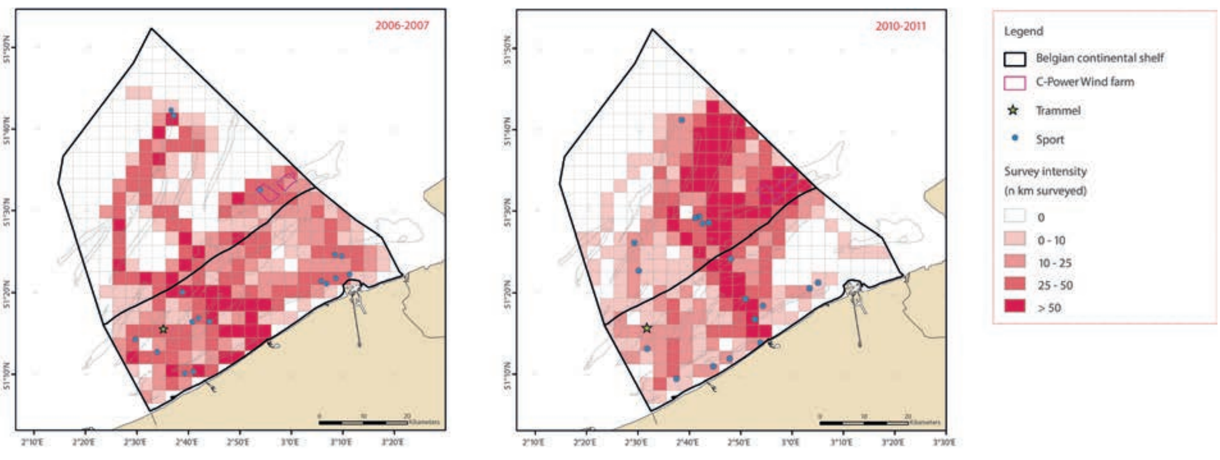


Table 11 gives an overview of the commercially and recreationally important fish, bivalves and crustaceans that have shown to be influenced by the presence of the wind farm (studies on the wind farms of the Thornton and the Bligh Bank in the BNPS, Vandendriessche et al. 2013, and on wind farms in Denmark (Leonhard et al. 2011), The Netherlands (Lindeboom et al. 2011) and Germany (Thomson et al. 2006)).

themselves, which could provide suitable habitat for reefs with Ostrea edulis, do not facilitate this development. The community of the intertidal zone of the wind turbines today differs from the community of oyster banks with Ostrea edulis, and the wind turbines have a relatively short lifetime of 20 to 30 years so that they do not provide a long-term solution for the restoration of oyster reefs (Kerckhof et al. 2012).

TABLE 11.

Overview of commercially and recreationally important fish, bivalve and crustacean species affected by the presence of the C-Power wind farm (+ positive effect, - negative effect, blank no information), based on Vandendriessche et al. 2013.

Species	Density	Body length
Plaice (*Pleuronectes platessa*)	+	+
Turbot (*Psetta maxima*)	+	+
Sole (*Solea solea*)	+	
Dab (*Limanda limanda)*	-	-
Whiting (*Merlangius merlangus)*	+	+
Blue mussel (*Mytilus edulis)*	+	
Lobster (*Homarus gammarus)*	+	

A note should be made on the increase of the Japanese oyster (Crassostrea gigas), which is a non-indigenous[1] species that has found its way to the BPNS due to the presence of artificial hard substrate such as the wind turbine foundations (stepping stone). Although an increase of the density of this species on the wind turbines foundations may at first seem to have a positive effect on fisheries (increased water quality, see paragraph 0), the risk exists that the species outcompetes the blue mussel, which is a commercially important species in the North Sea. The Japanese oyster on the other hand has no commercial value at all (Degraer et al. 2013b).

The restoration of oyster banks with the native oyster species Ostrea edulis, which is of commercial importance, has not yet been observed on the BPNS today. The wind turbines

In case the erosion protection layer remains or is reused, chances of oyster reef development may increase. The prohibition of trawling in the concession area may potentially help the recovery of oyster reefs on soft substrate, as was seen at Horns Rev, but has not yet occurred on the BPNS (Vandendriessche et al. 2013)

4.3.2 REGULATING ECOSYSTEM SERVICES

Water quality regulating

Following changes in water quality may be associated with the C-Power wind farm:

(1) Water quality improvement as a result of increased consumption of primary production (algae) by higher biomass of fouling communities on the newly available hard substratum

(2) Water quality improvement as a result of the development of bivalve reefs with high rates

[1] Indigenous species: if its presence in a region is the result of only natural process, with no human intervention

of nutrient retention and denitrification.

(3) The loss of soft substratum habitat underneath GBF's reduces the surface area for nutrient burial. This is however largely compensated by the increase in biomass from fouling communities and the development of bivalve reefs with much higher nutrient burial and denitrification rates.

(4) Decreased turbidity and nutrient resuspension as a result of prohibition of trawling (reduced stirring up of sediment).

The increase of biomass production due to colonization of the newly introduced hard substrate (including bivalves) and the presence of healthy populations of higher trophic levels and well-balanced food webs reduces the abundance of phytoplankton and the risk of algal blooms associated with eutrophication. The available nutrients are cycled within the system and thus temporary, or on the long term in case of storage in shells or exploitation, removed from the water column. As can be seen from Figure 9, the area where the wind farm is located is characterized by relatively high phytoplankton concentrations (orange zone). The service provided by the wind farm can thus be of relative importance here. Table 12 gives an overview of the potential effects of the C-Power wind farm on water quality regulation. The calculations are based on the general quantification methods for water quality regulation paragraph 0 and habitat changes related to C-Power in paragraph 4.2.

FIGURE 9.

Eutrophication class based on chlorophyll-a 90 percentile over the phytoplankton growing season with the red zone (>15 µg/l) exceeding the Marine Strategy Framework Directive requirements (www.highroc.eu). White star = approximate location of C-power wind farm.

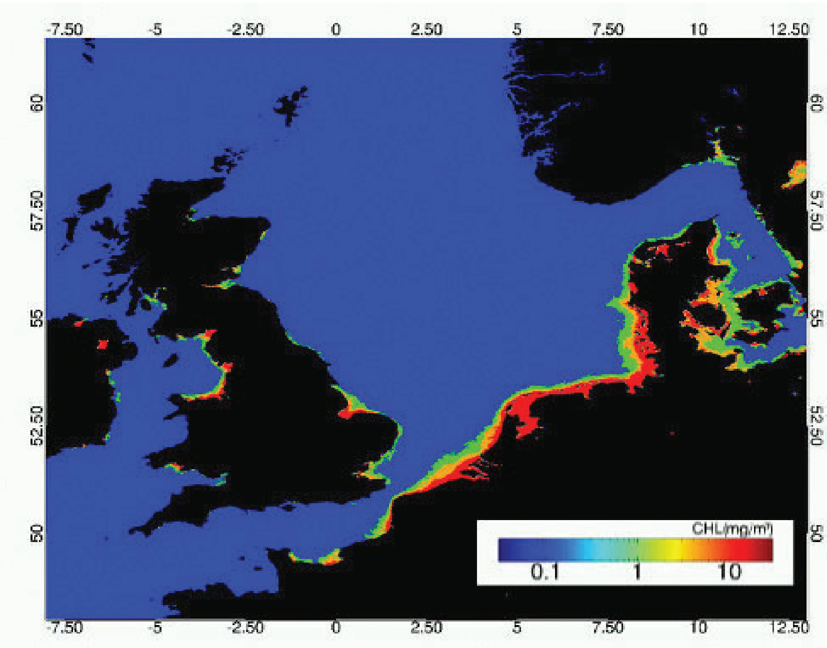


TABLE 12.
Potential effects of the C-Power wind farm on water quality regulation.

Habitat type	Surface area change (ha)	Denitrification		N-burial		P burial	
		kg N/ha.y^{-1}	€/y	kg N/ha.y^{-1}	€/y	kg P/ha.y^{-1}	€/y
Shallow, soft substrate	- 1.50	- 32.85	- 1,314	- 0.77	- 31	- 0.15	- 8
Hard substrate – subtidal zone	+ 6.67	+ 146.07	+ 5,843	+ 3.4	+ 136	+ 0.67	+ 37
Hard substrate – intertidal bivalve zone	+ 0.29	+ 75.49	+ 3,019	+ 129.5	+ 5,179	+ 20.9	+ 1148
Total		*+ 188.71*	*+ 7,548*	*+ 132.13*	*+ 5,284*	*+ 21.42*	*+ 1,177*

The total benefit for water quality regulation of the C-Power wind farm is €14009 per year. The effect of the wind farm on water quality in absolute terms is rather limited due to the relatively small surface area compared to the area for which water quality improvement is needed (eutrophied part of the North Sea, see Figure 9). If we extrapolate this to the approximately 530 wind turbines from different companies which will be installed by 2018, impacts on the risk of eutrophication in the BPNS may potentially become more important.

Flood protection

The wind farm of C-Power is located at 30 km from the Belgian shoreline. The distance to the shoreline is too large and the footprint of the wind turbine foundations too small to influence erosion and sedimentation processes along the shoreline, hence to decrease or increase of flood protection.

4.3.3 CULTURAL ECOSYSTEM SERVICES

Recreation

Recreational potential in the area close to the wind farm is low due to the large distance from the shoreline (30 km). Recreational fisheries (mostly anglers) concentrated near the concession area just after the start of the works (2008-2009) but disappeared gradually during the last years of the construction phase. Several reasons might explain this: the distance to the area is too far for day-trips, the effect of the wind farm on the amount of fish is less than expected and the anglers cannot fish close to the hard substrates (Vandendriessche et al. 2013).
The presence of marine mammals in coastal waters is known to have a positive effect on recreation. The most abundant marine mammal in the BPNS, harbor porpoise, may be affected by the presence of the wind farm in positive and in negative ways. The heavy sounds during installation may deter the animals, while the increased abundance of prey fish near the hard substrate may attract porpoises (Haelters et al. 2013). The distance of the C-Power wind farm to the shoreline however is too large for a day-trip porpoise-watching so changes in concentrations of porpoises related to the wind farm are likely not to affect recreation in the Belgian coastal zone.

4.3.4 BIODIVERSITY

There is an overall positive effect of the installation of the wind farm on species diversity:

- The declaration of a no-trawling zone stops the destruction of benthic habitat and reduces stress on vulnerable species that are dependent of the sea floor.
- The no-trawling zone also offers a refuge for pelagic fish, resulting in increased density and body size of the individuals.
- Water quality improves with the introduction of the no-trawling zone as sediments are no longer stirred up (less turbidity, less resuspension of nutrients), decreasing stress (light and nutrient availability) on benthic organisms.
- The newly available hard substrate in a dominantly soft sediment environment attracts species that could previously not establish in the area such as anemones, hydroids, ….
- Increased biomass on the hard substrate increases biomass and diversity of the larger benthos on the surrounding soft substrate (such as sea stars, urchins, hermit crab).
- Changes in granulometry and hydrodynamics around the GBF structures (reduction of current velocity and finer sediments in the wake of the foundation and erosion protection layer) also change community composition and increase species diversity in the BPNS. A three- to fourfold number of benthic species is recorded in the direct vicinity of the GBF's in the after compared to the before situation (Coates et al. 2013).
- Increased biomass production on the soft sediment surrounding the turbines on its turn supports higher trophic levels (fish, birds and mammals). Densities of several fish (e.g. cod) and bird species (herring gull and red list species black-backed gull) increase, and species favoring rocky habitats (e.g. European shag) are more frequently spotted. Not only feeding opportunities increase but the wind turbines also offer resting places (Vanermen et al. 2013).

Despite the positive effects on species diversity, wind farms also have important negative consequences for biodiversity:

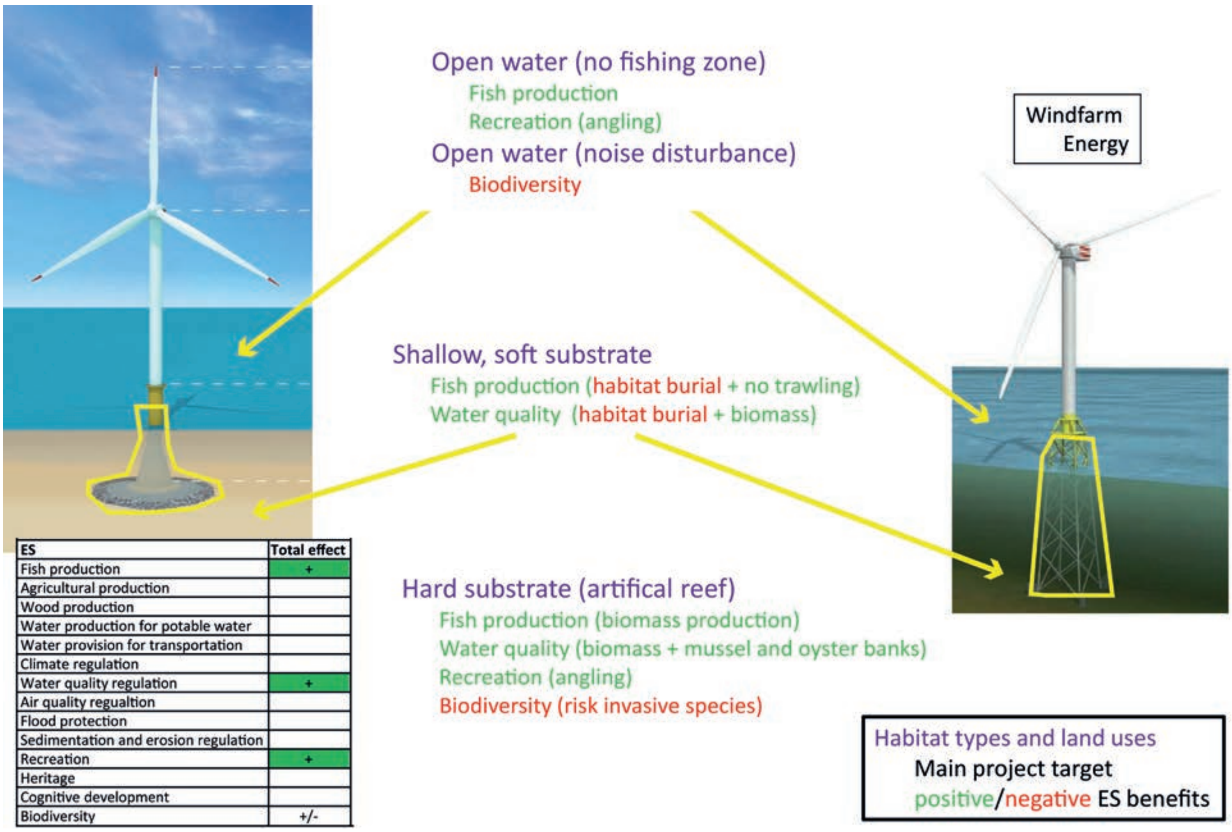
- Some bird species are attracted to the wind turbines as they offer feeding and resting places. A higher density of birds however increases the risks of collision with the rotating blades of the wind turbines. Especially gulls appear to be at risk of colliding with the turbine blades. Collision risk modelling learned that the C-Power wind farm with its 54 turbines is expected to cause 129 strikes with gulls per year (Vanermen et al. 2013). An increase in the number of wind mills may become a serious threat for the survival of certain bird species.
- Bird species with important feeding grounds on the shallow sand bank on which the GBF is placed may suffer from habitat loss if no equally suitable feeding grounds are found elsewhere (Vanermen et al. 2013). However, no reporting of this for the C-Power wind farm is found, and the wind farm only consists of 6 GBF with a total surface area of 1.5 ha (inclusive the erosion protection layer).
- Half of the increased species richness on the hard substrate (8 out of 17 species) results from the introduction of non-indigenous species. The presence of the hard substrate may act as a stepping stone for species associated with rocky shores to intrude new areas further into the North Sea. When these species become invasive (when they develop dense populations and outcompete native species or disrupt ecosystem functioning), this may become a threat to native biodiversity and may affect commercially important species. Commercial exploitation of mussels for example becomes difficult when the mussel beds are infested with C. gigas (Degraer et al. 2013b).
- The construction of the wind farm (especially pile-driving of the jacket foundations) generates very high levels of noise that disturb marine mammals and fish. The protected harbor porpoise avoids the area around the construction site up to a distance of 20km. The exact consequences on the population of porpoise in the North Sea is still unknown. Given that the installation period for the C-Power wind farm lasted from 2008 till 2012 (installation of GBF's in May/June 2008; installation of jacket foundations in 2011/2012), the installation of other wind farms is ongoing till 2020, and the wind turbines have an average lifetime of 20 to 30 years (after which they need to be replaced), the effect of loud noise is not be neglected.

4.4 DISCUSSION AND CONCLUSION

Although the offshore wind farm has clear positive effects on the delivery of several ecosystem services, that is water quality regulation, fish production, recreational angling and biodiversity (Figure 10), there are also some potentially important negative side-effects. The most important negative effects to be expected are the spreading of invasive species into the North Sea, the increased risk of collision with sea birds, habitat burial, and habitat and noise disturbance during construction. While several positive effects have been demonstrated by scientific research, knowledge on the negative impacts is often lacking and might only become obvious on a longer time scale. This makes it difficult to come to an overall conclusion on whether the wind farm is positive or negative in terms of ecosystem services and biodiversity, not taking into account the ecological and economic benefits of sustainable energy production. Although the different types of foundations have similar effects on ecosystem services and biodiversity, the extent to which they impact service delivery and biodiversity varies.

FIGURE 10.

Summary of the ES effects of the C-Power project.
All additional ecosystem services effects are positive and indicated in green.



ES	Total effect
Fish production	+
Agricultural production	
Wood production	
Water production for potable water	
Water provision for transportation	
Climate regulation	
Water quality regulation	+
Air quality regualtion	
Flood protection	
Sedimentation and erosion regulation	
Recreation	+
Heritage	
Cognitive development	
Biodiversity	+/-

5. BOTANY-BAY CONTAINER TERMINAL

5.1 INTRODUCTION

Sydney Ports (Sydney, Australia; Figure 11A) expanded Port Botany to ensure sufficient port capacity (availability of berths) to meet the forecasted growth in New South Wales (NSW) container trade after 2010. The project was approved in 2005 and completed in 2011. It extended the existing Patrick Stevedores container terminal with 1,850 metres of additional wharf face (approximately 550 m west and 1,300 m north) (Figure 11) good for five extra shipping berths adjacent to the existing berths. Additionally, 63 ha of terminal area was created. An area of 2 ha adjacent to the tug berth facility is reclaimed to create a new public boat ramp and car park with direct access to Foreshore Road (URS Australia and Sydney Ports Corporation 2003) (Figure 11C).

The extra terminal area and berths have a capacity of about 1.6 million TEUs per year which brings the total capacity at Port Botany to more than 3 million TEUs per year for the next 25 years and beyond. The depth of the port basin (up to 16.5 metres) allows large container ships with a capacity of up to 8.000 TEU. Dredging of approximately 7.8 million cubic metres of fill material was necessary to deepen shipping channels and berth boxes (Figure 11B). The total cost of the Port Botany Expansion amounts $1 billion. Economic benefits are related to improving the efficiency of cargo handling, making exports more competitive and avoiding congestion costs. Furthermore, the construction of the project and the expanded terminal generate many direct and indirect jobs.

The main target of the project is the creation of additional benefits from the ecosystem service water regulation for transportation. This has a large economic importance. In the ecosystem services assessment, as presented in this report, additional benefits from other ecosystem services will be assessed.
Most information about the project is taken from the environmental impact statement (URS Australia and Sydney Ports Corporation 2003), Port Botany Expansion overview brochure (Sydney ports 2009a) and Annual Environmental Management Report of 2009 (Sydney ports 2009b).

Broad context: also other influences in the area Botany Bay has been subject to many changes related to previous human activities including the creation and removal of habitats, contamination of water and sediment from industrial activities, introduced species, fishing activities, and shipping operations.

Land uses surrounding the site comprise primarily open space, industrial, residential and transport-related uses with associated support services. Residential areas in the vicinity of the site are located to the north, northwest and northeast of the site. The industrial/residential suburb of banksmeadow lies to the north of the site. Botany residential area is located approximately 0.5-1 km to the northwest and the East Botany residential area is located some 2.5 km to the north of the site. A relatively large residential area consisting of Hillsdale, matraville and Maroubra is located to the north and east of the site.

The key developments in the region that result in significant impacts are the existing port facilities, Sydney Airport and the Green Square redevelopment in Alexandria. Sydney Airport, the major aviation gateway to Australia and a major focus of economic activity, is located approximately 1.5 km west of the site. The Botany Freight Rail Line, which is used for rail transport of freight to and from Port Botany, occupies a corridor north and northeast of the site. At the port end of the freight line is Botany Yard which facilitates shunting activities and the breaking up of trains prior to entering the port terminals. Increasing aviation, train and shipping traffic, independent of the Botany Bay expansion, caused a lot of effects in the area.

FIGURE 11.

A: Location of the new terminal area for the Port Botany expansion, Botany Bay, Sydney, Australia (URS Australia and Sydney Ports Corporation 2003).

B: Project area before (2001) and after (2015) the port expansion (from google earth).

C: Project layout: New terminal area, boat ramp, Penrhyn estuary, foreshore, dredging area (Sydney ports 2009b).

5.2 HABITAT CHANGES RELATED TO THE BOTANY BAY PROJECT

Different zones and habitat types are affected by the project (Table 13). In the shore zone, the relevant habitat types are the bay, seagrass and mangroves. North/north-west of the new terminal (Figure 11B,C), the inner Penrhyn estuary is located with subtidal shallow water, intertidal flats and marshes. The hard substrata of the new terminal and berths is considered as a separate category ('artificial habitat'). The last part is terrestrial, with planted shrubland.

The description of habitat changes is mainly based on following references: Port Botany Expansion Environmental Impact Statement (URS Australia and Sydney Ports Corporation 2003), Penrhyn estuary Habitat Enhancement Plan (Sydney ports 2006), Port Botany Post Construction Environmental Monitoring: Seagrass Summary Report, April 2015 (Sydney ports 2015).

TABLE 13.

Summary of habitat changes.

Habitat		Change (projected completed in 2011)	ha
Shore	Beach, foreshore beach	*Restored and enhanced*	
	Lagoon, bay	- 57 ha reclaimed (ship berths up to 16.5 m depth) - 2 ha adjacent to the tug berth facility for the new boat facility *Small channel developed in the inner estuary*	**-59**
	Seagrass	2001: 10 ha; 2008: 0.03 ha (=300 m²); 2015: 40 m² (=0.004ha) → Planned: 6 ha new = + 6 ha	**+6**
	Mangroves	Project: - 1 ha	**-1**
Inner estuary	Subtidal shallow	*Loss of a previously dredged hole and some areas of shallow subtidal sand habitat* *Will partly develop to seagrass and intertidal flat*	
	Intertidal flat	Initial: 3.4 ha; Project: -1.7 ha → Planned: 10 ha new = + 8.3 ha	**+8.3**
	Marsh	Initial: 1.4 ha; Project: -0.4 ha → Planned: 2.4 ha new = + 2 ha	**+2**
Outer estuary			
Hard substrata	Ship berths	- 57 ha reclaimed (ship berths up to 16.5 m depth)	
	Rock rubble	+ 1,850 m of wharf face + 3,300 tubular steel piles + 500 m of seawall adjacent to seagrass habitat within the access channel and Penrhyn estuary + 1,000 m rock wall adjacent to intertidal habitat + 500 m of seawall used for the tug berths and recreational boat ramp -------------------- + subtidal rock wall between the tug berth area and the downstream end of the estuary channel (average height of 5.5 m) + 4.5 m subtidal rock wall as an extension of the boat ramp rock revetment	+ 3850 m = 19250 m² (average 5 m height) = 1.9 ha
Terrestrial	Dune, planted shrubland	Project: - 0.6 ha and - 10.5 ha Retained: 4.5 ha	**-11.1**
	Surrounding area (road, residential, industry)		
Freshwater habitat	Drains		

Shore

Lagoon, bay: About 57 ha in the bay is reclaimed to construct five new container ship berths (approximately 63 ha). The deep water berths have depths of up to 16.5 m.
A tidal channel of about 1.5 m deep at low tide is the main access to the Penrhyn estuary. Within the estuary, a small channel was developed for the flow of water from two drains (Floodvale Drain and Springvale Drain) and a deeper lagoonal area (approximately 1.4 m deep) to promote the growth of seagrass.

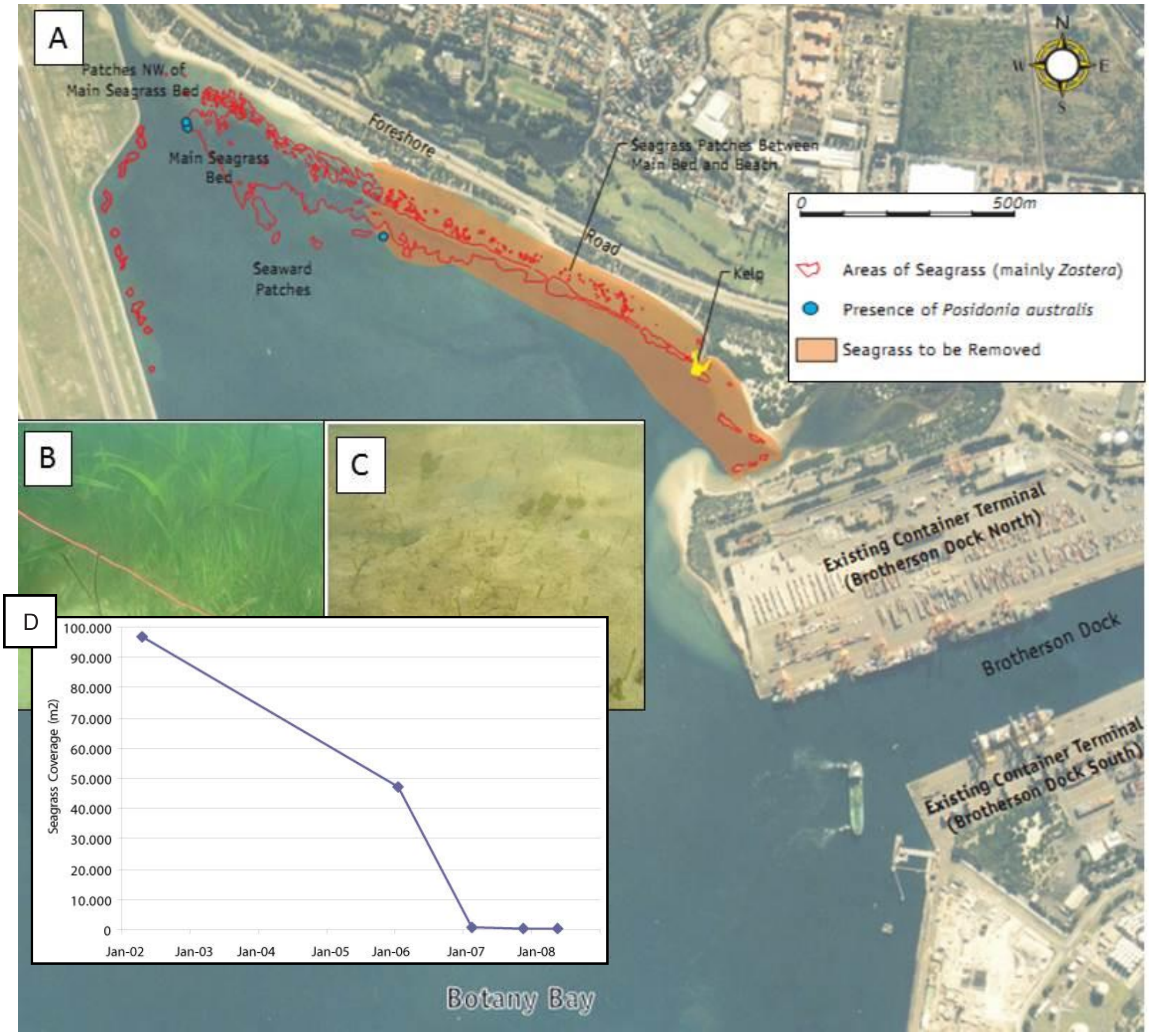
Beach: Design development concluded that a beach along the northern side of the estuary channel was not viable as the slope required to create a stable beach (gradient 1:20+) would require more land than is available between the channel and Foreshore Road. The Foreshore Beach is restored and enhanced with the main purpose of providing public access and recreation opportunities along the foreshore and towards the Penrhyn estuary.

Seagrass habitat: Seagrasses are the only flowering plants occurring in salt water and they have a significant role as primary producers in estuarine systems as well as providing structural habitat for many other species. Seagrass beds provide an important nursery area for fish and crustaceans by providing shelter and food. Seagrass leaves act as a filter; the strap-like leaves of seagrass plants slow the overlying water thus allowing sediment suspended in the water to settle out into the seagrass bed. The extensive seagrass rhizome system stabilizes the underlying sediment and prevents sediment movement.
In the period between 2001 and 2008 a serious decline in the area covered by seagrass (mainly Zostera capricorni) along the Foreshore Beach occurred from about 10 ha in 2001 to only 0.03 ha in 2008 (Figure 12). Dredging and channel forming works caused this decline. No seagrass was recorded in the inner estuary. Impacts to seagrasses as a result of the Port Botany Expansion are therefore relatively minor to the variability (natural or otherwise) observed over the six year period prior to any construction works taking place. A high quality silt curtain was used during construction to protect the remaining areas of seagrass. Monitoring carried out during the construction works indicated that seagrass condition and distribution remained relatively stable during this period. Initial findings of the post-construction monitoring (March 2012 to March 2013) at Foreshore Beach and the Rehabilitation Area (Quibray Bay; in the south of Botany Bay) are positive and suggest early signs of recovery. The transplantation of Posidonia australis from Foreshore beach to Quibray Bay appears to have been highly successful and will have helped offset direct losses of seagrass as a result of dredging and reclamation at Foreshore Beach (Cardno and Sydney ports corporation 2013).

Mangroves: Approximately 1 ha of mangroves in the Penrhyn estuary is removed with the purpose of enhancing shorebird habitat by allowing additional saltmarsh habitat to establish. The removal of mangroves is undertaken in a manner that minimizes disturbance of potentially contaminated sediment. The loss of the small stand of mangroves in the Penrhyn estuary is not considered significant since it only represented about 0.1 % of the mangroves in Botany Bay and the advantages associated with the opportunity to enhance shorebird habitat with saltmarsh provide a strong ecological justification for their removal. In addition, it was also argued that in many locations within the Sydney region saltmarsh is being lost due to colonization by mangroves.

FIGURE 12.

A: Existing seagrass areas and seagrass areas to be directly impacted.
B: Typical seagrass condition pre-burial by sand (2004).
C: Seagrass condition January 2006. D: Decline in seagrass coverage April 2002 to May 2008.
(Sydney ports 2006, 2009b).

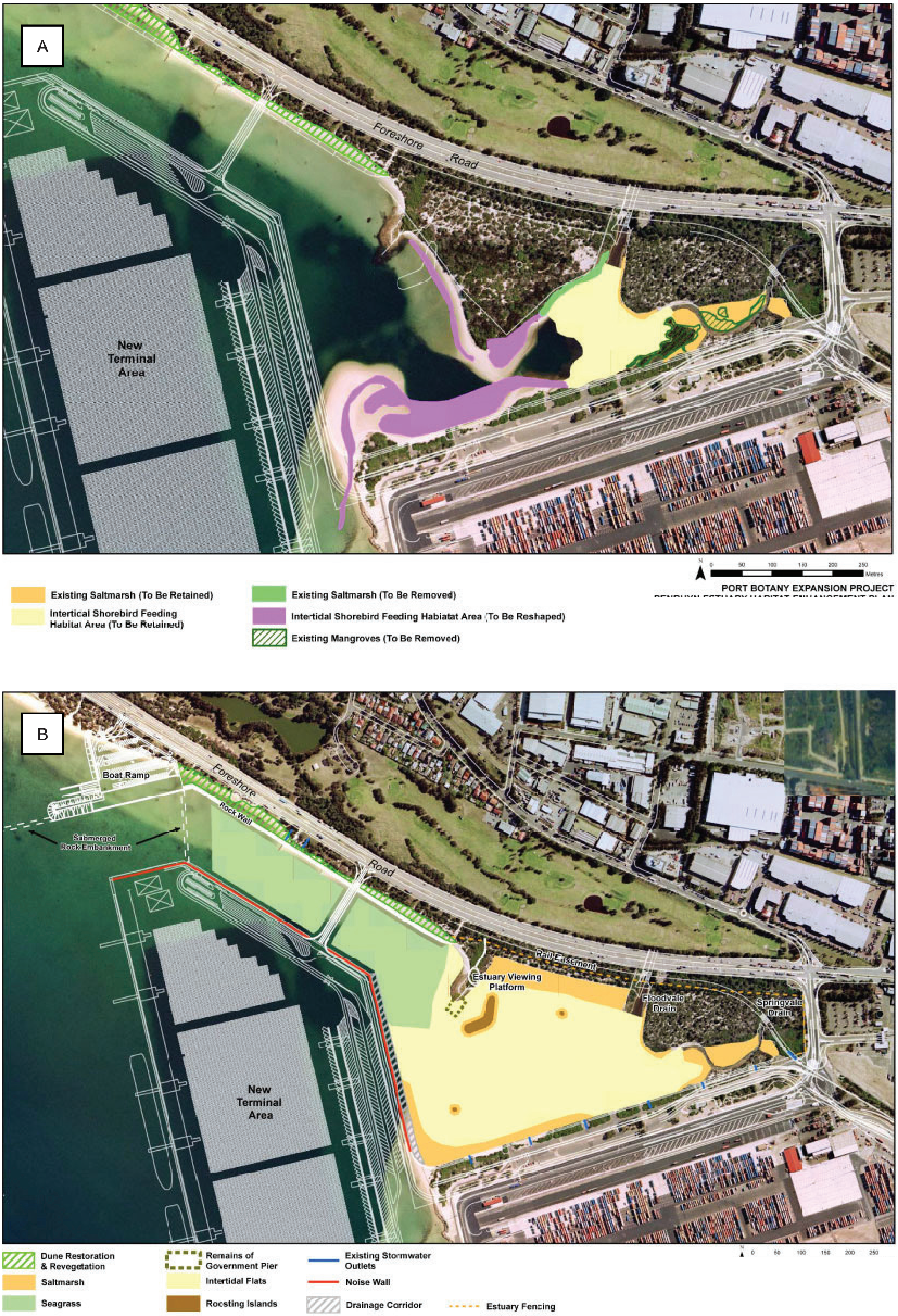


Estuary

Port Botany is located in the Penrhyn estuary which is essentially comprised of an inner estuary and an outer estuary. The Penrhyn estuary is a locally significant site for migratory shorebirds and contains saltmarsh and seagrass habitat. Sydney Ports was committed to protecting and enhancing the habitats and prepared the Penrhyn estuary Habitat Enhancement Plan for that purpose (Figure 13).

FIGURE 13.

A: Existing saltmarsh and intertidal shorebird feeding habitat in Penrhyn estuary (Sydney ports 2006);
B: Penrhyn estuary habitat enhancement layout.



Subtidal shallow habitat: A previously dredged hole and some areas of shallow subtidal sand habitat is lost with the creation of a deep basin as an extension to the existing navigation channel.

Intertidal sand and mud flats: The initial area of 3.4 ha of intertidal flats is halved with the project but an additional 10 ha of intertidal sand and flats is created with the program to enhance shorebird habitat in the Penrhyn estuary.

Marsh: The main saltmarsh species occurring in the Penrhyn estuary are Suaeda australis, Sarcocrnia quinqueflora, Sporobulus virginicus and Juncus kraussi. Saltmarshes play a key role in stabilizing the banks of estuaries, filtering surface runoff, reducing nutrients and providing additional bird habitat and help attract migratory birds. The existing saltmarsh habitat in the Penrhyn estuary was 1.4 ha, of which 0.4 ha was removed and an additional 2.4 ha of saltmarsh habitat is created and planted with suitable saltmarsh species (Figure 14A). The retained areas of saltmarsh were protected by the exclusion zones established during the construction phase. Sarcocornia quinqueflora and Sporobulos virginicus species from the transformed area were transplanted into existing saltmarsh habitat within the estuary. This resulted in a new total of 3.4 ha habitat suitable for saltmarsh. The creation of additional saltmarsh habitat was considered to be a positive impact as it represents a substantial increase in the total area of this habitat within Botany Bay (approximately 4% increase) and helps in restoring saltmarsh habitat that was lost due to the construction of the Parallel Runway. An appropriate timeframe for measurement of success was considered to be five years following completion of habitat enhancement works. The habitat creation and planting to realize a four-fold increase in saltmarsh area was successful (Cardno and Sydney ports corporation 2013). However, DGPS mapping revealed that the total area of saltmarsh habitat at the Penrhyn estuary decreased by 12.8% between the 2013 and 2014 surveys (Sydney ports 2014) (Figure 14B). Losses in habitat area were recorded at all the different treatment locations in the estuary. Preliminary investigations and field observations suggest that the decrease is due to the variability of the new growth and outcrops of plants on the seaward margin of the saltmarsh communities at the Penrhyn estuary. The reference locations have a much less variable seaward margin boundary due to the established mangrove stands (Sydney ports 2014).

FIGURE 14.

A: Saltmarsh monitoring locations (Sydney ports 2009b);

B: Penrhyn estuary saltmarsh sites and mapped 2014 vegetation boundary (Sydney ports 2014).

Outer estuary: Apart from levelling some high spots within the existing navigation channel, there were no physical changes to the Bay outside the study area. In addition, aquatic habitats elsewhere in the Bay was not affected by the Port Botany Expansion. Changes in wave energy and direction were predicted to be small, with negligible effect on sensitive habitats such as Towra Point Aquatic Reserve in the south of Botany Bay.

Freshwater habitat

The two creeks that flow into Penrhyn estuary (Floodvale Drain and Springvale Drain) have freshwater habitat in their upper catchments. These drains are highly disturbed by surrounding development and contaminants from industry and their value as freshwater habitat was considered to be very limited. Notwithstanding that these drains were already highly degraded, changes to the Penrhyn estuary still resulted in the preservation of connectivity and hence fish passage to and from these drains.

Hard substrate

Ship berths: About 57 ha in the bay was reclaimed to construct five new container ship berths (approximately 63 ha) . The deep water berths have depths of up to 16.5 m.

Rock rubble (public boat ramp): Originally, most of the northern shoreline of Botany Bay consisted of sandy substratum. The amount of hard substratum in the Bay has increased over time with the developments of Port Botany and Sydney Airport replacing sections of natural sandy shoreline with artificial hard structures. The amount of hard substrata increased substantially as a result of the proposed port expansion. This included an additional 1850 m of wharf face and some 3300 tubular steel piles, 500 m of seawall adjacent to seagrass habitat within the access channel and Penrhyn estuary, 1000 m rock wall adjacent to intertidal habitat, and 500 m of seawall used for the tug berths and recreational boat ramp. The structure associated with the port expansion was generally made of rock.

An area of 2 ha adjacent to the tug berth facility is reclaimed to create a new public boat ramp and car park with direct access to Foreshore Road. A subtidal rock wall with an average height of 5.5 m was constructed between the tug berth area and the downstream end of the estuary channel. Another 4.5 m subtidal rock wall was constructed as an extension of the boat ramp rock revetment. The purpose of these rock walls is to dissipate energy arising from tug vessel operations, which reduces potential for scour of the estuary channel and protect recreational boat users from tug vessel wash.

Terrestrial

Dune, Planted shrubland above the high water mark: Where the Penrhyn estuary interfaces with the port terminal and the northern side of the estuary channel it was bounded by rock walls with maximum 1:2 slope. Elsewhere, the estuary was bounded by restored and enhanced native dunal vegetation which is described in a Visual Amenity Management Plan. Approximately 12 ha of planted shrubland existed behind Foreshore Beach, of which approximately 0.6 ha is removed directly with the port expansion. In addition, another 10.5 ha is removed to enhance shorebird habitat in the Penrhyn estuary. Approximately 4.5 ha of the planted shrubland within the Penrhyn estuary is retained at the site. The removal of the planted shrubland community was not considered to be significant in a local or regional sense and is required to facilitate the enhancement of a recognized important migratory shorebird habitat site.

5.3 ECOSYSTEM SERVICES OF THE BOTANY BAY PROJECT

5.3.1 PROVISIONING ECOSYSTEM SERVICES

Fish production

Commercial fishing:

Commercial fishing is not directly affected by the port expansion because this activity is no longer permitted within Botany Bay. There is, however, commercial fishing at the entrance to the Bay and within adjacent coastal waters. Based on modelling of hydrology and coastal processes, it is highly unlikely that the proposed port expansion would affect the physical nature of fishing activities outside the Bay. Given that many species of fish and invertebrates utilise the Bay waters as juveniles and then migrate into coastal waters, a possible concern is that there would be some effect on fish stocks as a result of the proposal. Under the proposal there would be an overall increase in the amount of seagrass present in the core study area, hence it is expected that there would be no net loss in fisheries productivity related to seagrass beds, and potentially a small increase. (URS Australia and Sydney Ports Corporation 2003)

Aquaculture, oyster farming:
Currently aquaculture (including oyster farming) occurs on the southern side of Botany Bay. No effects of the port expansion are expected since the changes to Botany Bay outside the study area are considered negligible. As far as is known, there are no plans to introduce aquaculture to parts of the northern section of Botany Bay, particularly within the study area. However, in some areas of the shore there are oysters on the mud flats. (URS Australia and Sydney Ports Corporation 2003)

Fish passage, fish communities, nursery function and feeding opportunities:
Shore: Bay: Fish sampling in the existing brackish portion of the Penrhyn estuary indicates usage by a variety of fishes such as sea mullet (Mugil cephalus), sand mullet (Myxus elongatus), flat-tail mullet (Liza argentea), yellowfin bream (Acanthopagrus australis), tarwhine (Rhabdosargus sarba) and silver biddies (Gerres subfasciatus). These species would use the estuary for a variety of functions, including shelter and feeding. Currently, access to the inner estuary is restricted to a narrow shallow channel at low tide, but with access at high tide unrestricted. Fish passage in the water column is important to enable fish and invertebrates access to spawning sites, nursery habitat and feeding grounds. Fish passage would generally not be altered under the proposed port expansion.
The access channel parallel to Foreshore beach would be sufficiently deep (1.5 m at low tide) to enable access by fish (URS Australia and Sydney Ports Corporation 2003). It is possible that fish could be affected by any powerful lights shining on the channel at night. It would therefore be preferable to have strong lights facing away from the channel (URS Australia and Sydney Ports Corporation 2003).
Subtidally, dredging and reclamation would replace a large area of shallow sandy habitat with deeper soft sediments. The dredging would cause a temporary loss of benthic productivity whilst the reclamation would cause a permanent loss of productivity within the terminal footprint. Colonisation of the dredge holes would be rapid (timescale of months), but 'recovery' to a condition that could be considered representative of this type of deep habitat could take in excess of two years (URS Australia and Sydney Ports Corporation 2003). Furthermore, fish assemblages in the dredge hole would differ to the shallows (URS Australia and Sydney Ports Corporation 2003).

Shore: Foreshore beach: Unvegetated soft sediments provide habitat for mainly invertebrate animals (polychaete worms, amphipods and molluscs), which in turn are a supply of prey for wading birds and food for fish in deeper water. Shallow, soft sediment habitats provide habitat for transient fish species of commercial value (tailor (Pomatomus saltatrix), southern herring (Herklotsichthys castelnaui), sand mullet, flat-tailed mullet and sea mullet) and non-commercial species including bait fish, gobies (Gobiidae), hardyheads (Atherinidae), perchlets (Ambassidae), sprats (Sprattus) and toad fish (URS Australia and Sydney Ports Corporation 2003).
The beach to the east of the boat ramp would be adjacent to the new terminal and would become very sheltered from waves. Under these conditions, the pattern of erosion and accretion would cease at the eastern portion of the beach and be largely unchanged for the western portion. Given that the western beach would have a similar aspect to the present condition, it is to be expected that similar types of benthic assemblages would be present following construction of the new terminal. Assemblages colonising the beach adjacent to the terminal and in the Penrhyn estuary would be likely to reflect a more sheltered, estuarine habitat. Surveys of benthic invertebrates in the intertidal zone indicate a relatively diverse assemblage of organisms, particularly in sheltered locations around the Penrhyn estuary. (URS Australia and Sydney Ports Corporation 2003).

Shore: Seagrass habitat: Seagrass provides food and habitat for fish and invertebrates and provides “nursery habitats” for recreationally and commercially important species of fish and invertebrates such as prawns and crabs (URS Australia and Sydney Ports Corporation 2003).
From a study on fish communities inhabiting separate meadows of the seagrasses Zostera capricorni and Posidonia australis in Botany Bay it was concluded that about 50% of the dominant fish species associated with each seagrass habitat were of some economic importance (Middleton et al. 1984). Such species were usually residents or transients and made up most of the biomass in each habitat. Adults of these dominant economically important species were most abundant in both seagrass habitats during summer.
Hence, increase in seagrass habitat is beneficial to attract additional fish and marine life. The extent to which fish can use the seagrass lagoons would depend on their depth. Anything more than about 1 m deep would be used by a variety of large and small fish. The design of the seagrass habitat takes this into account as it would be covered during low tide and water would be able to drain into the access channel to prevent any stranding of larger fish (URS Australia and Sydney Ports Corporation 2003).

Shore: Mangroves: The loss of 1 ha of mangroves results in a foregone opportunity for fish, shellfish and molluscs (539 kg/y) and for shrimps (146 kg/y), with an economic value for fisheries of 23,613 US$/y.

Freshwater habitat: The freshwater habitats of the drains are limited in size, restricted in diversity and polluted. They are also subject to very rapid flushing due to the highly cleared catchment. Therefore, there would be few fish that access the drains (e.g. some eels, mosquito fish, gudgeons and mullet) and fish passage is not likely to be a major issue into and out of the drains. Fish sampling in the existing brackish portion of the Penrhyn estuary indicates usage by a variety of fishes such as sea mullet, sand mullet, flat-tail mullet, yellowfin bream, tarwhine and silver biddies. These species would use the estuary for a variety of functions, including shelter and feeding. (URS Australia and Sydney Ports Corporation 2003)
Some fish species in New South Wales (NSW) travel to and from freshwater and barriers can cause local population extinctions. In the Penrhyn estuary, access needs to be considered in relation to movement between the estuary and Botany Bay, and the movement between Springvale and Floodvale Drains and the estuary and into Botany Bay. (URS Australia and Sydney Ports Corporation 2003)

Hard substrata (1.9 ha): The structure associated with the proposed port expansion would generally be made of rock which could provide habitat for a variety of invertebrates and fish fauna. Limited information is available on the ecology of hard-substrata communities within the Bay, although much is known about the ecology of rocky intertidal and subtidal habitats at the entrance to the Bay (Cape Banks). Species lists available for these habitats suggest that communities on artificial surfaces are similar to those on natural rocky reefs, but often differ in the structure of the assemblage. (URS Australia and Sydney Ports Corporation 2003)
Benthic algae are attached on some of the seawalls, on rubble and derelict pylons at the old Government Pier near the Penrhyn estuary. Most of this would be removed as a result of the proposed expansion (except for the Government Pier), but would colonise the new solid structures associated with the new terminal. (URS Australia and Sydney Ports Corporation 2003)

Threatened aquatic species: Aquatic species that are considered critically endangered and endangered in the vicinity of the site are: Loggerhead Turtle, Grey Nurse Shark, Murray Hardyhead, Eastern Freshwater Cod, Trout Cod, Oxleyan Pygmy Perch, River Snail, Green Sawfish, Blue Whale and Southern Right Whale.

Agricultural production

Aquaculture, e.g. oyster farming: see fish production.

Wood production

Given the potential of mangroves for wood production, the loss of 1 ha of mangrove results in a forgone opportunity for timber production (5976 kg/y) and fuel wood (5,140 kg/y) with a monetary value for forestry of 38,115 US$/y. However, due to the very small mangrove area in the project area this service is considered negligible.

Fresh water production and water production for industrial use

There should be no water used for human consumption from Botany Bay. The Sydney Desalination Plant and pipeline are situated near and across Botany Bay with the intake pipe on the seaward side of the southern Botany Bay headland (Kurnell Peninsula). Industry water use (if any) should be directed to the Port Authority (www.nswportsbotany.com.au).

5.3.2 REGULATING ECOSYSTEM SERVICES

Climate regulation

Due to the habitat changes and the carbon burial capacity of each habitat type, it was estimated that the port expansion project results in a negative effect (Table 14). The main contribution to this effect is the loss of shrubland.

in the Penrhyn estuary as a result of a reduction in tidal flushing and water quality is difficult to predict. (URS Australia and Sydney Ports Corporation 2003)

As a consequence of the dredging and reclamation, the Environmental Impact Statement predicted that there would be greater turbidity at the discharge location and that dredging in clay areas was expected to lead to extended turbidity (Sydney ports 2011). Decreasing water clarity is particularly critical in order to protect the remaining seagrass from potential damage (URS Australia and Sydney Ports Corporation 2003). Turbidity associated with dredging is generally lower than predicted. Modelling predicted up to 20 mg/L, however monitoring indicates less than 5 mg/L outside the silt curtain. Total suspended solids (TSS) throughout the period of dredging and reclamation has not exceeded 50mg/L, and has only reached a maximum of 23 mg/L once (Sydney ports 2009b).

TABLE 14.

Calculation of the impact on climate regulation (carbon burial).

Habitat		Ha	C burial	TonC/y
Shore	Lagoon, bay	**-59**	0.068 ton C/ha/y	- 4
	Seagrass	**+6**	1.38 tonC/ha/y	8-12
	Mangroves	**-1**	0.83 – 3 tonC/ha/y	- 0.83-3
Inner estuary	Intertidal flat	**+8.3**	2 – 9 ton CO_2-eq./ha/y (= 0.5-2.5 tonC/ha/y)	4-20
	Marsh	**+2**	2 – 9 ton CO_2-eq./ha/y (= 0.5-2.5 tonC/ha/y)	1-5
Hard substrata	Rock rubble	+1.9		
Terrestrial	Dune, planted shrubland	**-11.1**	6.8 ton C/ha/y	-75
			Total (average)	**-56**
			Monetary value €/y (220 €/tonC)	**-12,320**

Water quality regulation

Predicted impacts on the Penrhyn estuary include a small increase in siltation, small changes in temperature and dissolved oxygen and an increase in nutrients and faecal coliforms. Such predicted impacts may place pressures on the Penrhyn estuary in providing viable habitat for shorebirds, although direct and indirect impacts on shorebirds and their habitats

While some water quality indicators have varied from pre-construction averages, overall water quality outcomes in the Penrhyn estuary are suitable to support the habitats enhanced by the Penrhyn estuary Habitat Enhancement Plan, with no indication of potential for the formation of eutrophic conditions to date. Total nitrogen and total phosphorous did not change post-construction. (Cardno and Sydney ports corporation 2013)

Based on the habitat changes, an overall negative effect on water quality regulation is estimated for the area (Table 15). This is mainly due to the loss of relatively large areas in the bay and shrubland compared to the newly created areas of seagrass, intertidal flat and marsh. For the bay area, no effect for N and P burial is included since sedimentation rates are considered limited.

Air quality regulation

Air quality is expected to be affected by dust emissions during the construction of the Port Botany Expansion. Dispersion modelling of dust emissions during construction showed that dust concentrations and deposition rates comply with EPA criteria and would therefore not result in significant impacts on surrounding land uses (URS Australia and Sydney ports 2003). Monitoring in 2011 did not recorded PM10 exceedances compared to the PM10 dust goal of 50 µg/m3 (Sydney ports 2011).

Changes in habitat types decreased the potential for fine dust capture in the area (Table 16). Loss of 11.1 ha planted shrubland and 1 ha mangroves is replaced by only 2 ha of marshes, the only habitat types with a potential for fine dust capture.

TABLE 15.

Calculation of the impact on water quality regulation (denitrification, Nitrogen and Phosphorous burial).

Habitat		**Ha**	**Denitrification (kgN/y)**	**N-burial (kgN/y)**	**P-burial (kgP/y)**
Shore	Lagoon, bay	**-59**	-3,658	/	/
	Seagrass	**+6**	177	804	120.6
	Mangroves	**-1**	*No data*	*No data*	*No data*
Inner estuary	Intertidal flat	**+8.3**	1,660	472 - 2,091 (average 1281)	30 - 332 (average 181)
	Marsh	**+2**	280	28.4 - 504 (average 266)	2 - 80 (average 41)
Hard substrata	Rock rubble	+1.9	41	1	0.19
Terrestrial	Dune, planted shrubland	**-11.1**		-3,075	-222
	Total (average)		**-1,500**	**-723**	**+120**
	Monetary value €/y (40 €/kg(N); 55 €/kg(P))		**-60,000**	**-28,920**	**+6,643**

TABLE 16.

Calculation of the impact on air quality regulation (fine dust capture by vegetation).

Habitat		Ha	Fine dust capture (kg/y)
Shore	Lagoon, bay	**-59**	0
	Seagrass	**+6**	0
	Mangroves	**-1**	-44-88 (average -66)
Inner estuary	Intertidal flat	**+8.3**	0
	Marsh	**+2**	36-72 (average 54)
Hard substrata	Rock rubble	+1.9	0
Terrestrial	Dune, planted shrubland	**-11.1**	-200-400 (average -300)
	Total change fine dust capture (average)		**-312**
	Monetary value €/y (54 €/kg)		**-16,848**

Flood protection

Hydrologic modelling (to determine surface water flow rates under design rainfall conditions) and hydraulic modelling (to determine the flood water levels) before and after the proposed development showed that the Port Botany Expansion would not have an adverse impact on local flood behavior in the catchments surrounding Port Botany or cause an increase in flood levels within the Penrhyn estuary (URS Australia and Sydney ports 2003). Modelling concluded that there would be very little change in the tidal prism of the Bay due to the expansion. Tide heights in the Penrhyn estuary are, and would be, the same as in the rest of Botany Bay. Since these heights are unchanged, the tidal penetrations in Springvale and Floodvale Drains would also remain the same (URS Australia and Sydney Ports Corporation 2003).

The purpose of the subtidal rock walls, constructed between the tug berth area and the downstream end of the estuary channel and as an extension of the boat ramp rock revetment, is to dissipate energy arising from tug vessel operations, which will reduce potential for scour of the estuary channel and protect recreational boat users from tug vessel wash (Sydney ports 2006). In the longer term, the new terminal would causes a small reduction in wave energy in some parts of the study area and have no effects in other parts. Importantly, there would be no increase in wave height in areas where seagrass would be retained (URS Australia and Sydney Ports Corporation 2003).

The loss of mangrove areas is considered to be negative for coastal protection (Lee et al. 2014). However, in the case of the Botany Bay port expansion this seems of low importance and the area is small to have a significant impact for the protection of the city Sydney.

Sedimentation and erosion regulation

No physical disturbances of the seagrass patches were observed. Sedimentation was different at each location and was generally below 20 mm/y (Sydney ports 2009b) and later generally below 25 mm/y (Sydney ports 2011). Due to a lack of comparable pre-construction data, it was not possible to compare this to pre-construction conditions. Increased deposition was observed in March 2011, however this returned to normal levels the following month. The increased deposition was associated with observed beach erosion along Foreshore Beach, and likely disturbance due to removal of the seagrass silt curtain. The decrease and increase of sediment deposition at the various stations over time indicates sand movement in the retained seagrass area. However, sand deposition has remained low across the retained seagrass area.

For the estuary (intertidal flat and marsh), there is a trend towards deposition. Due to a lack of comparable pre-construction data, it was not possible to determine if the observed rate of deposition to date is within the normal pre-construction range. Sediment deposition does not appear to be related to dredging or other project related activities. The predicted average deposition rate was 20 mm/y, and the recorded average sediment deposition rate varied between years: 11 mm/y (Sydney ports 2009b) and 23.7 mm/y (Sydney ports 2011). While this exceeds the 20 mm/y annual deposition limit set in the Minister’s Conditions of Approval (MCOA), it remains below the annual siltation rate of 26 mm/y predicted by modelling carried out for the Environmental Impact Statement. (Sydney ports 2011).

Overall, sediment deposition in the area will be enhanced with the project which is positive for nutrient and carbon burial. However this could result in a complete silting up of the Penrhyn estuary, since the area cannot further expand with the surrounding walls (road). For the survival of seagrass, deposition rates are not too high.

TABLE 17.

Summary: calculation of the impact on sedimentation and erosion regulation (sediment volumes).

Habitat		Ha	Sedimentation (mm/y)	Sediment volumes (m^3/ha/y)	Sediment volumes (m^3/y)
Shore	Lagoon, bay	**-59**			
	Seagrass	**+6**	Max. 25	Max. 250	Max. 1500
	Mangroves	**-1**			
Inner estuary	Intertidal flat	**+8.3**	11-23.7	110-237	913-1967
	Marsh	**+2**	11-23.7	110-237	220-474
Hard substrata	Rock rubble	+1.9	0	0	
Terrestrial	Dune, planted shrubland	**-11.1**	0	0	

5.3.3 CULTURAL ECOSYSTEM SERVICES

Recreation

Part of the habitat enhancement design for Penrhyn estuary habitat is, on the one hand, to provide controlled public access and, on the other hand, minimize disturbances within the estuary (Sydney ports 2006). A number of facilities are part of the project to benefit the local community. A pedestrian and cycle path, large car park and amenity buildings should improve the access to the area in a controlled way. An elevated viewing platform and native landscaping near the mouth of the Mill Stream (Figure 15 zone 1) are developed to enjoy the enhanced natural features of the area (reinstatement of foreshore dune areas, intertidal sand/mudflats, salt marsh and seagrass habitat) without disturbing the nature area. A specially designed bird watching platform with access via a boardwalk and seating at Penrhyn estuary is developed to enjoy the migratory shorebirds for which Penrhyn estuary is an important ecological habitat (URS Australia and Sydney Ports Corporation 2003).

Improvements on Foreshore Beach would enhance access arrangements and public recreation opportunities along the foreshore and linkages to Sir Joseph Banks Park. In the northern part (Figure 15 zone 3), the development of a beach was considered not viable as the slope was too steep. Instead, a rock wall was constructed which will discourage swimming in the estuary channel. This has further benefits such as additional protection for seagrass habitat from disturbance and discouragement from entering Penrhyn estuary other than along the designated access path (Sydney ports 2006). To improve the land-water connection, a new four-lane boat launching ramp was developed (Figure 15 zone 2). With the port expansion, there would be a loss of about 1.5% of Bay waters for recreational fishing (URS Australia and Sydney Ports Corporation 2003). As seagrass is an important habitat for the fish communities, enhanced seagrass habitat is expected to improve the occurrence, abundance and biomass in the area (Middleton et al. 1984). Furthermore an enclosed fish cleaning facility is foreseen which prevent birds from being attracted to the area, an important feature because of the proximity to the airport (Sydney ports 2009a).

The loss of mangrove area is negative for recreation, but it is expected that this is compensated by the newly created areas, opportunities for recreational fishing and the attraction of birds.

The presence of marine mammals could be affected by the port expansion. Effects are mainly expected for the Southern Right Whales which is sensitive to sounds (Sydney ports 2006). The port expansion could reduce opportunities for whale watching in the area.

Although several large national parks are present around Botany Bay (south), the presence of the Foreshore Beach and Penrhyn estuary could add an important recreational benefit to the inhabitants (Figure 16).

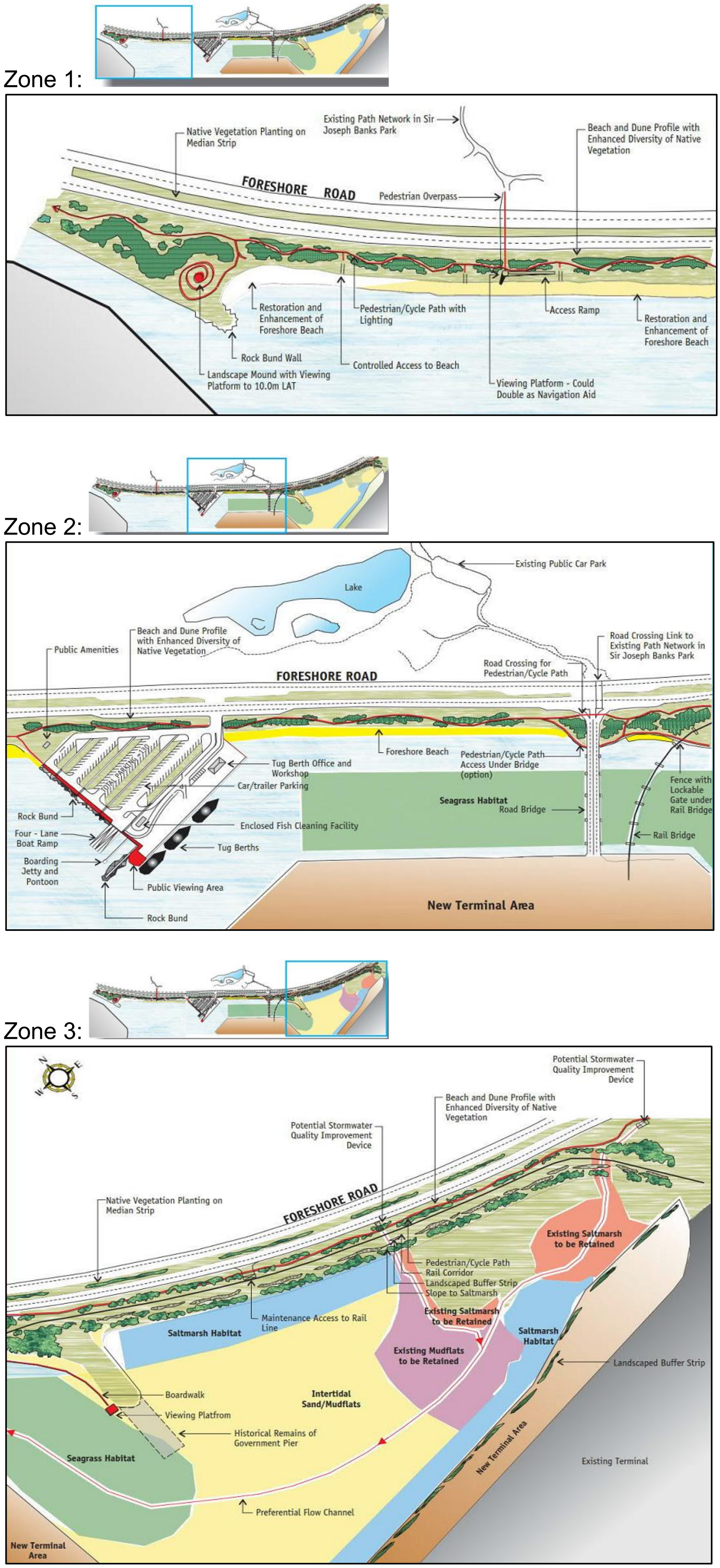
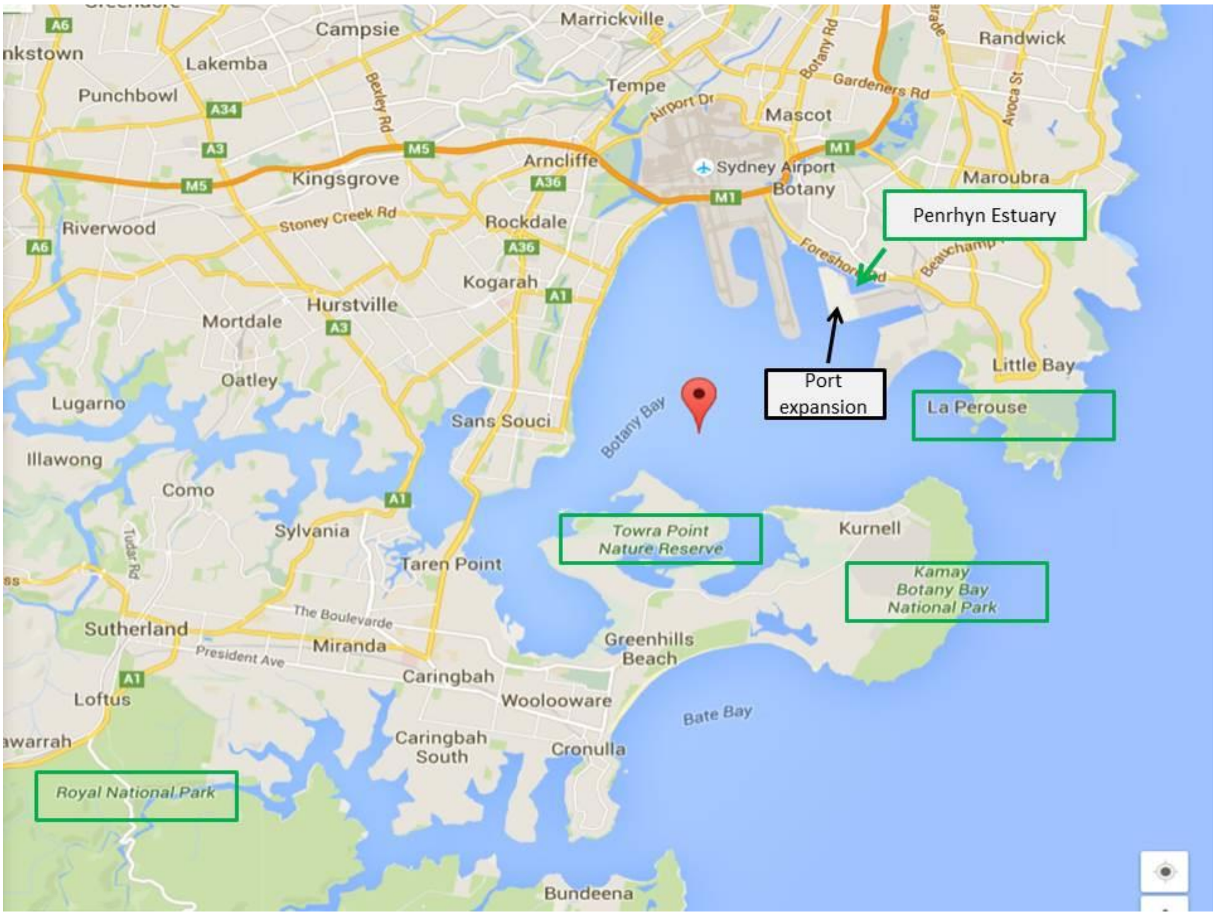


FIGURE 15.
Detailed overview recreation plan, in 3 zones (left, middle, right). (URS Australia and Sydney Ports Corporation 2003).

FIGURE 16.

National parks in the vicinity of Botany Bay (Google maps).



Heritage

Two features are of notice in the study area: Government Pier and Aboriginal heritage. Historic remains of Government Pier are present in the study area but will not be disturbed as part of the works (Figure 15 zone 3). The significance of the Pier lies in its association with the Government's first attempt at fostering trade and creating port infrastructure within Botany Bay (URS Australia and Sydney ports 2003). In the project site no Aboriginal sites or artefacts have been found (Sydney ports 2011).

5.3.4 BIODIVERSITY

Shorebirds

The port expansion project could potentially affect 23 shorebird and 1 seabird species, with mainly seven key species: the Bartailed Godwit, Red-necked Stint, Double-banded Plover, Curlew Sandpiper, Red Knot, Pacific Golden Plover, and Sharp-tailed Sandpiper. Feeding and roosting areas could be disturbed from change in lighting regime, increased movement, noise from construction and operation of the port (URS Australia and Sydney Ports Corporation 2003). This might be problematic since the Penrhyn estuary is a significant habitat for migratory shorebirds listed under international treaties or as threatened species under both Commonwealth and NSW legislation (Sydney ports 2006).

The habitat enhancement plan developed along with the port botany expansion has a central aim to improve shorebird feeding and roosting habitat as this area and especially Penrhyn estuary is an important spot for migratory shorebirds. Planted shrubland (10.5 ha) and mangroves (1 ha) are removed and converted to intertidal flats (11 ha), saltmarsh habitat (5 ha) and seagrass habitat (8 ha) (URS Australia and Sydney Ports Corporation 2003). In order to provide secure roosting sites for shorebirds, three islands have been included in the estuary design (Sydney ports 2006).

Benthos is an important feeding source for birds. Benthic assemblages were studied in Botany Bay to study the short- and the long-term consequences of dredging in marine sedimentary environments (Fraser et al. 2006). Monitoring in the study area revealed a positive trend with increasing benthos abundance and biomass (Sydney ports 2009b).

A positive link is expected between the benthic community and shorebirds, but it is too early to test properly. It is expected that at least a 5 year period is needed for the benthic community to fully colonize the newly created area.

Nevertheless, many shorebird species have been observed at Penrhyn estuary: 16 species after the first monitoring period with 11 migratory and 5 non-migratory shorebird species (Sydney ports 2009b) and a total of 22 species after the second monitoring period with 16 migratory and 6 non-migratory species (Sydney ports 2011). Bar-tailed Godwits, Black-winged Stilts, Masked Lapwing, Pacific Golden Plover and Red-capped Plovers have been the most numerous, with other shorebird species being observed occasionally, or rarely. Between 2009 and 2011, a reduction in the number of migratory birds has been observed (Sydney ports 2011). For the resident shorebirds, there has been a shift in the species of birds observed in the estuary with a reduction in black winged stilts, but an increase in red capped plovers and masked lapwings. It is difficult to make conclusions as to what has caused this shift in resident species and reduction in migratory species – it is likely to be from a combination of factors that may not be directly attributable to construction activities. Further monitoring is required to see the real impact of the port expansion and the habitat enhancement plan.

Marine mammals

Botany Bay and surrounding water are visited by the Southern Right Whale (Eubalaena australis) and the Humpback Whale (Megaptera

FIGURE 17.
Left: Southern Right Whale (Eubalaena australis) in Botany bay (22/7/06, provided by DEC).
Right: Australian Fur Seal (Arctocephalus pusillus doriferus), off Molineaux Point, Botany Bay (22/7/06, provided by DEC). (Sydney ports 2006).

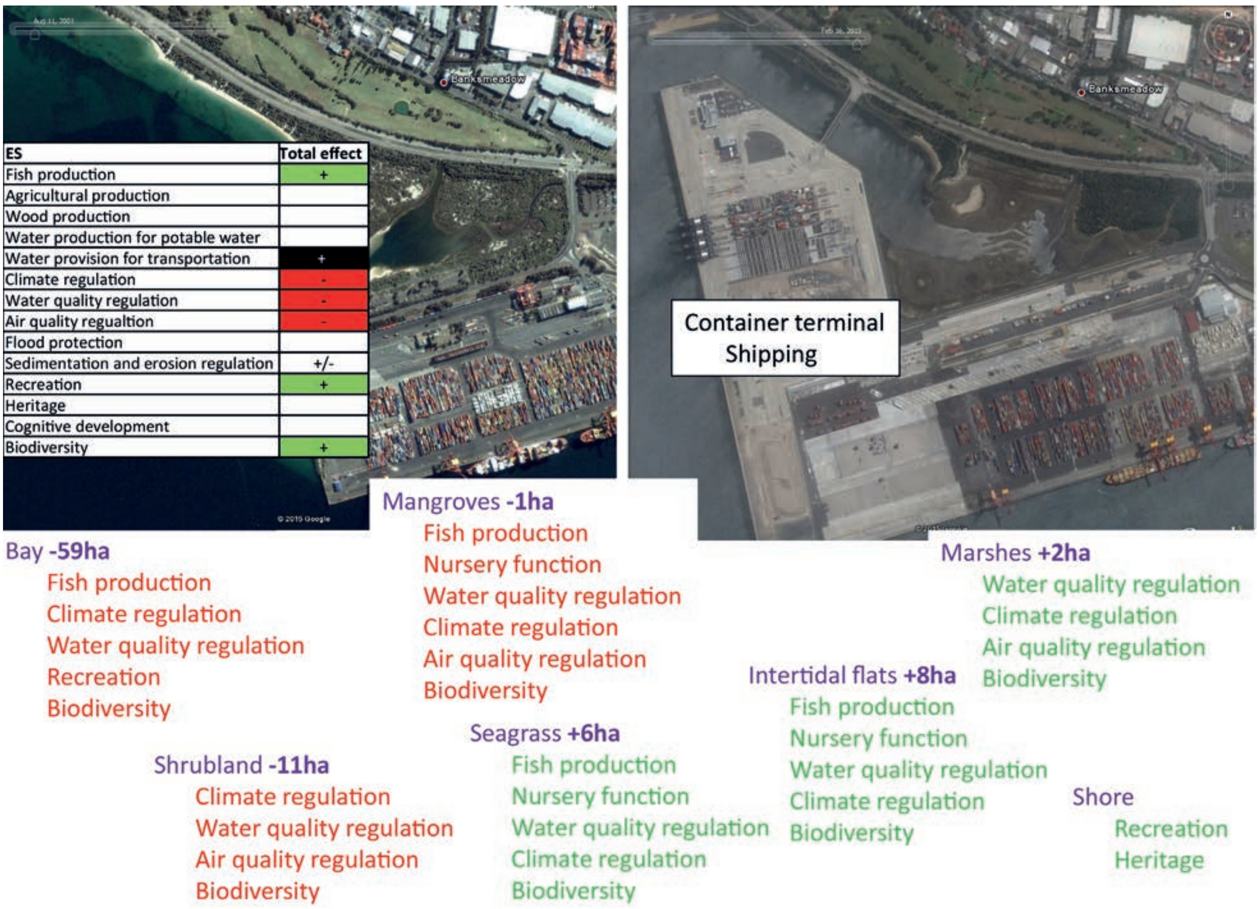
novaeangliae). Occasional visitors to Port Botany may include the Bottlenose Dolphin (Tursiops truncates), Common Dolphin (Delphinus delphis), Pygmy Sperm Whale (Kogia breviceps), Australian Fur Seal (Arctocephalus pusillus doriferus) and Leopard Seal (Hydruga leptonix). Mainly the Southern Right Whales, which visit more regularly in deeper parts of the Bay, may be affected from the port expansion due to the lower frequency noise sources and slower moving commercial shipping vessels (Sydney ports 2006).

Impact introduced species

Commercial shipping, enhanced with the port expansion, could potentially bring 'introduced species', among which toxic and pest species and exotics that could affect the fauna and flora local community. This risk existed already in the area with the port facilities, but could be increased with the expansion. In terms of introduced species already in Botany Bay, there is some risk of changes in distribution associated with the proposed port expansion for: toxic dinoflagellates that are present as cysts in sediments that would be dredged and Caulerpa taxifolia presently occurring along Foreshore Beach which could threaten the seagrass habitat (URS Australia and Sydney Ports Corporation 2003).

FIGURE 18.

Summary of the ES effects of the Botany Bay project. The main benefit for the container sector (in black: shipping) is the main project benefit considered in the initial project evaluation. All additional ecosystem services effects are indicated in green (if positive) or red (if negative).



ES	Total effect
Fish production	+
Agricultural production	
Wood production	
Water production for potable water	
Water provision for transportation	+
Climate regulation	-
Water quality regulation	-
Air quality regualtion	-
Flood protection	
Sedimentation and erosion regulation	+/-
Recreation	+
Heritage	
Cognitive development	
Biodiversity	+

5.4 DISCUSSION AND CONCLUSION

The conversion of a part of the bay, shrubland and mangroves for the port expansion and including the habitat enhancement of the Penrhyn estuary generates both positive and negative effects on ecosystem services (Figure 18, Table 18). The habitat enhancement plan is developed for biodiversity (shorebirds mainly) and recreation. This is also positive for fish production by the development of more nursery area. However, the large areas of habitat that are converted result in negative effects for climate regulation, water quality regulation and air quality regulation. Since the main benefits (recreation and biodiversity) are some of the most difficult ES to put in monetary values, a monetary assessment of this project does not add to an objective project evaluation. The negative effects should be evaluated in a broader management plan for the area (related to water quality, climate, etc.).

TABLE 18.

Summary of the impact of the port expansion project in Botany Bay on ES.

ES	Overall effect	Summary main effect
Fish production	+	increase nursery area
Agricultural production		No impact
Wood production		not relevant since the area is too small to be beneficial for potential harvesting of timber and fire wood from mangroves
Water production		No impact
Water provision for transportation		No impact. Increased possibilities to use this service (economic benefit)
Climate regulation	-	Positive effect of newly created habitat is smaller than the negative effect of the lost habitat
Water quality regulation	-	Positive effect of newly created habitat is smaller than the negative effect of the lost habitat larger areas lost habitat
Air quality regulation	-	loss aboveground vegetation
Flood protection		not relevant, small area
Sedimentation and erosion regulation	+/-	sediment deposition: positive and negative for other functions
Recreation	+	enhanced with the recreation plan
Heritage		no impact; remains are integrated in the design
Biodiversity: shorebirds, marine mammals	+	positive impact on shorebirds is expected, but more time is needed to see the full impact

6. WESTERN SCHELDT CONTAINER TERMINAL (WCT)

6.1 INTRODUCTION

The Western Scheldt container terminal (WCT) is a new deep-sea container terminal in the harbour and industry area of Vlissingen-Oost (east) (Figure 19). This project was initiated by the Exploitation company Scheldt Maas (ESM), a cooperation between Zeeland Seaports and the Harbour Company of Rotterdam. The WCT project is never implemented as a consequence of a negative decision from the Council of State in 2003 due to ‘insufficient investigation of potential effects of the project’. The WCT project as it was planned forms the subject of this chapter and the aim is to investigate if an ecosystem services assessment would contribute to a more consistent study of the potential effects of the project.

All information is based on the most environmental friendly alternative described in the Environmental Impact Assessment report of the project (ESM 2006). The main change compared to previous project alternatives is a shorter quay wall, with fewer effects. The WCT project (total area of circa 160 ha) consists of land winning along the Western Scheldt (130 ha, running from NAP +6.0 meter to NAP +5.0 meter), the construction of a quay wall for both intercontinental and continental shipping (2250 meter long, 500 meter width), sand winning to fill the area between the new quay wall and the old shore, connection of the terminal with the existing roads and railways. The expected cost is €284 million (including hinterland connection) (Ecorys 2006a). The capacity of the terminal is expected to be 1.5 million containers per year or 2.25 million TEU. This will create new jobs in the area, but could also cause (negative) effects in other regions of the Netherlands and Belgium because it will affect neighbouring harbours.

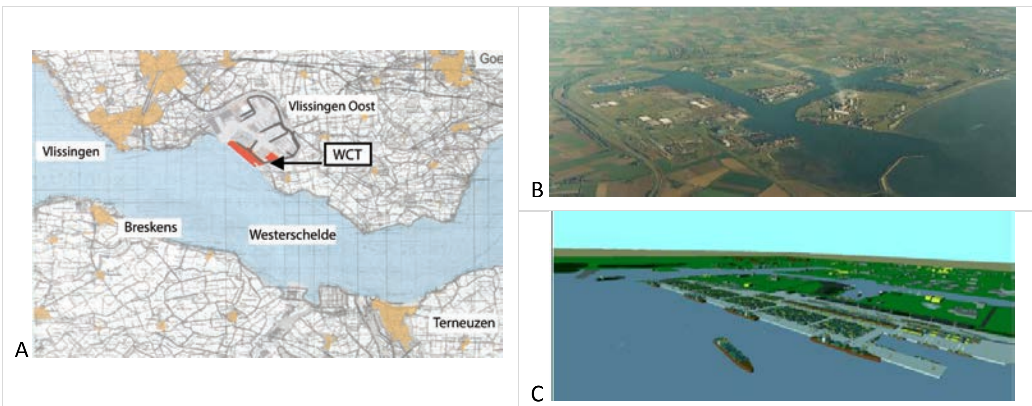
The main target of the project is the creation of additional benefits from the ecosystem service water regulation for transportation. For details regarding the direct benefits of the WCT project for the shipping sector and the labour market in Zeeland, The Netherlands and Flanders we refer to the Cost Benefit Analysis (CPB 2006, Ecorys 2006a, Ecorys 2006b). In the ecosystem services assessment, as presented in this report, additional benefits from other ecosystem services will be assessed.

FIGURE 19.

A – Location of the Western Scheldt Container Terminal (WCT).

B – Aerial photograph of the harbour of Vlissingen (before the project).

C – Visualisation of the planned WCT project.



6.2 HABITAT CHANGES RELATED TO THE WCT PROJECT

With the construction of the new container terminal, deep gullies, shallow water and intertidal estuarine habitat is lost (Table 19). The habitat loss is compensated with an area that is larger than the lost area (166 ha compensation area versus 130 ha habitat lost), but it consists mainly of other habitat types (grassland, reed). In other words, deep gullies and shallow water are not compensated and intertidal estuarine habitat only to a limited extend. To understand the impact of the habitat changes, a detailed ecosystem services assessment of the different habitat types is made.

Subtidal deep habitat: Channel and deep water habitat (51 ha) is lost due to the building of the new quay wall. This habitat is not compensated since there is no obligation and deep water habitat is not rare in the Western Scheldt. Therefore it is considered to have no ecologic effects and the function of the gullies for marine mammals is considered to be untouched (Provincie Zeeland 2002).

Subtidal shallow habitat: Subtidal shallow habitat is lost (22 ha) due to the building of the new quay wall. This habitat is not compensated since it is not rare in the Western Scheldt and it would require high investment costs. It is considered that this money is better spent by realising new marsh area instead (rare habitat in the mouth of the Western Scheldt). Nevertheless, the loss of subtidal shallow habitat is considered to be negative, for example because of its function as resting and breeding area for fish (Provincie Zeeland 2002).

TABLE 19.

Habitat and land use/land cover before and after the WCT project (in hectare).
The habitat areas correspond to the Most Environmental-friendly Alternative for the WCT.

Category	Habitat type	Before WCT	After WCT	Change (ha)
Offshore	Shallow, soft substrate		xx	xx
	Open water			
Shore	Foreshore			
	Beach			
	Lagoon			
Estuary (subtidal)	Subtidal deep habitat	51		-51
	Subtidal moderately deep habitat			
	Subtidal shallow habitat	22		-22
Tidal flat	Bare tidal flat	54	20	-34
	Low tidal marsh		10	+10
	High tidal marsh			
Hard substrate	Artificial reefs at all depth	1	6	+5
Terrestrial	Dunes	0.35		-0.35
	Cropland			
	Grassland		120	+120
	Forest			
	Wetland (reed, shrub)		10	+10
		128.35	166	+37.65

Offshore shallow, soft substrate: Sand to fill the area between the new quay wall and the former shore (about 20 million m³) is mainly retrieved from the existing sand mining area in the North Sea (sandbank Rabsbank, about 70 km shipping distance from the project area).

Bare tidal flat: Intertidal flat habitat is lost (54 ha) due to the building of the new quay wall. Estuarine habitat (protected under the European Habitat Directive, Natura 2000-gebied Western Scheldt & Saeftinghe since 2009) is compensated (ca. 30 ha) by a marsh restoration project (managed retreat) at Schorerpolder (reopening the former connection to the harbour of Middelburg) (Figure 20 right: A). For the further assessment, an area of 20 ha of new intertidal flat is assumed (the remaining 10 ha is assumed to develop as low tidal marsh).

Low tidal marsh: The compensation of intertidal flat habitat creates also opportunities for the development of low tidal marsh, a habitat type not present in the project area (but creation is necessary in the Western Scheldt under the European Habitat Directive). For the further assessment, 10 ha of the compensated estuarine habitat is assumed to develop as low tidal marsh.

Artificial reefs at all depths
Breakwaters (strekdam): A breakwater (1 ha) is lost due to the building of the new quay wall.

Quay wall: With a length of 2250 m and a width of 500 m, an area of 130 ha new quay wall is constructed. The concrete floor is only considered for its benefit regarding shipping opportunities and container traffic. The area of the new quay wall under water is about 6 ha (length 2250 meter and depth 26.75 m. The surface and material of the quay wall are a topic of research because of its potential as artificial reef for algae, anemones, shellfish, etc. (Provincie Zeeland 2002).

FIGURE 20.

Left: location of the compensation area (green) and WCT plan area (red).
Right: Image compensation area.
A: south-east part outside the new dike (intertidal flat 20 ha and marsh 10 ha).
B: north and west part mainly grassland (120 ha) and also reed and willow shrub (10 ha). Reference: ESM, 2009.

Dunes: Dune formation (example Figure 21) at Rammekenshoek, Kaloot and Hooge Platen are affected by the building of the new quay wall. In the Most Environmental-friendly Alternative, only 0.35 ha of dunes will be lost. However, due to the changing morphodynamics in the surrounding area it is expected that erosion will take place in the remaining dunes leaving only water (sand will flush away from the beach). Since the location is part of the Natura 2000 area Western Scheldt & Saeftinghe, the habitat type dunes (embryonic shifting dunes and white dunes) are protected and should be conserved. Making the ES assessment only for the lost 0.35 ha is hence a conservative estimate.

6.3 ECOSYSTEM SERVICES OF THE WESTERN SCHELDT CONTAINER TERMINAL

6.3.1 PROVISIONING ECOSYSTEM SERVICES

Fish production

Following changes in fish production may be associated with the WCT project:

1) Fish biomass and fish catch might be influenced due to sand extraction in shallow, soft substrate.
2) Loss of fish production due to a net loss suitable fish habitat.
3) Improved fish production due to a net increase in hard substrate.

FIGURE 21.
Dune formation. Source: Vereniging redt de kaloot, 2009.

Grassland: The nature compensation area consists mainly of wet grassland (ca. 120 ha) in the Schorerpolder and Welzingepolder (currently mainly agricultural land) (Figure 20 right: B). The location is adjacent to the existing nature areas Rammekenshoek and Rammekonsschor.

Wetland: The nature compensation area consists furthermore also of ca. 10 ha reed and willow shrub (Figure 20 right: B).

The impact of sand extraction (Shallow, soft substrate) on fish biomass and fish catch is negative although it can be very limited depending on the local conditions. Since the impact is location specific, we are not able to present quantitative data. Since an existing sand extraction area will be used, the contribution of the WCT project could be considered rather limited or could add to cumulative effects. For a qualitative description, see 6.3.4 Biodiversity.

Subtidal deep habitat (gully: -51 ha) is used by fish, but the decrease in this habitat type due to the WCT project will not affect fish biomass.

The building of the WCT decreases the area of subtidal shallow habitat (-22 ha) which is considered to be valuable for fish production e.g. for its nursery function. However, knowledge on the role of nursery habitat for fish production is lacking/still weak and therefore the impact of a loss in this habitat for fish production could not be estimated but will be negative.

Bare tidal flat (-54 ha, +20 ha compensation): Idem as for subtidal shallow habitat.

Low marsh (+10 ha compensation): Idem as for subtidal shallow habitat.

Artificial substrate is lost with the removal of a headwater (1 ha) but newly created with the new quay wall (6 ha). Çinar et al. (2008) investigated the mussel production on harbour infrastructure (e.g. concrete blocks) and concluded that the number of individuals (maximum 209,000 ind/m²) and biomass (maximum 24,563 g wet weight per m², see Figure 22) of the assemblages are higher for the harbour locations compared to the reference in the sea, but that number of species and diversity index values (maximum 4.19) were lower (Çinar et al. 2008).
Based on the data from Çinar et al. 2008, the potential increase in mussel biomass due to the WCT project is estimated at ca. 380 ton wet weight. Following numbers are used for this estimate:

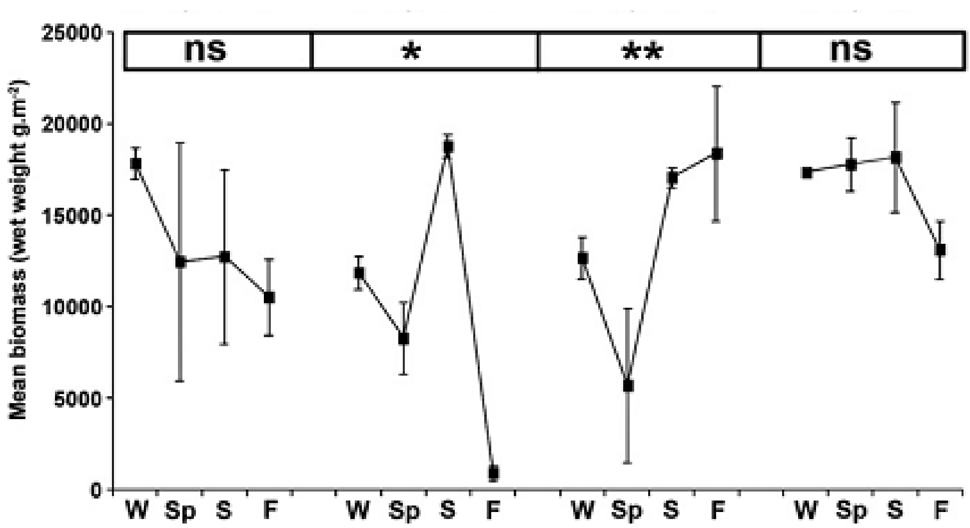
- Net change in surface: - 1 ha headwater, + 3 ha quay wall (we assume that only 50 % of the surface can be covered because of the frequent passage of large ships)
- Mussel biomass: mean 19,000 g wet weight m² (Figure 22) = 190 ton wet weight/ha

Agricultural food production

The building of a new quay wall requires space at the cost of other land uses. Agricultural food production is lost when agricultural land is converted for this purpose. In the case of WCT, land is gained in the river and therefore the ES agricultural food production is not affected in this case. However, for the compensation area agricultural land (crops and livestock) will be lost.

FIGURE 22.

Temporal fluctuations in the mean biomass (g wet weight per m−2) index at each station, with ±standard error. One-way ANOVA was used to find out if the means values of these parameters are significant according to sampling time at each station (*Pb0.01, **Pb0.05, ns = not significant). (W:Winter, Sp: Spring, S: Summer, F: Fall). Source: Çinar et al. 2008.



6.3.2 REGULATING ECOSYSTEM SERVICES

Climate regulation

The WCT project results in a positive effect for climate regulation of 0,1 million €/y due to the changes from bare tidal flat to low marsh (less greenhouse gas emissions) and increased grassland area (see Table 20 for the calculation). Apart from changes in ecosystems (and ecosystem services), the WCT project results in an increase in traffic causing an increase in greenhouse gas emissions of 10 – 40 kton CO2/y (Ecorys 2006a). The increase in GHG emissions due to the WCT project is huge compared to the net additional capacity for carbon sequestration due to the WCT project. The net carbon sequestration increase covers only 7% of the increased GHG emissions.

Water quality regulation

Different aspects of water quality regulation are influenced by the WCT project:

1) Nitrogen removal by burial and denitrification
2) Phosphorous removal by burial
3) Heavy metal removal
4) Carbon removal
5) Effects artificial reefs: new quay wall

(1) Nitrogen removal by burial and denitrification

The WCT project results in a negative effect for nitrogen removal of 192,320 €/y due to the loss of bare tidal flats. The calculation is summarised in Table 21.

TABLE 20.

Calculation: impact of the WCT project on the climate regulation service.

Habitat	Habitat change	Carbon burial[1]	GHG emissions[1]	Economic impact (€/y)[2]		
	ha	ton CO_2-eq./ha/y	ton CO_2-eq./ha/y	From burial	From GHG	Total
Subtidal deep habitat	- 51	0.25		- 765		- 765
Bare tidal flat	- 34	2 - 9	44	- 11,000 (range: 4,000 – 18,000)	+ 90,000	+ 79,000
Low marsh	+ 10	2 - 9	44	+ 3,300 (range 1,200 – 5,400)	- 26,400	- 23,100
Dunes[3]	- 0.35	0		0		0
Grassland	+ 120	7.3		+ 52,260		+ 52,260
Wetland (reed, shrub)	+ 10	24.88		+ 14,928		+ 14,928

[1]see chapter 3.2.1 for more details
[2]Economic value: 60 €/ton CO_2-equivalent
[3]The dunes that are lost are not vegetated (young, white dunes). However, erosion of the remaining, vegetated, dunes will result in negative effects for carbon sequestration (900 kgC/ha/y). This potential negative effect is not taken into account.

TABLE 21.

Calculation: impact of the WCT project on the nitrogen removal service (N burial and N removal by denitrification).

Habitat	Habitat change (ha)	N burial (kgN/ha/y)	N removal by denitrification (kgN/ha/y)	Total N removal (kgN/ha/y)	Economic impact (€/y)[1]
Bare tidal flat	- 34	252	200	452	- 614,720
Low marsh	+ 10	252	107	359	+ 143,600
Grassland	+ 120	35		35	+ 168,000
Wetland (reed, shrub)	+ 10	277		277	+ 110,800

[1]Economic value: 40 €/kg(N)

(2) Phosphorous removal by burial

The WCT project results in a negative effect for phosphorous burial of -33,220 €/y due to the loss of bare tidal flats. The calculation is summarised in Table 22.

(3) Heavy metal removal

The WCT project results in a negative effect for heavy metal removal of - 55,000 €/y due to the loss of bare tidal flats. The calculation is summarised in Table 23.

(4) Carbon removal

The WCT project results in a negative effect for carbon removal of - 4,000 €/y due to the loss of bare tidal flats. The calculation is summarised in Table 24.

(5) Effects artificial reefs: new quay wall

The new container terminal has several effects on water quality: (1) increased turbidity and sedimentation during the construction, (2) water contamination from run off, (3) biomass on the hard substrate is likely to result in a positive impact on local water quality (Paalvast et al. 2012; Kellogg et al. 2013). Overall, a rather negative effect is to be expected.

Summary water quality regulation

Overall, the WCT project results in a negative effect for water quality regulation of -286,235 €/y.

TABLE 22.

Calculation: impact of the WCT project on the phosphorous removal service (P burial).

Habitat	Habitat change (ha)	P burial (kgP/ha/y)	Economic impact (€/y)[1]
Bare tidal flat	- 34	40	- 74,800
Low marsh	+ 10	40	+ 22,000
Grassland	+ 120	1.3	+ 8,580
Wetland (reed, shrub)	+ 10	20	+ 11,000

[1]Economic value: 55 €/kg(P)

TABLE 23.

Calculation: impact of the WCT project on the heavy metal removal service.

Habitat	Habitat change (ha)	Metal (kgCd, Pc etc/ha/y)	Economic impact (€/y)[1]
Bare tidal flat	- 34	7686	- 81,000
Low marsh	+ 10	7686	24,000
Grassland	+ 120	*Unknown*	
Wetland (reed, shrub)	+ 10	109	338

[1]Economic value: 0.31 €/kgCd, Pc etc (Ruijgrok 2006b)

TABLE 24.

Calculation: impact of the WCT project on the carbon removal service (related to the water quality regulation service).

Habitat	Habitat change (ha)	Carbon removal (kgC /ha/y)	Economic impact (€/y)[1]
Subtidal deep habitat (gully)	- 51	68	- 513
Bare tidal flat	- 34	1500	- 7,548
Low marsh	+ 10	1500	2,220
Grassland	+ 120	0	0
Wetland (reed, shrub)	+ 10	1222	1,808

[1]Economic value: 0.148 €/kgC (Ruijgrok 2006b)

Air quality regulation

The WCT project results in a positive effect for air quality regulation (+204,120 €/y). The calculation is summarised in Table 25. Apart from changes in ecosystems (and ecosystem services), the WCT project results in an increase in traffic causing an increase in fine dust emissions of 4 – 547 ton/y PM10 (Ecorys 2006a attachment E). The increase in fine dust emissions due to the WCT project is huge compared to the additional ecosystem capacity to capture fine dust due to the WCT project. The net fine dust removal covers only 1% of the increased fine dust emissions. Furthermore, increased shipping traffic will also result in NOx emissions (95 – 463 ton/y NOx, Ecorys 2006a attachment E).

Flood protection

Large scale sand extraction (Shallow, soft substrate) could change tidal ranges, phases and currents at near but also far distance from the extraction area with consequences for long-term sediment transport (de Boer et al. 2011). This could even have consequences for coastal safety as “bathymetry and coastal morphology result from subtle balances in long-term sediment transport” (de Boer et al. 2011).

Sedimentation and erosion regulation

The sand extraction area (Shallow, soft substrate) is under frequent influence of sand extractions with consequences for biodiversity (benthic species, primary production, fish). Recovery is not really to be expected, at least at short to middle long term, since the extraction area used for the WCT project is widely used for many other projects. The fact that this area is also used by many other projects also implies that the effects are only partially due to the WCT project.

The loss of the deep gully (Subtidal deep habitat, -51ha) forms an important factor for the changes in morphology and currents in the area.

With the disappearance of the bare tidal flat (-54 ha, +20ha compensation), the potential of sediment storage (and hence of reducing sedimentation in the harbour entrance) is lost. The new tidal flat in the compensation area is also located at the entrance of the harbour and could hence compensate for this loss, although only to a small extent because the surface is much smaller. Furthermore, other tidal flats in the surrounding of the project could be influenced by the project due to morphologic and hydrologic changes with possible consequences for sedimentation and erosion and hence the long term existence of these areas.

TABLE 25.

Calculation: impact of the WCT project on the air quality regulation service.

Habitat	Habitat change (ha)	Fine dust removal (kgPM10/ha/y)	Economic impact (€/y)[1]
Shallow, soft substrate		0	
Subtidal deep habitat		0	
Subtidal shallow habitat		0	
Bare tidal flat	- 34	0	
Low marsh	+ 10	18-36	+14,580 (average)
Dunes	- 0.35	0[2]	0
Grassland	+ 120	18-36	+174,960 (average)
Wetland (reed, shrub)	+ 10	18-36	+14,580 (average)

[1]Economic value: The removal of 1 kg of fine dust corresponds to a monetary value of 54 € (Oosterbaan et al. 2006).
[2]In the WCT case, dunes are not vegetated (young, white dunes) and hence do not contribute to fine dust capture. However, erosion of the remaining, vegetated, dunes will result in negative effects for air quality regulation (18-36 kg/ha/y). This potential negative effect is not taken into account.

Low marsh (+10 ha compensation): Idem with bare tidal flat.

The new container terminal (Artificial reefs at all depth) will form a closed wall affecting currents in the area (Provincie Zeeland 2008). This may influence sedimentation processes.

Supply of sand is crucial for the positive growth and development of the dunes not directly affected by the project. Changes in morphology, currents and silt content could hamper this process.

Permanent vegetated land such as grassland (+120 ha) and wetland (+10 ha) contributes to erosion prevention (i.e. not losing the valuable and fertile top layer).

Quantitative estimate: Quantitative data is only available for the sediment storage capacity of intertidal areas and erosion prevention in grassland and shrub. Changes in sediment storage and erosion prevention is estimated at 19,000 €/y. The calculation is summarised in Table 26.

6.3.3 CULTURAL ECOSYSTEM SERVICES

Recreation

The sand extraction area (Shallow, soft substrate) is being used for recreational diving. Since an existing sand extraction area is being used, the WCT project will not improve this service.

- The loss of 54 ha bare tidal flat ('Kaloot' beach) has a negative effect on recreation opportunities. Although part of the beach will remain under the most environmental friendly alternative, it is feared by specialists that morphologic and hydrologic changes will diminish the palaeontological and overall recreation value of the beach. For an estimation of this effect, see 3.3.2 Palaeontology.
  Recreation like walking, independent of the fossils that could be found on the 'Kaloot' beach, is more situated in the existing nature and recreation area south of the project area. This area has the capacity for additional recreation activities (Provincie Zeeland 2002). In addition, also in the nature compensation area recreation opportunities are planned. Both alternatives could however not replace the specific fossil-linked recreation.
- The low marsh (+10ha) created in the nature compensation area can add to new recreation opportunities.
- The loss of 0.35 ha dunes and potential loss of a much larger area of dunes, has a negative effect on recreation opportunities since it forms an integral part of the Kaloot beach.
- The nature compensation area (grassland, wetland, reed, shrub, 130ha) will create new recreation opportunities but cannot replace the typical recreation types present before the project.

TABLE 26.

Calculation: impact of the WCT project on the sediment storage and erosion prevention service.

Habitat	Surface (ha)	Sediment storage (m^3 sediment/ha/y)[1]	Erosion prevention (m^3 sediment/ha/y)[2]	Economic impact[1,2]
Flat	-34	200		-27,200
Marsh	+10	200		+8,000
Grass	+120		0.31	+186
Wetland	+10		0.31	+15.5

[1]Sediment storage capacity intertidal area. Monetary value sediment storage: 4 €/m^3 (Ruijgrok 2006b)
[2]Erosion prevention capacity grassland, shrub. Monetary value erosion prevention: 5 €/m^3 (Ruijgrok 2006b)

Heritage

Palaeontology

The loss of 54 ha bare tidal flat ('Kaloot' beach) has a negative effect on recreation opportunities. Although part of the beach will remain untouched under the most environmental friendly alternative, it is feared by specialists that morphologic and hydrologic changes will diminish the palaeontological and overall recreation value of the beach. The Kaloot beach is one of the rare spots in the Netherlands with marine fossils (www.fossiel.net; www.geologievannederland.nl; www.werkgroepgeologie.nl). Losing this place will create (1) a loss for fossil related recreation and (2) losing the inheritance value (loss of knowledge for future generations). Both elements are valued with the willingness-to-pay method (i.e. the amount of money that people are willing to pay to prevent the loss of the service). The first part is based on a survey among recreants at the Kaloot, the second part among people that value the fossil area. The benefits were estimated in the Environmental Cost Benefit Analysis of the WCT project: €40,000 – €80,000 per year for the recreational benefit and €200,000 – €400,000 per year for the inheritance value (Table 27, Ecorys 2006a Attachment F). This results in a total value of €0.24 – €0.48 million per year. This value is conservative since it does not include the decreasing value of the remaining part of the Kaloot.

Landscape

Cranes (up to 75 meter and maximum 118 meter) and container stacks (up to 9 meter) on the new terminal will disturb the open landscape along the Western Scheldt (Figure 23). This has consequences for (1) people that live in the surroundings, (2) people that come by for recreation, and (3) the inheritance and non-use value of the area. An effect on the living quality could affect the housing prices. For the WCT project, a decrease in housing prices is unlikely since residential areas are not really close and the area had already an industrial character (Ecorys 2006a Attachment F). A decrease in the number of recreants due to the disturbance of the open landscape is expected to be small. The monetary value as estimated in the Environmental Cost Benefit analysis amounts circa €1,000 per year (1095 visits, 1 €/visit willingness to pay). The inheritance value is assumed to be much larger since many people live in the area (residents from Vlissingen, Borsele and Middelburg): €50,000 – €250,000 per year (53,000 residents, €1 – €5 per person) (Table 28, Ecorys 2006a Attachment F). The WCT project will enhance the industrial harbour landscape in the area. The harbour of Vlissingen is important for the economy of Zeeland. More people start to appreciate the presence of important economic centres which could be noted with the high number of visitors during open harbour days (Ecorys 2006a). However, it could be discussed whether this represents peoples appreciation for the industrial landscape.

TABLE 27.

Benefits of the fossil beach 'de Kaloot' (from: Ecorys 2006a Attachment F).

1. Benefits recreation: archaeologists and fossil hunters	WCT alternative
Decrease in number of archaeologists per year (number of visits)	2,555 – 588 = 1,967
Willingness-to-pay per person per visit (euro)	21.20 – 42.40
Benefits for recreation per year (euro)	ca. 41,700 – 83,400
Present value for recreation/archaeology (i=4%) (*million euro)	1.08 – 2.17
2. Benefits palaeontology fossil beach 'de Kaloot'	**WCT alternative**
Number of households in the region (province)	101,100
Willingness-to-pay per household per visit (euro)	1.98 – 3.96
Lost benefits inheritance fossil beach per year (euro)	ca. 200,200 – 400,400
Present value for inheritance fossil beach (i=4%) (*million euro)	5.20 – 10.41

A special designing is planned to make the typical elements that could not be covered (e.g. high cranes) more attractive (e.g. through w ell-chosen colours). Another mitigation measure that is planned is the creation of a forest area as a buffer for the landscape disturbance.

Zeeland Seaports is willing to contribute to the creation of the forest Sloebos to contribute a nicer landscape (Ecorys 2006a).

TABLE 28.

Benefits of the landscape (from: Ecorys 2006a Attachment F).

1. Benefits recreation: landscape	WCT alternative
Decrease in number of additional recreants (number of visits)	1,095
Willingness-to-pay per person per visit (euro)	1.0
Lost benefits recreation per year (euro)	Ca. 1,000
Present value additional recreation (i=4%) (*million euro)	0.03
2. Value of the openness of the landscape	WCT alternative
Number of households in Vlissingen, Borsele and Middelburg (2004)	52,195
Willingness-to-pay per household per visit (euro)	1.00 – 5.00
Lost benefit open landscape per year (euro)	Ca. 53,200 – 266,000
Present value open landscape (i=4%) (*million euro)	1.38 – 6.92

FIGURE 23.

Lanscape views surrounding the project location of WCT (Ruijgrok, 2006).

6.3.4 BIODIVERSITY

Disturbance of the seabed through sand extraction (Shallow, soft substrate) clearly affects bottom fauna communities (benthos) (de Groot 1986, Simonini et al. 2005, Simonini et al. 2007) which in its turn will affect fish communities that feed on benthos (Simonini et al. 2005, Simonini et al. 2007). The impact of sand extraction on fish biomass and fish catch is overall negative although it can be very limited depending on the local conditions. Following factors have negative effects on fish production: excavation on vegetated bottoms, close to migratory routes of fishes, close to spawning areas of fish, and furthermore certain fish are more vulnerable than others (Oulasvirta and Lehtonen 1988; Marchal et al. 2014; de Jong et al. 2014). On the other hand, the water column is enriched by the organic matter attracting suspension-feeders, omnivorous, and/or scavenging species and also fish such as common sole, black seabream, and cod (Marchal et al. 2014). Furthermore, the duration of the effect depends on the frequency of the disturbance. Without continuation of the disturbance, recovery of benthic communities is possible between 1 and 4 years (Simonini et al. 2007; Essink 2005). The latter is however not relevant for the project since the excavation area is in use for many more projects. No quantitative data is presented because the impact is too location specific and in particular because the excavation site is also used for many more projects.
Nevertheless, this does not mean these effects are justified and that mitigation should not be considered if possible. Recent studies show that ecosystem-based landscaping techniques are feasible and effective in influencing fish assemblages (de Jong et al. 2014).

The reduction of channel area (Subtidal deep habitat, -51ha) does not result in ecological effects since its wide presence in the Western Scheldt (Provincie Zeeland 2002). The function of channels for marine mammals is not affected (Provincie Zeeland 2002).

The loss of subtidal shallow habitat (-22ha) results in an irreversible negative effect for fish and bird species (feeding on the habitat). This habitat type is not compensated because this would require radical and very costly measures. It was argued that investing in the creation of intertidal area, rare habitat in the Western Scheldt, would be much more cost efficient and could also contribute to the nursery function in the region.

The loss of bare tidal flat (-54 ha, +20ha compensation) is negative for biodiversity due to its function as feeding and resting area for birds and fish.

Headwaters (-1ha) form a habitat for algae, anemones and shellfish, and hence a feeding ground for birds. The new quay wall (+6ha under water) can form a limited alternative for these fauna and flora species (Provincie Zeeland 2002). Nevertheless, quay walls can function as habitat for mussels (Çinar et al. 2008, De Witte et al. 2014; see ES fish production). Furthermore, recent initiatives of ecological engineering help to improve the habitat provision function of hard engineering infrastructure (Paalvast et al. 2012, Dafforn et al. 2015, Coombes et al. 2015; see ES fish production).

The dune area lost (-0.35ha) with the WCT project is limited in size and not rich in species composition, but 18 butterfly species and some protected plant species have been found there (Provincie Zeeland 2002). Therefore, the loss of the dune area will have a limited but negative result.

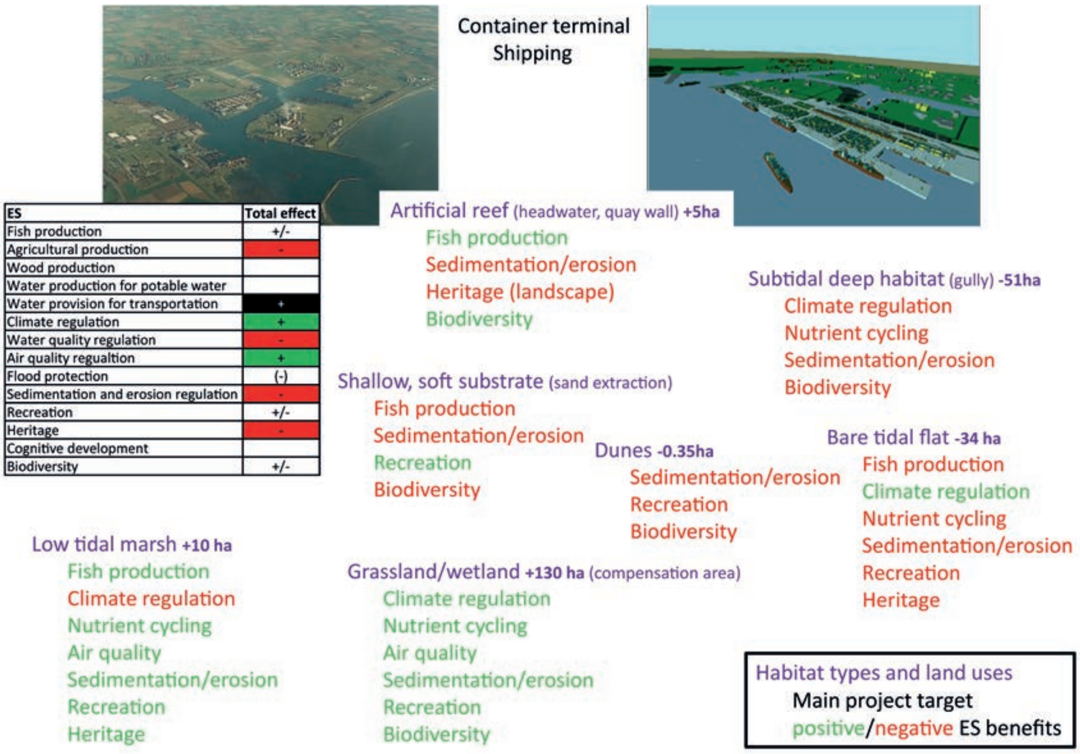
Compensation area (+130ha): The intertidal area (outside the new dike) can only partly compensate the loss in bare tidal flat. The grassland and shrub is larger than the area that is lost, but will result in a shift in fauna and flora. The compensation area will consist of a freshwater to saline gradient and elevation gradient, which contributes to a higher biodiversity. The main part of the compensation area is not intertidal and hence not valuable for marine fish species. However, this area can have a large contribution for bird species (for breeding, feeding, resting). The creation of a new dune system in the compensation area will form a habitat for protected plant species such as sea holly (Eryngium maritimum) and samphire (Crithmum maritimum) (Provincie Zeeland 2002).

6.4 DISCUSSION AND CONCLUSION

The WCT project results in an overall negative effect for ecosystem services (Figure 24). The economic evaluation of changes in ecosystem services shows a loss of 0.5 million €/y (Table 29). This is low compared to the expected investment cost of €284 million. However, the evaluation of other effects, not in monetary value, suggests a larger loss due to the deterioration of ecosystem services (fish production) and other environmental problems (increase in GHG emissions, increase in fine dust and NOx emissions, noise pollution, etc.). For recreation and biodiversity, the compensation area could contribute to increase the service. However, the types of recreation and biodiversity will change and it is not really possible to give an objective opinion on whether these changes are good or not. On the other hand we may off course not forget the economic benefits of the project for the harbour and broader employment in the region. Estimates of the benefits are highly discussed due to difficulties to predict future prognoses for container traffic and also potential (negative) consequences for other harbours and employment in the Netherlands and Flanders (CPB 2006, Ecorys 2006a, Ecorys 2006b).

FIGURE 24.

Overview changes in land use and land cover with associated benefits and negative effects. The main benefit for the container sector (black: shipping) is the main project benefit considered in the initial project evaluation. All additional ecosystem services effects are indicated in green (if positive) or red (if negative).



ES	Total effect
Fish production	+/-
Agricultural production	-
Wood production	
Water production for potable water	
Water provision for transportation	+
Climate regulation	+
Water quality regulation	-
Air quality regualtion	+
Flood protection	(-)
Sedimentation and erosion regulation	-
Recreation	+/-
Heritage	-
Cognitive development	
Biodiversity	+/-

Nevertheless, many options are possible to reduce the negative effects:

Quay wall:
negative effects on habitat and biodiversity

- In the most environmental friendly alternative, a shorter quay wall is suggested leaving part of the Kaloot beach and most of the dunes untouched. The positive ecological effect of this alternative is in reality diminished by the fact that also the remaining habitats will suffer from indirect effects (e.g. changes in morphology and currents).
- Recently, initiatives to improve the habitat provision function of hard engineering infrastructure are initiated with ecological engineering (Dafforn et al. 2015). Different techniques are being investigated, such as: adding complexity and microhabitats (Dafforn et al. 2015, Figure 25), using fine-scale textural manipulations in concrete coastal infrastructure (Coombes et al. 2015), and using hanging ropes of different materials (Paalvast et al. 2012). The success of these experiments was overall positive to increase biodiversity. Biomass production was investigated for the hanging rope structures (Paalvast et al. 2012).

Quay wall:
negative effects on landscape and amenity

- High cranes will always remain visible from some distance, but with a special design and for example well-chosen colours at least the attractiveness could be increased.
- A forest area could function as a buffer to reduce landscape disturbance. Zeeland Seaports is willing to contribute to the creation of the forest Sloebos to contribute a nicer landscape (Ecorys 2006a).

Paleontological importance of the Kaloot beach:
compensation options

- An option is to dredge fossils and dispose it on a location accessible by the public. This is valuable for recreation but also from a scientific perspective because this will give additional knowledge regarding the layers where the fossils are found. This information is lacking when the fossils are drifted ashore (Ecorys 2006a).

Compensation area:
loss of agriculture

- Grazing on grassland gives opportunities to combine nature development with agriculture.

Emissions:
GHG, fine dust, NOx

- Reduce GHG, fine dust, NOx emissions from machinery and vessels.

FIGURE 25.

Example of an unplanned (A) and managed (E) coastal and offshore scenario. A. Unmodified homogenous seawalls for coastal defence lack a diverse natural assemblage (Photo: R. Morris), Eco-engineering of structures to enhance biodiversity (e.g. “flowerpots”) (Photo: R. Morris). Taken from Dafforn et al. 2015.

TABLE 29.

Overview ES effects WCT project: qualitative (positive or negative), or monetary (€/y).

Category	Habitat type	Change (ha)	Fish production	Water provisioning for transportation	Climate regulation (€/y)	Water quality (€/y)	Air quality (€/y)	Sedimentation, erosion (€/y)	Recreation	Heritage (palaeontology, landscape) (€/y)	Biodiversity	**TOTAL (€/y)**	**Overall effect**
Offshore	Shallow, soft substrate	xx	(NEG)					NEG	(POS)		NEG		**NEG**
Estuary (subtidal)	Subtidal deep habitat	-51			-765	-513		NEG			NEG	**-765**	**NEG**
	Subtidal shallow habitat	-22	NEG								NEG		**NEG**
Tidal flat	Bare tidal flat	-34	NEG		+78,780	-778,068		-27,200	NEG	- 360,000	NEG	**- 1 million**	**NEG**
	Low tidal marsh	+10	POS		-23,100	+191,820	+14,580	+8,000	POS		POS	**+ 190,000**	**POS**
Hard substrate	Artificial reefs at all depth	+5	POS (e.g. 380 ton mussels)					NEG		-150,000	POS	**-150,000**	**POS**
Terrestrial	Dunes	-0.35			0			NEG	NEG		NEG	**-510**	**NEG**
	Grassland	+120			+52,260	+176,580	+174,960	+186	POS		POS	**+400,000**	**POS**
	Wetland	+10			+14,928	+123,946	+14,580	+15.5	POS		POS	**+150,000**	**POS**
SUMMARY			**NEG**		**+122,103**	**-286,235**	**+204,120**	**-18,999**	**POS (based on ha); but shift**	**- 510,000**	**POS (based on ha); but shift**	**-0.5 million**	**POS/NEG**
Additional information				*Positive (infrastructure; not ES)*	*-1.5 million (additional traffic emissions)*		*-15 million (additional traffic emissions)*						

7. SAND ENGINE

7.1 INTRODUCTION

The sand engine is a mega suppletion of 21 million m³ which is deposited on the foreshore near Ter Heijde/Kijkduin (Hoek van Holland, The Netherlands). It is an innovative pilot project developed to study the potentialities of a mega nourishment as a more efficient, economical and environmentally friendly alternative to counteract the effects of coastal recession (Stive et al. 2013). The project is designed in such a way that it should also generate additional benefits for nature development, recreation and knowledge development. In this chapter, the main benefits from flood protection are calculated and effects on different ecosystem services are assessed.

7.2 HABITAT CHANGES RELATED TO THE SAND ENGINE

Following habitats are associated with the sand engine (based on van der Moolen 2015): foreshore, beach, lagoon, brackish lake and dunes. The sand engine is a highly dynamic feature and the surface area of each habitat changes over time. Especially during the first years after construction high volumes of sand have been displaced. The pace at which sand is displaced decreases over time.

FIGURE 26.

Identification of habitats in different stages of the sand engine (photographs: Joop Van Houdt in van der Moolen 2015; habitat indication: van der Moolen 2015). Terms of the different geomorphic features slightly differ with terms used in the project: tidal flats are considered part of the beach; sandbanks are part of the foreshore.

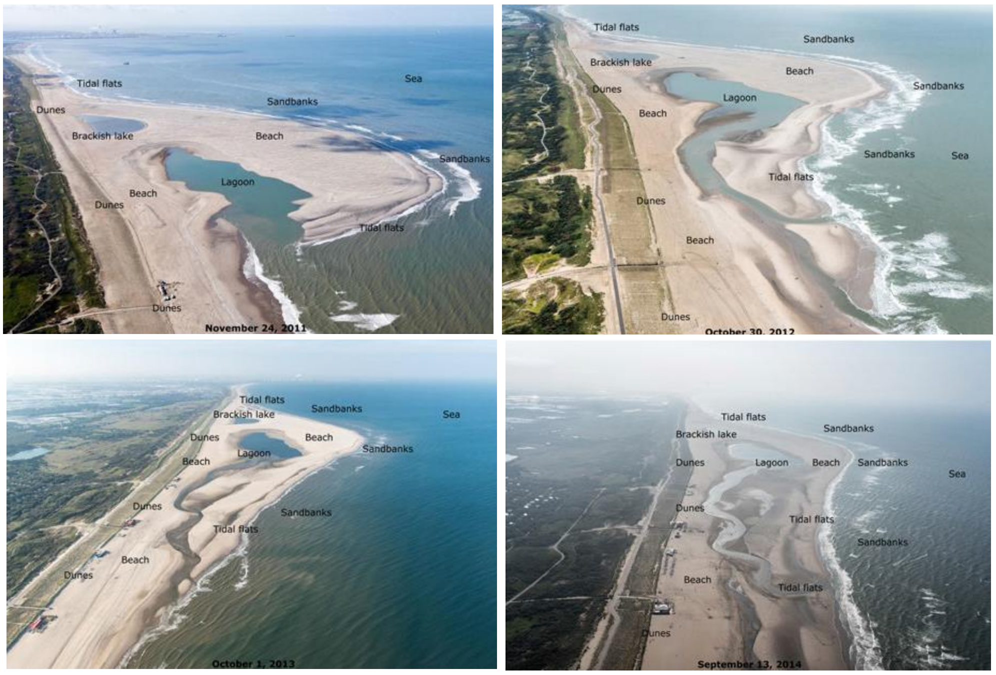


TABLE 30.

Habitat before and after deposition of the sand engine (in hectare).
Based on voorkeursalternatief Haak-Noord MER (DHV 2010) and data from Stive et al. 2013. * extrapolation.

Category	Habitat type	Before SE	After SE Year 0	Year 10	Year 20
Offshore	Shallow, soft substrate		xx	xx	xx
Shore	Foreshore	755-815	0	276-320	603-632
	Beach	32	762-822	435-496	200
	Lagoon		17	14	8
Terrestrial	Dunes			14-17 *	28-33
	Dune lake		7.5	7.5	7.5

Shore: The shoreline and associated habitats are drastically impacted by the deposition of 21 million m³ of sand. The largest part is deposited on the foreshore below the mean low water level. A total of 755 to 815 ha of foreshore is lost (Table 30), and replaced by the newly created beach habitat. Additionally, 32 ha of existing beach is buried under the sand engine. This burial has a temporary negative effect on benthos and on the food web dependent on it. Recovery of benthos after suppletion is expected to take 1 to 2 years (DHV 2010). Maintenance of the sand engine on the long term (> 20 y) would result in a regular disturbance every 20 years. On the beach, a brackish lake is created which is not expected to diminish in size, and a lagoon of which the initial wide opening to the sea quickly becomes narrowed down to a 50 m wide channel. The size of the lagoon diminishes over time but is still expected to be present after 20 years (Stive et al. 2013). The largest part of the beach will be lost but ~200 ha is expected to remain after 20 years (Stive et al. 2013).

Dunes: Dunes are growing gradually as a result of eolian sand transport from the sand engine's beach, deposition in front of existent dunes and subsequent colonisation by pioneer species (Natura2000 habitat embryonic dunes) and Amophilia arenaria or marram grass (Natura2000 habitat white dunes). Due to the seaward extension of the dune foot, existing white dunes become more and more cut off from eolian sand supply and transform into more fixed dunes (Natura2000 grey dunes and buckthorn shrub). The thus lost area of white dunes will be fully compensated by the newly created white dunes.

Offshore: The sand of the mega suppletion is extracted about 10 km offshore. This results in local habitat destruction and temporary reduction of primary and secondary production. The reduction in primary productivity results from increased turbidity (sediment plume) and decreased light availability for algae. The reduction in secondary production results from destruction of habitat of benthic species. The effects on habitat are relatively small in comparison with the available area of similar habitat in the North Sea. The impact is also temporary with an expected restoration of the benthic life after 1 to 4 years (Simonini et al. 2007; Essink 2005).

7.3 ECOSYSTEM SERVICES OF THE SAND ENGINE

7.3.1 PROVISIONING ECOSYSTEM SERVICES

Fish production

The environmental conditions make the lagoon particularly suitable as nursery area for flatfish and other organisms. The water is sheltered from intense wave action and slightly warmer in comparison to the open sea. The deposition of fine, nutrient rich sediment resulting from reduced wave action are a food source for benthic species upon which juvenile fish feed.

A threat to the production of juvenile fish is eutrophication and the reduction of dissolved oxygen by excessive algae growth. A healthy population of filter feeding benthos species may reduce the risk of eutrophication (van der Moolen 2015). The economic value of nursery area is related to the potential benefits for production of commercially important fish (mainly flatfish). Very little research is available that monetizes this value. De Groot et al. (1992) estimated the value of the nursery function of the Wadden Sea to be 281 €/ha/y (taking into account USA consumer price index and the conversion from USD to EUR). For a total area of 8 to 17 ha (Table 30), this comes to a yearly benefit varying between €2417 and €4777, and a total benefit of €0.08 million after 20 years.

Fresh water production

Coastal dunes are very suitable for the production of drinking water because of the rapid infiltration through the coarse sand and the relatively easy way to exploit the aquifer. The sand engine is located close to an existing water production area in the Solleveld dunes and is expected to affect fresh water availability. The seaward extension of the beach created by the mega suppletion shifts the interface between salt and fresh water seawards (Figure 27). This shift, together with the growing dune formation north and south of the sand engine, is expected to increase the volume of the coastal aquifer and the capacity for drinking water production.

An increase in the volume of the dune aquifer can only be realized after a certain period of time and depends on the width of the beach at that time. In the EIA-study (DHV 2010) it was predicted that maximum replenishment is achieved after 10 years, when the seaward extension of the beach is ~600 m (Stive et al. 2013). The freshwater reserve was estimated to be replenished with a maximum of 50000 m³ extra water per year. This volume diminishes with decreasing width of the beach over time. After 20 years, the width of the beach is expected to be ~450 m (Stive et al. 2013). Assuming a linear decrease of volume of water with width of the beach, the volume of water decreases with 1250 m³/y between 2021 en 2031 (Table 32). The building up of the extra water reserve from 2011 to 2021 is also expected to be linear with time.

TABLE 31.

Estimated benefits from fish production resulting from functioning of the lagoon as nursery for flatfish.

year	ha	€/y	year	ha	€/y
2011	17.0	4777	**2021**	14	3934
2012	16.7	4693	**2022**	13.4	3765
2013	16.4	4608	**2023**	12.8	3597
2014	16.1	4524	**2024**	12.2	3428
2015	15.8	4440	**2025**	11.6	3260
2016	15.5	4356	**2026**	11	3091
2017	15.2	4271	**2027**	10.4	2922
2018	14.9	4187	**2028**	9.8	2754
2019	14.6	4103	**2029**	9.2	2585
2020	14.3	4018	**2030**	8.6	2417

FIGURE 27.

Coastal aquifer (water.usgs.gov, February 2016).

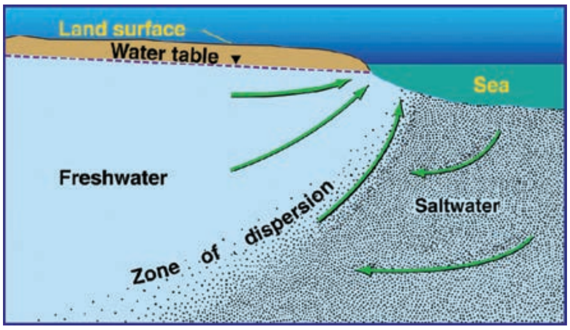


TABLE 32.

Estimated volume of additional recharge resulting from sand engine.

Year	Volume (m³/y)	Year	Volume (m³/y)
2011	5,000	2021	48,750
2012	10,000	2022	47,500
2013	15,000	2023	46,250
2014	20,000	2024	45,000
2015	25,000	2025	43,750
2016	30,000	2026	42,500
2017	35,000	2027	41,250
2018	40,000	2028	40,000
2019	45,000	2029	38,750
2020	50,000	2030	37,500

Table 32 summarizes the estimated volume of freshwater produced by the sand engine and the monetary value per year (0.075 à 0.2 €/m³). Over a period of 20 years, an additional benefit of €0.05 to €0.14 million is created for the drinking water production sector.

The sand engine might also negatively affect drinking water provision. The extra volumes of sand alter the groundwater flows of fresh and salt water in the area where water is abstracted. To prevent pollution and salinization of the freshwater lens some technical measures were taken, reducing the small benefits for drinking water provision.

7.3.2 REGULATING ECOSYSTEM SERVICES

Climate regulation

The reduced stream velocity in the lagoon favors the deposition of fine sediment, rich in organic matter. The size of the lagoon is expected to reduce with 9 ha over a period of 20 years due to this sedimentation. The lagoon thus constitutes a permanent sink for carbon, in case no measures are taken to maintain the size of the lagoon. With an average sedimentation rate of 2.8 cm/y (see paragraph 3.2.1), the amount of carbon stored in the lagoon is summarized in Table 33.

Over a period of 20 years, a total amount of 1902 tons of carbon is sequestered, with a value of €0.42 million. The loss of the area of foreshore habitat is not taken into account as this habitat is negligible in terms of carbon storage (Beaumont et al. 2007).

Water quality regulation

The reduced stream velocity in the lagoon favors the deposition of fine sediment, rich in organic matter and nutrients, thus increasing primary production by algae. Benthic species that feed upon algae benefit from their growth and from the slightly warmer water and sheltered conditions in the lagoon. Within the lagoon, higher densities and diversity of benthic communities have indeed been reported (van Gelder-Maas 2014). The presence of high densities of benthic species may contribute to water quality regulation of the open sea by removing (excessive) nutrients flowing in with the tide or supplied from the land (run-off or river discharge).

Well-developed communities of benthic species are also important to maintain water quality within the lagoon itself. By feeding upon algae and subsequently being fed upon by fish and birds they help remove excessive nutrients from the lagoon system. The assimilation of nutrients for their growth and temporary retention in the sediment after die-off can help mitigate eutrophication. This reduces the risk of oxygen depletion, fish mortality and unpleasant conditions for recreation (odor and murkiness).

The deposition of the sand engine has negative effects on water quality regulation due to the disappearance of a large area of foreshore, but the functioning of the lagoon for nutrient storage

TABLE 33.
Amount of carbon stored in the lagoon per year.

year	ha	ton C/y	year	ha	ton C/y
2011	17.0	120.0	**2021**	14.0	98.8
2012	16.7	117.9	**2022**	13.4	94.6
2013	16.4	115.8	**2023**	12.8	90.3
2014	16.1	113.6	**2024**	12.2	86.1
2015	15.8	111.5	**2025**	11.6	81.9
2016	15.5	109.4	**2026**	11.0	77.6
2017	15.2	107.3	**2027**	10.4	73.4
2018	14.9	105.2	**2028**	9.8	69.2
2019	14.6	103.0	**2029**	9.2	64.9
2020	14.3	100.9	**2030**	8.6	60.7

TABLE 34.

Effects of the sand engine on water quality regulation per year and integrated over period of 20 years (* median of the estimated range in Table 30).

	Area (ha) *		Denitrification x 10^3 kg N/y		N burial x 10^3 kg N/y		P burial x 10^3 kg P/y	
	Foreshore	Lagoon	Foreshore	Lagoon	Foreshore	Lagoon	Foreshore	Lagoon
2011	-785	17.0	-16.88	1.07	-0.40	20,21	-0.08	1,30
2012	-755	16.7	-16.23	1.05	-0.39	19,86	-0.08	1,28
2013	-725	16.4	-15.59	1.04	-0.37	19,50	-0.07	1,26
2014	-695	16.1	-14.94	1.02	-0.35	19,14	-0.07	1,24
2015	-665	15.8	-14.30	1.00	-0.34	18,79	-0.07	1,21
2016	-635	15.5	-13.65	0.98	-0.32	18,43	-0.06	1,19
2017	-605	15.2	-13.01	0.96	-0.31	18,07	-0.06	1,17
2018	-575	14.9	-12.36	0.94	-0.29	17,72	-0.06	1,14
2019	-545	14.6	-11.72	0.92	-0.28	17,36	-0.05	1,12
2020	-515	14.3	-11.07	0.90	-0.26	17,00	-0.05	1,10
2021	-487	14.0	-10.47	0.88	-0.25	16,65	-0.05	1,07
2022	-455	13.4	-9.78	0.85	-0.23	15,93	-0.05	1,03
2023	-423	12.8	-9.09	0.81	-0.22	15,22	-0.04	0,98
2024	-391	12.2	-8.41	0.77	-0.20	14,51	-0.04	0,94
2025	-359	11.6	-7.72	0.73	-0.18	13,79	-0.04	0,89
2026	-327	11.0	-7.03	0.69	-0.17	13,08	-0.03	0,84
2027	-295	10.4	-6.34	0.66	-0.15	12,37	-0.03	0,80
2028	-263	9.8	-5.65	0.62	-0.13	11,65	-0.03	0,75
2029	-231	9.2	-4.97	0.58	-0.12	10,94	-0.02	0,71
2030	-199	8.6	-4.28	0.54	-0.10	10,23	-0.02	0,66
2011 -	**TOTAL**		**-213.5**	**17.01**	**-5.06**	**320.44**	**-0.99**	**20.68**
2030	***VALUE (€)***		***€-7.86 million***		***€12.62 million***		***€0.79 million***	

compensates this loss. The sand engine results in a total benefit for water quality regulation of €5.55 million over a period of 20 years.

Flood protection

The sand engine was developed to test the efficacy of a new form of coastal protection (Stive et al. 2013). The aim of the sand engine is to feed local and adjacent beaches (north and south) along a stretch of 10 to 20 km. The grain size of the mega suppletion is such that sand can be transported by the wind and deposited in the dunes, thus supporting dune formation and keeping existing dunes vital. The choice of the location of the sand engine is driven by the fact that it is a pilot project to study better and more sustainable ways of coastal protection in the future. Although the sand engine has a positive impact on the sand balance, the actual benefits to protect against storms are relatively small due to several measures that were taken in the years before its construction (DHV 2010). The main benefit of the sand engine on the short term is the replenishment of eroding suppletions carried out before 2011. The expected seaward extension of the dunes (20 – 40 m) after 20 years is also minor in comparison with the 200 m wide existing dunes (DHV 2010).

To get an idea of the potential impact of the sand engine on flood protection, an estimate is made of the benefits in case no previous safety measures would have been taken. The economic damage resulting from a flood at the coast near the sand engine (Ter Heijde) varies amongst different studies. Jonkhoff et al. (2008) calculated the damages for a storm in 2100 at €11.5 billion (taking into account inflation and 0% disconto).

Berendsen et al. (2005) find a total costs from a flood with a return period of 1/100000 at €24 billion (incl. inflation). Rijkswaterstaat Dienst Getijdewateren (in Berendsen et al. 2005) estimates for the same flood a cost of €48 billion (incl. inflation). In this project, the average of the three estimates is used: €27.8 billion, or 0.28 million €/y for a period of 100,000 years. The total benefits from protection against floods for the life span of the sand engine are thus expected to be €5.6 million, in case the coastal section would not have been reinforced in the years before construction of the sand engine.

The deepening of sand banks resulting from the extraction of sand on the other hand may negatively affect flood protection. At the time of writing no literature was available that quantifies this effect related to the sand engine. According to Verwaest et al. (2008) it can be expected that the effect is negligibly small if the extraction takes place at a certain distance from the shoreline and below a certain depth.

7.3.3 CULTURAL ECOSYSTEM SERVICES

Recreation

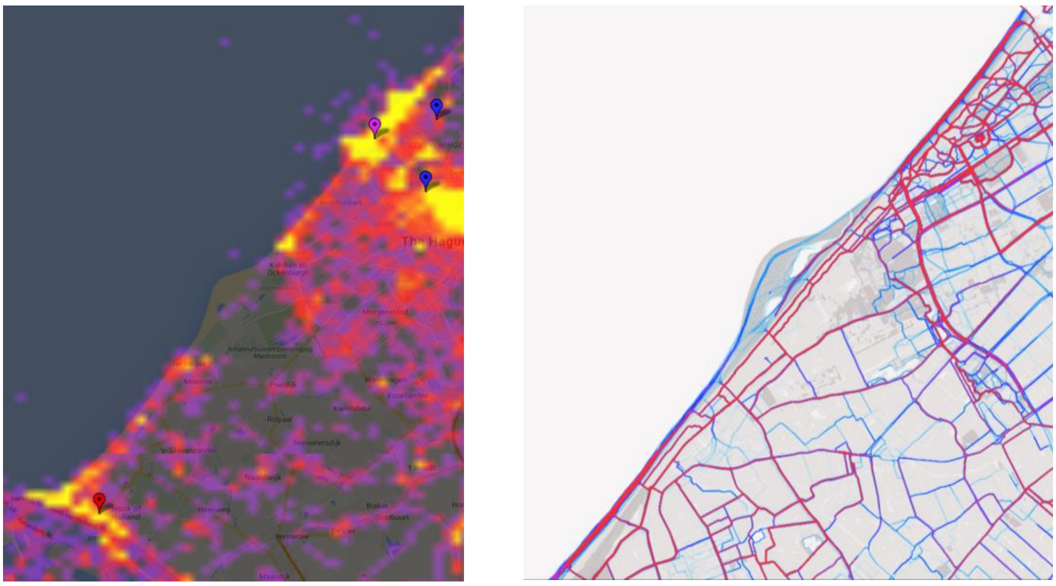
One of the main goals of the sand engine, besides safety, knowledge development and nature, is recreation. The drastic increase in beach and dune area is expected to benefit the recreational sector. As no quantitative information is available on the number of visitors before and after the construction, alternative sources were used to assess the impact of the sand engine on recreation.

Figure 28 shows two maps of indicators of the relative amount of visitors on and around the sand engine. The map on the left shows the sightseeing popularity based on the number of pictures taken, the map on the right shows the popularity of the place for joggers. The number of recreants on and around the sand engine does not seem to be remarkably higher than in the surrounding coastal areas. Several management or demographic related factors may explain this, such as number of inhabitants in the surroundings, presence of recreational facilities, promotion and type of recreation.

The sand engine for example has become a

FIGURE 28.

Frequency of photos taken since 2012 (left) and runners in 2015 (right) on and around the sand engine.
Left: yellow = high frequency (Sightsmap, sightsmap.com).
Right: blue = low frequency, red = high frequency (Strava Global Heatmap, labs.strava.com).
Images downloaded 25/01/2016.



popular place for kite surfers. These types of recreation might not be reflected in the images below. Factors more related to the ecosystem may also play a role. The increase in the width of the beach and the distance people have to walk to get to the sea or to drinking or eating facilities for example may negatively affect tourism. Safety for swimming and walking and water quality of the lagoon may also affect recreational potential of the sand engine. Wave conditions in the bay at the northern side of the sand engine are milder and may be more pleasant for swimmers. The seaward limit of the sand engine however creates conditions of increased stream velocity and risks for swimmers. Different types of atypical currents flow in offshore (rip currents and return currents) or longshore directions (van der Moolen 2015). Also, the water flowing in and out the bay through the channel has a relatively high stream velocity and may surprise inattentive swimmers. The water quality in the lagoon may decrease because of algal growth and accumulation of faecal bacteries of birds (DHV 2010). Algal growth is especially a risk for the lagoon where a combination of reduced stream velocity favors deposition of fine, nutrient rich sediments and shallow, warmer water are favorable for plant growth. A high concentration of algae on its turn decreases the availability of oxygen, creating conditions in which bacteria produce sulphur (van der Moolen 2015). The associated odor may affect recreation. Incidents have also happened with hikers that were surprised by the upcoming tide and got stuck on the sand engine. The need for lifeguards, technical measures to reduce current velocities (e.g. excavation of trench, dumping of stones), information signs and investments to keep the water clean increases the costs of the project (not taken into account in the valuation).
The relative amount of visitors near the sand engine compared to the surrounding coastal areas at a certain point in time does not give a complete image of the effects of the sand engine on recreation. A comparison of the number of visitors before and after the deposition of the sand engine would give a more comprehensive picture of the impacts of the sand engine on recreation. This information however is lacking at the time of writing but is expected to be included in the 2016 evaluation.

As mentioned earlier, not all types of recreation are reflected in the images above and the place is especially popular for kite surfers. It is specifically the lagoon with still and shallow water, the wide open space and the particular wave climate on the seaside that is appealing for kite surfers. Other water sports such as windsurfing also benefit from the sand engine. The importance of the sand engine for water sports is underlined by the establishment of a kite and wind surf school on the sand engines' beach. Based on consultation of the owners of the kite surf school we estimated the number of kite surfers that visit the sand engine per year. Kite surfers visit the area only on days with at least 12 knots wind speed (about 314 days per year in Vlissingen, www.klimaatatlas.nl). On warm, windy summer days (>20°C) about 300 kite surfers visit the area and on other windy days about 40. Temperatures reach >20°C about 65 days per year in Vlissingen (www.klimaatatlas.nl). The number of visitors can then be calculated by multiplying the chances for the different weather conditions with the number of estimated visitors in each condition and summing up the total number of visitors in each weather condition as follows:

$$\left(\frac{65 \times 314}{365}\right) \times 300 + \left(\frac{300 \times 314}{365}\right) \times 40 = 16775 + 10323$$

The average number of kite surfers that visit the sand engine per year is thus estimated to be 27098.
Average daily spend for water recreation by day trippers in 2013 in Flevoland was 39.29 €/day/visitor (ZKA Consultants & Planners 2014). This includes costs for travel, storage of material, courses, … If we assume all kite surfers are day visitors, than the total amount spent by kite surfers on the sand engine per year is estimated to be €1.06 million, or €20.29 million in 20 years time. The added value for the economic (10% of the spending) is estimated to be 0.11 million €/y, or €2.03 million in 20 years. This is probably an underestimation of the real budget spent in recreation as it does not take into account expenses related to overnight stays and visits other than for water sports.

It can be concluded that the positive effects of the sand engine on recreation are mostly situated in a widening of the scope of recreational activities (Voortgangsrapportage Zandmotor 2014) and therewith associated increase in number of visitors. Research also demonstrated that the appreciation of the area by visitors has increased, in part because of the ever changing landscape (van Gelder-Maas 2014). Additional benefits from the sand engine may be related to alleviation of other areas with intense recreation during hot summer days.

Cognitive development

The sand engine is a pilot project to study the effects of a mega nourishment on coastal safety, recreation and nature. The development of generic knowledge and innovation are amongst its main targets. An intense and long-term monitoring program was set up to study the primary impacts for which it is designed (safety, recreation, nature) and secondary impacts on ecological structures and processes (groundwater, salt intrusion, swim water quality, hydrodynamic conditions, sediment composition, …), see Figure 30. Research investments are financed by governments, dredging and other private companies, non-profit organizations, knowledge institutes and the European Union. As explained in paragraph 3.3.3, the investment costs in research and monitoring are not representative for the added economic value generated by the developed knowledge and should therefore not be used for the monetary valuation of this service. The total invested costs however can be used as a qualitative indicator for the importance of the sand engine for cognitive development. Another qualitative indicator is the number of scientific reports and publications.

The Monitoring and Evaluation Plan foresees a budget of €6.80 million until 2015 for monitoring and evaluation (Dulfer et al. 2014). Part of the monitoring and research was also financed in the frame of the Building with Nature research program (2008-2012), in which a total amount of €6.75 million was dedicated to the sand engine. The NatureCoast program and NEMO (Nearshore Monitoring and Modelling) continue the investment in research and analyses of monitoring data. NatureCoast foresees a budget of €5.15 million to be invested over a period of 5 years (starting in 2013). With this budget at least 3 postdoc researchers, 12 doctoral students and 7 non-scientific personnel members will be employed. NEMO employs 3 postdocs and 3 doctoral students.
As the goal of the sand engine is to study its long term impacts, it can be expected that investments in research will continue. It is however unclear whether a similar amount of money will be spent, as the morphological evolution of the coast will be at a slower pace than during the first years after construction, and a lot of understanding will already be gained during the first monitoring programs. With the mid-term evaluation of 2021 in mind, we assume that at least one extra research program of similar extent as NatureCoast will be financed (€5.15 million). It is also assumed that monitoring in the frame of the Monitoring and Evaluation Plan will continue at least until the midterm evaluation. With an average cost of €333667 per year, this comes to a total of €2 million (2016-2021). The total amount of money spent in research is expected to be at least €25.85 million (Figure 29).

Up till now, 7 peer-reviewed papers have been published that contain the term ‘sand engine’ or ‘sand motor’ (Web of Science), with 29 citations in total. Through Google Scholar, a total of 778 scientific publications were found for the terms ‘sand engine’, ‘sand motor’ or ‘zandmotor’, of which several study the potential for application of sand engine-like structures in other areas.

Other cultural services

Other cultural services delivered by the sand engine are heritage and education. The sand of the sand engine is extracted 10 km offshore and contains bone remnants from land mammals dating back to the Quaternary. These attract fossil hunters. No information is available on the amount of people visiting the area for fossil hunting. It is however expected that this is a relatively small number and that there is an overlap with the service ‘recreation’ as illustrated in Figure 28 (left).

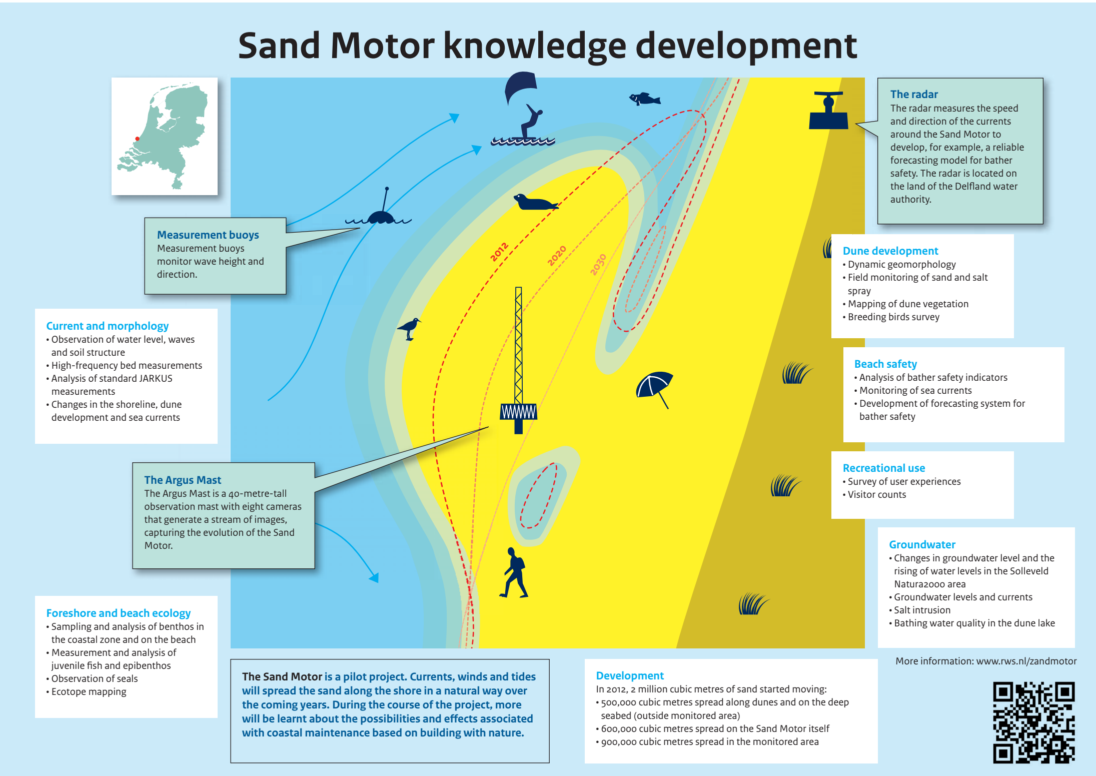
FIGURE 29.

Overview of investments in monitoring and research related to the sand engine (* assumption).

Program	Period	Budget (million €)
Monitoring en Evaluatie Plan	2010 – 2015	6.80
Building with Nature	2008 – 2012	6.75
NatureCoast	2013 – 2018	5.15
NEMO	2013 – 2018	*No data*
Monitoring en Evaluatie Plan	2016 – 2021	2.00 *
Midterm	2019 – 2021	5.15 *
TOTAL		25.85

FIGURE 30.

Overview of monitoring efforts on and around the sand engine (translated from www.dezandmotor.nl).



Excursions for groups of students and organizations are also given on a regular basis. In 2013, Zuid Hollands Landschap and ARK Natuurontwikkeling organized 16 excursions with a total of 250 participants (Update Kennisontwikkeling Zandmotor 2013). An excursion costs €34.50 per person (www.zuidhollandslandschap.nl). If we assume the number of participants continues to be of the same magnitude as previously, a total amount of €0.17 is generated through excursions on the sand engine (20 years * 250 persons/year * 34.50 €/person). Excursions organized by other institutes are not included. For excursions there might also be overlap with the service 'recreation' as illustrated in Figure 28 (left).

7.3.4 BIODIVERSITY

The sand engine generates many opportunities for biodiversity which may otherwise not exist. The sand engine creates multiple gradients in the physical environment, thus providing possibilities for different usages (nursery, forage, hatching, refuge, resting). The lagoon functions as a nursery area for several types of fish, the dry sands are used by certain species of birds for nesting, the most remote areas that are hard to reach by people are used by seals for resting (van der Moolen 2015).
Highly dynamic areas (seaward of the suppletion and in the channel connecting the lagoon with the sea) alternate with low dynamic areas (western part of the lagoon; dune lake), new features are formed such as shallow sandbanks at the foot of the sand engine. The lagoon is a feature which is unique along this part of the Dutch coast and attracts unique and rare species such as Atriplex laciniata. It creates a gradient in hydrodynamics as well as in nutrient status (deposition of fine, nutrient rich sediments). Algal growth in and near the lagoon enriches the food web and provides favorable conditions for species that could otherwise not survive on the nutrient poor sand or for which algae are a source of food (fish and bird species). The presence of algae and dead organic material on the beach also enables the development of embryonic dunes by creating the right conditions for the establishment of pioneer species.

Research has shown that the number of ecotopes and habitats has increased, the density and diversity of benthic fauna is greater, more birds and bird species are found, and seals are often spotted on the sand engine (van Gelder-Maas 2014). Quantitative information to assess the value of biodiversity generated by the sand engine (e.g. number of habitats, species, densities, …) were not available at the time of writing. Besides more habitat and more diversity, the quality of habitats has also improved. The total surface area of grey dunes will increase, and the vitality of the dunes increases due to freshly supplied sand.

The negative effects on biodiversity during and in the first years after the construction of the engine (such as burial and high sedimentation and erosion rates) are small compared to the many positive effects (Stive et al. 2013). The median grain size of the supplied sand falls within the range of the natural beach grain size in order to prevent negative effects on biodiversity (DHV 2010). It is uncertain to what extent recreation exert a negative impact on biodiversity.

7.4 DISCUSSION AND CONCLUSION

The largest benefits are created by water quality regulation, flood protection and recreation (Figure 31, Table 35). The benefits from flood protection are relatively small compared to the investment costs of €60 million. One of the main goals of the sand engine is cognitive development, and the sand engine is to be considered a pilot project. In case a similar project would be developed in a more densely populated area, it can be expected that the benefits from flood protection would become much more important. The benefits from water quality regulation are relatively high compared to the small area where they are generated (the lagoon). This is related to the high economic value for nutrient removal. Although different features of the sand engine are important in delivering ecosystem services, it can be stated that the lagoon is a hot spot for service delivery (water quality regulation, nursery function for fish production, habitat and biodiversity, recreation).

The sand engine is expected to gradually reduce in size. After 20 years the remaining beach area is 200 ha, and the lagoon has shrunk to 9 ha. The greatest benefits generated by the sand engine thus have to be regarded as temporary, although some benefits might still be delivered after 20 years.

The EIA in 2010 indicated that the benefits are expected to be less than 10% of the investment costs (DHV 2010). Our research shows different results. This may be related to the inclusion of additional ecosystem services such as water quality regulation. The sum of the benefits as calculated in Table 35 does not include the effects of cognitive development due to the uncertainty on the valuation method. The investment costs however neither include investment costs in research and monitoring that allow knowledge gathering.

FIGURE 31.

Summary of the ES effects of the Sand Engine project. Flood protection (indicated in black) is the main project benefit considered in the initial project evaluation. All additional ecosystem services effects are indicated in green (if positive).

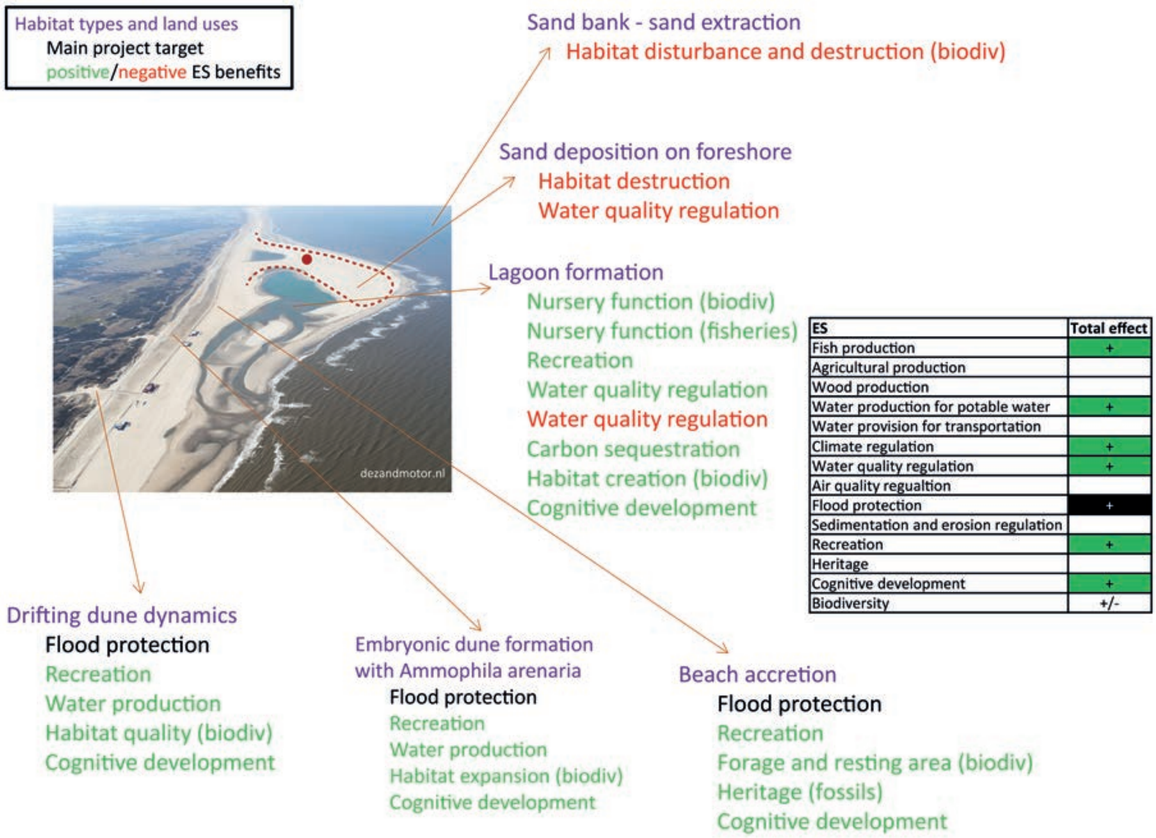


TABLE 35.

Estimated benefits from the sand engine (* average of range given in paragraph 7.3).

Ecosystem service	Benefits 2011 – 2031
Fish production	€0.08 million
Water production	€0.10 million *
Climate regulation	€0.42 million
Water quality regulation	€5.55 million
Flood protection	€5.60 million
Recreation	€2.03 million
Education	€0.17 million
Cognitive development	7 peer reviewed scientific papers, 778 Google Scholar references
Biodiversity	Increased habitat and ecotope diversity, increased species density and diversity
SUM	*minimum €16.33 million*

8. POLDERS OF KRUIBEKE

8.1 INTRODUCTION

The Polders of Kruibeke are located in the Sea Scheldt, the Belgian part of the tidal Scheldt river (Figure 32A). This is one of the projects of the Sigmaplan, the Flemish management plan for the Sea Scheldt estuary with a focus on safety, navigation and nature. Within this project two techniques are used to create a buffer zone 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 33. The project (currently still under construction) uses a combination of both techniques and the result is a mixed habitat configuration of wetland, wet meadows, alder brook forest and tidal wetland (consisting mainly of tidal marshes and to a lesser extend tidal flats and gullies) (Figure 32B).

The main development targets of this project are flood prevention and nature development linked to the European habitat and bird directives and the recovery of the Scheldt estuary. Besides those benefits, also the effects on other ecosystem services are assessed in this chapter.

This project is assessed in more depth to illustrate to broader applicability of the ES assessment. The construction of the project is compared with some hypothetical alternatives to show that the ES assessment could be used to compare alternative scenarios in an integrated way (including different effects).

FIGURE 32.

A) Study area Polders of Kruibeke in the Sea Scheldt(Belgian part of the tidal Scheldt river).
B) Integrated Plan for the Polders of Kruibeke Flood Control Area (FCA) with four different zones:
(1) Wet meadows, (2) Alder brook forest, (3) tidal wetland combined with wet meadows (FCA-CRT), (4) tidal wetland (FCA-CRT).

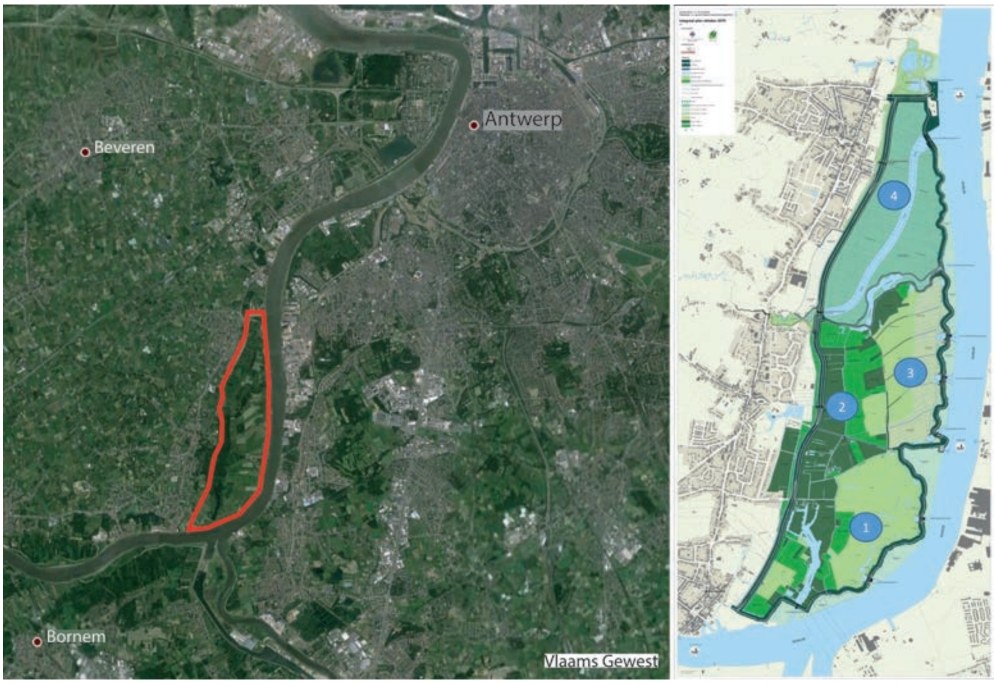
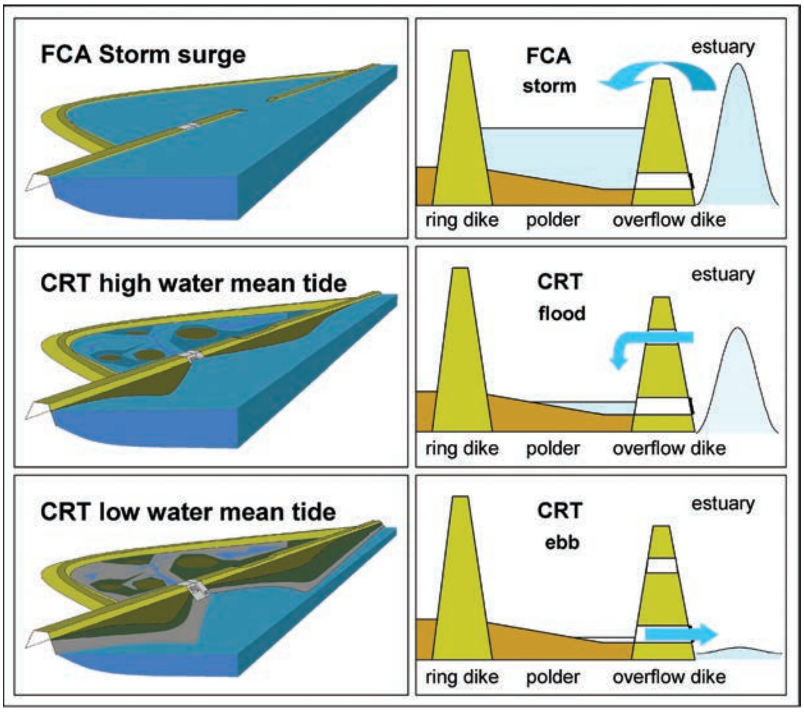


FIGURE 33.

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



8.2 HABITAT CHANGES RELATED TO THE POLDERS OF KRUIBEKE

The integrated plan for the project will be considered as the reference scenario. Four other scenarios (Figure 32) will be assessed in comparison with the reference scenario to check if alternative project developments can add more or other ecosystem services. For the dikes and meadows we assume natural management by cattle grazing in all scenario's.

- Reference: integrated plan as it is currently under construction (Figure 34). Creation of a mixed habitat: wetland, wet meadows, forest, tidal wetland
- Scenario 1: full area constructed as FCA-CRT for the creation of a tidal wetland
- Scenario 2: full area constructed as FCA with the creation of wet meadows
- Scenario 3: full area constructed as FCA with the creation of Alder brook forest (marsh forest)
- Scenario 4: full area constructed as FCA with agricultural use (classical agricultural practices, with pumping system to regulate the groundwater level)

For the agricultural scenario, three other alternatives are studied:

- Scenario 5: full area constructed as FCA with agricultural use (classical agricultural practices, without pumping system to regulate the groundwater level)
- Scenario 6: full area constructed as FCA with agricultural use (organic agricultural practices, with pumping system to regulate the groundwater level)
- Scenario 7: full area constructed as FCA with agricultural use (organic agricultural practices, without pumping system to regulate the groundwater level)

FIGURE 34.

Land use maps for the different scenarios. Relevant land uses: tidal wetland, Alder brook forest (marsh forest), wet meadows and agriculture with crops. For the dikes and meadows we assume natural management by cattle grazing.

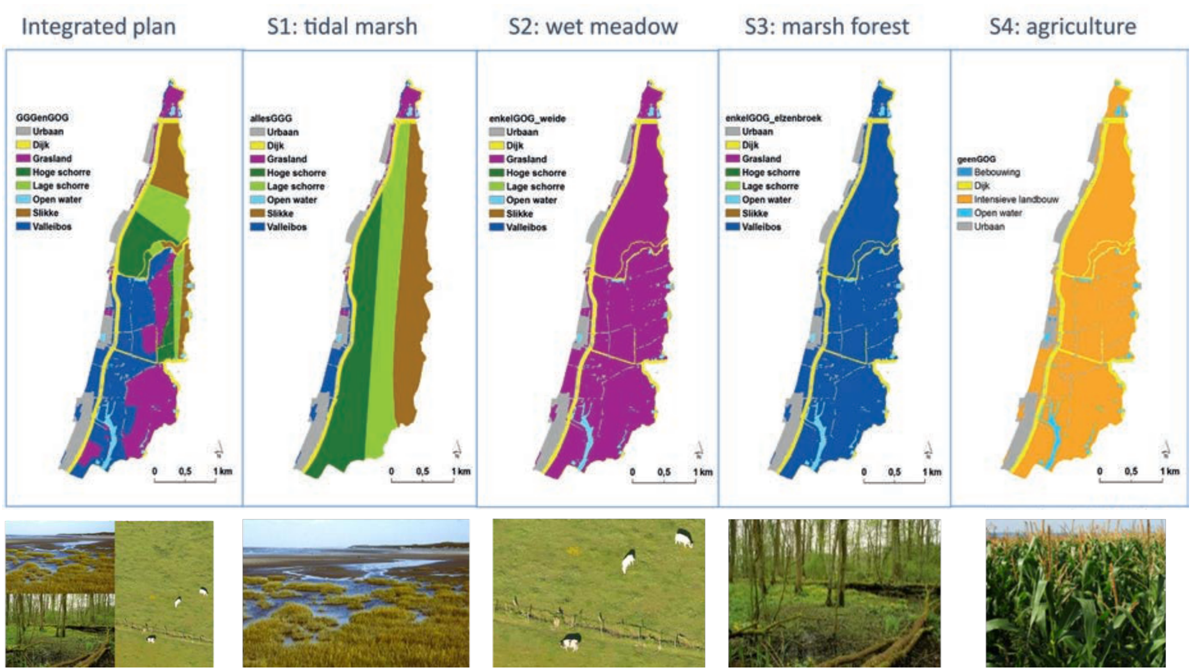


TABLE 36.

Investment cost and maintenance cost (100 years, 4% annuity rate) for the different scenarios (in million €). The investment cost consists of the construction cost, expropriation cost and is corrected for the expected project revenues (e.g. from organising events).

Million €	Integrated Plan (FCA & FCA-CRT)	S1: FCA-CRT (tidal wetland)	S2: FCA wet meadows	S3: FCA marsh forest	S4: FCA Agriculture
Investment cost	90	110 (=90+20)	80 (=90-10)	80 (=90-10)	80 (=90-10)
Maintenance cost (100y)	4	4	4	4	4+3

The investment cost and maintenance cost will differ between scenarios due to differences in the construction works needed and different habitat types require different maintenance. The investment cost and maintenance cost for the different scenarios are summarised in Table 36.

More details:

- Reference: integrated plan as it is currently executed. Creation of a mixed habitat: wetland, wet meadows, forest, tidal wetland. Data on the investment cost and maintenance cost for the integrated plan (reference scenario) are collected (Stabo, 1998; Triple E Trust & Natuur en Economie, 2015; W&Z, 2015; Polderbestuur 2015). The investment cost consists of a construction cost of about €75 million and an expropriation cost of about €25 million. Expected project revenues from organising events are also taken into account (390,000 euro/year, or €10 million for 100 years with 4% annuity rate). Furthermore an annual maintenance cost (e.g. mowing of dikes, maintenance of sluices) is accounted for (170,000 euro/year, or €4 million for 100 years). This gives a total investment of €94 million over 100 years.

- Scenario 1: full area constructed as FCA-CRT for the creation of a tidal wetland. The investment cost for this scenario will be more expensive compared to the reference scenario, due to the need for more inlet sluices (assumption: additional €20 million). For the maintenance cost a similar cost as for the reference scenario is assumed. This gives a total investment of €114 million over 100 years.

- Scenario 2: full area constructed as FCA with the creation of wet meadows. The investment cost for this scenario will be less expensive compared to the reference scenario because the absence of the inlet sluice (assumption: reduction of €10 million). For the maintenance cost a similar cost as for the reference scenario is assumed. This gives a total investment of €84 million over 100 years.

- Scenario 3: full area constructed as FCA with the creation of Alder brook forest (marsh forest). The investment cost for this scenario will be less expensive compared to the reference scenario because the absence of the inlet sluice (assumption: reduction of €10 million). For the maintenance cost a similar cost as for the reference scenario is assumed. This gives a total investment of €84 million over 100 years.

- Scenario 4: full area constructed as FCA with agricultural use (classical agricultural practices, with pumping system to regulate the water level). The investment cost for this scenario will be less expensive compared to the reference scenario because the absence of the inlet sluice (assumption: reduction of €10 million). For the maintenance cost a similar cost as for the reference scenario is assumed and the maintenance cost for the pumping system is added (about €3 million for 100 years). This gives a total investment of €87 million over 100 years.

Other agricultural scenarios:

- Scenario 5: full area constructed as FCA with agricultural use (classical agricultural practices, without pumping system to regulate the water level). Idem as scenario 4 but without the maintenance costs for the pumping system.

- Scenario 6: full area constructed as FCA with agricultural use (organic agricultural practices, with pumping system to regulate the water level). Idem as scenario 4.

- Scenario 7: full area constructed as FCA with agricultural use (organic agricultural practices, without pumping system to regulate the water level). Idem as scenario 4 but without the maintenance costs for the pumping system.

8.3 ECOSYSTEM SERVICES OF THE POLDERS OF KRUIBEKE

8.3.1 PROVISIONING ECOSYSTEM SERVICES

Agricultural production

Based on the method as described in chapter 3.1.2, the monetary benefits for agricultural production in the Polders of Kruibeke project are estimated between 35,000 and 1.1 million €/y depending on the project scenario (Figure 35).

FIGURE 35.

Monetary benefits for food production in the Polders of Kruibeke project, for 8 scenarios.

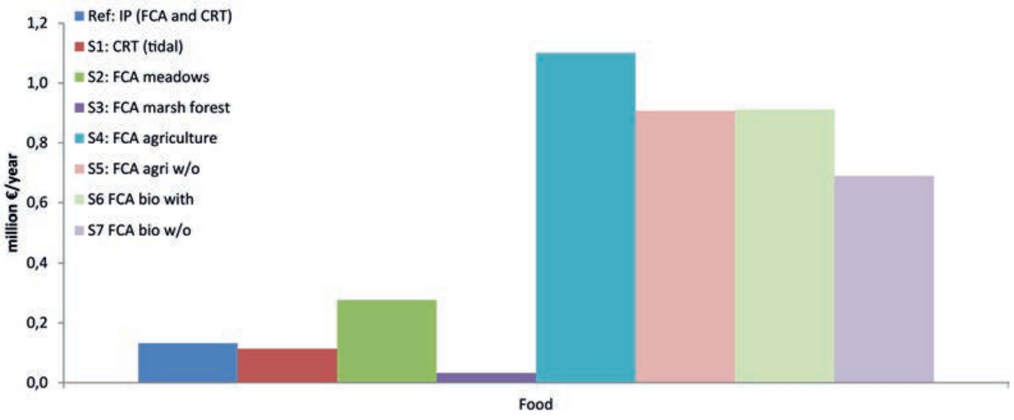
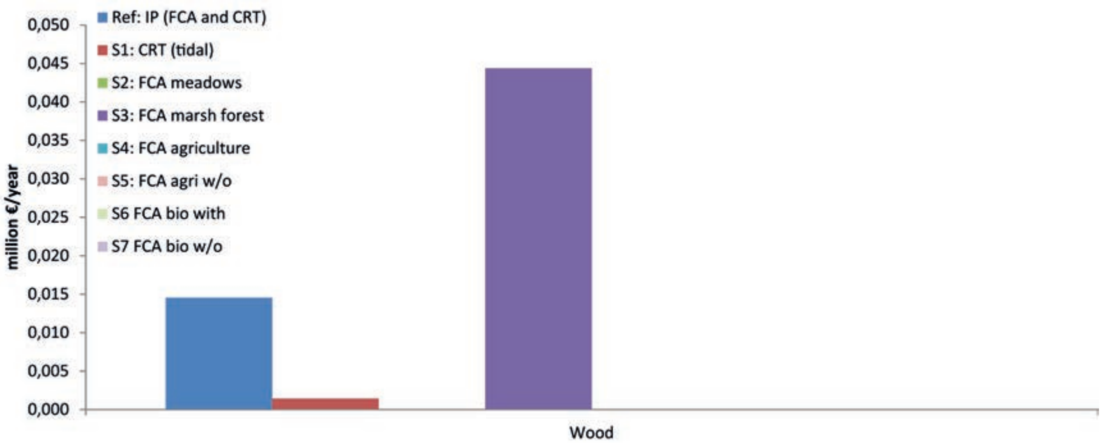


FIGURE 36.

Monetary benefits for wood production in the Polders of Kruibeke project, for 8 scenarios.



Wood provisioning

Based on the method as described in chapter 3.1.3, the monetary benefits for wood production in the Polders of Kruibeke project are estimated between 0 and 45,000 €/y depending on the project scenario (Figure 36).

8.3.2 REGULATING ECOSYSTEM SERVICES

Climate regulation

Based on the method as described in chapter 3.2.1 and additional details as described below, the monetary benefits for climate regulation in the Polders of Kruibeke project ranges between minus 0.8 million and + 0.2 million €/year, depending on the scenario (Figure 37). The main factor that determines the positive or negative outcome is the presence of tidal flats and marshes (CRT), for which the negative effect of GHG emissions was accounted.

Carbon burial in the tidal flat and marshes are calculated with the method explained in chapter 3.2.1 and using the data presented in Table 37. This results in a total of 14.64 ton CO2-eq./ha/y in bare tidal flats and low marshes and 3.66 ton CO2-eq./ha/y in high marshes.

FIGURE 37.
Monetary benefits for climate regulation in the Polders of Kruibeke project, for 8 scenarios.

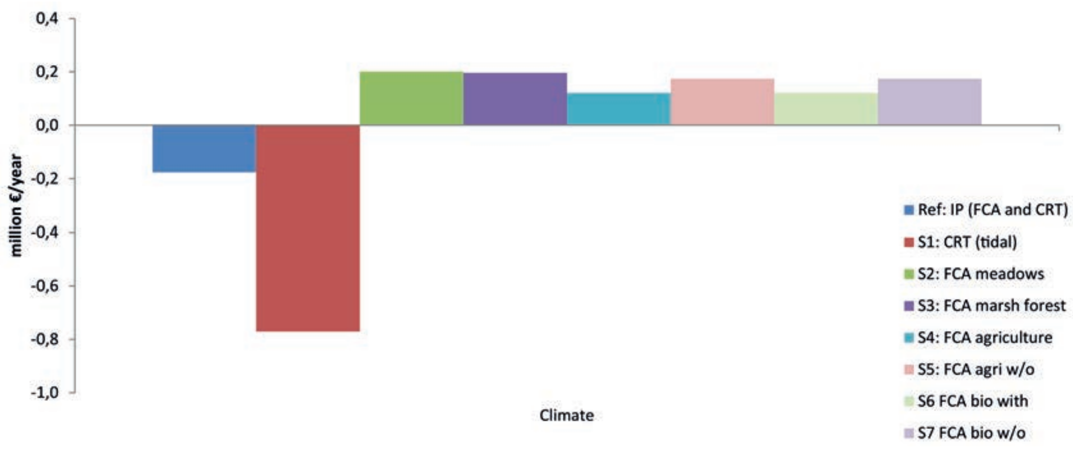


TABLE 37.
Data used to calculate the carbon burial potential.

Parameter	Unit	Bare tidal flat and low marsh	High marsh
Sedimentation rate [(1)]	m/y	0.02	0.005
Area unit	m^2/ha	10,000	10,000
Bulk density	kg/m^3	350	350
Particulate organic carbon content [(2)]	Mol/L	0.00045248	0.00045248
Molar mass carbon	g/mol	12	12
Suspended particulate matter [(3)]	g/l	0.095	0.095

Details:
(1) based on knowledge of the Lippenbroek project in the Scheldt estuary (pilot project to develop knowledge for the Kruibeke polders)
(2) 5y-average (OMES data from the Scheldt estuary, measure point Kruibeke)
(3) 5-y average (OMES data from the Scheldt estuary, measure point Kruibeke)

Water quality regulation
Based on the method as described in chapter 3.2.2 and additional details as described below, the monetary benefits for water quality regulation (denitrification, N burial and P burial) in the Polders of Kruibeke project ranges between minus 0.86 million and + 4 million €/year, depending on the scenario (Figure 38). Nitrogen and phosphorous burial in the tidal flat and marshes are calculated with the method explained in chapter 3.2.2 and using the data presented in Table 38. This results in a total of 452 kg N/ha/y and 11 kg P/ha/y in bare tidal flats and low marshes and 113 kg N/ha/y and 2.75 kg P/ha/y in high marshes.

FIGURE 38.

Monetary benefits for water quality regulation (denitrification, N burial and P burial) in the Polders of Kruibeke project, for 8 scenarios.

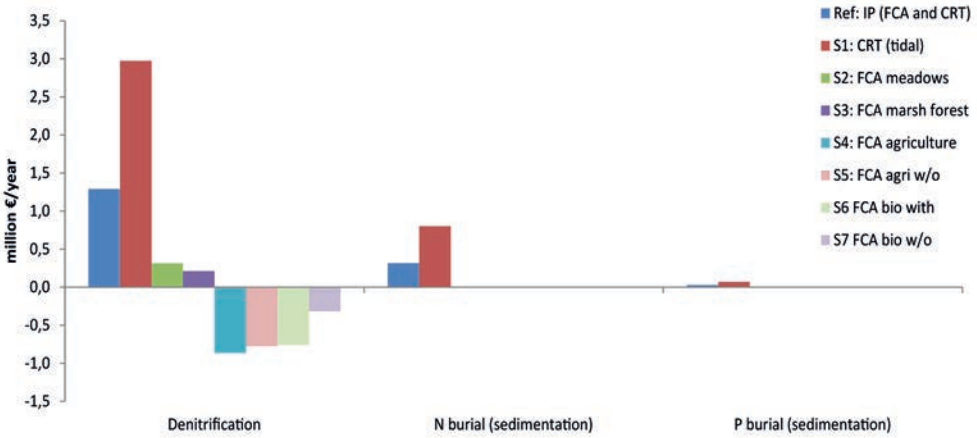


TABLE 38.

Data used to calculate the nitrogen burial potential.

Parameter	Unit	Bare tidal flat and low marsh	High marsh
Sedimentation rate [(1)]	m/y	0.02	0.005
Area unit	m^2/ha	10,000	10,000
Bulk density	kg/m^3	350	350
Particulate nitrogen content [(2)]	Mol/L	0.00004386	0.00004386
Molar mass nitrogen	g/mol	14	14
Particulate phosphorous content [(3)]	mg/L	0.015	0.015
Suspended particulate matter [(4)]	g/l	0.095	0.095

Details:
(1) based on knowledge of the Lippenbroek project in the Scheldt estuary (pilot project to develop knowledge for the Kruibeke polders)
(2) 5y-average (OMES data from the Scheldt estuary, measure point Kruibeke)
(3) 5y-average (OMES data from the Scheldt estuary, measure point Kruibeke)
(4) 5-y average (OMES data from the Scheldt estuary, measure point Kruibeke)

Air quality regulation

From the maps (Figure 39) (average daily concentration fine particles in Belgium, split up per type of fine dust (PM2,5 and PM10) - website ATMOSYS, March 2015) it is clear that the area of Kruibeke receives large amounts of fine dust particles, caused by the presence of the busy A12 and E17 that connects Antwerp to Brussels and Ghent, and the presence of industrial activity on the other side of the Scheldt estuary. For the area of the Kruibeekse polder the total concentration of fine dust per day is around 16-20 µg/m^3 PM2.5 and 21-25 µg/m^3 for PM10.

FIGURE 39.

Average daily concentration fine particles in Belgium (PM2.5 and PM10).
Website ATMOSYS, March 2015.

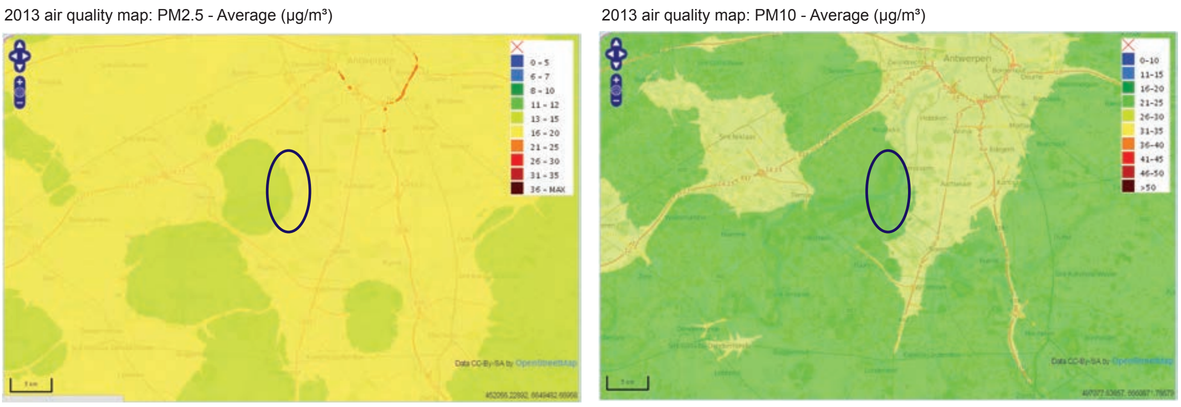
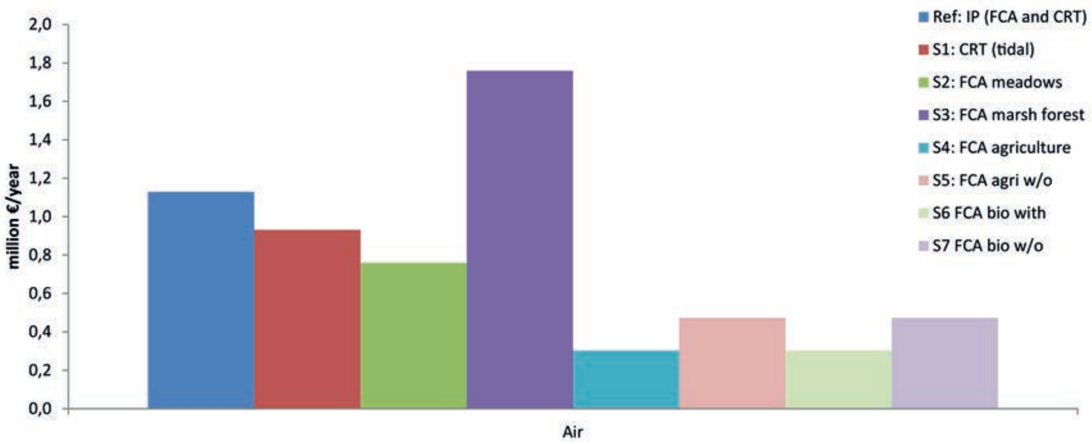


FIGURE 40.

Monetary benefits for air quality regulation in the Polders of Kruibeke project, for 8 scenarios.



The benefit for air quality regulation ranges between 0.3 and 1.8 million €/y depending on the scenario (Figure 40). Since large vegetation such as trees give the highest contribution for fine dust capture, scenario S3 (FCA marsh forest) gives the highest benefit.

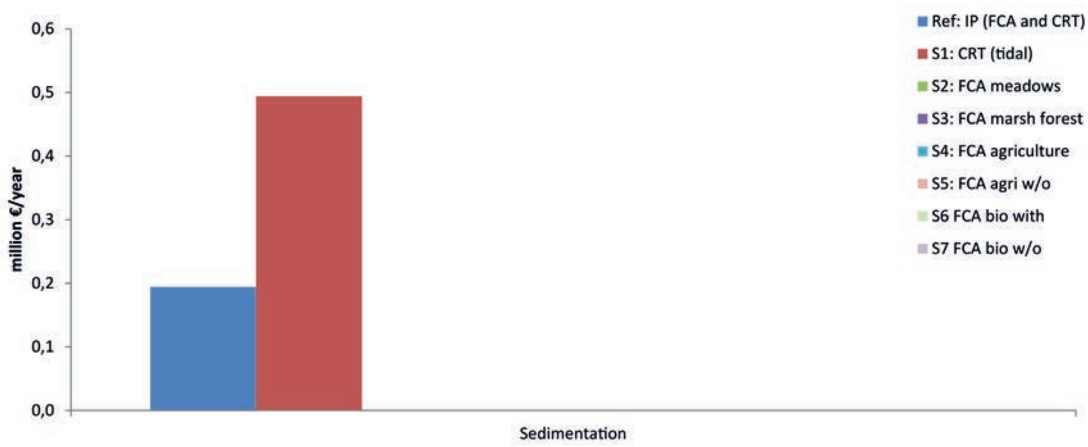
Flood protection

It is difficult to estimate the benefit of a single project in the estuary because this depends strongly on the implementation of all other Sigmaplan projects. For the Hedwige-prosperpolder project the safety benefit is estimated at €75 million (year 2010 until 2100). The polders of Kruibeke are expected to generate higher safety benefits (due to the larger area and location in the estuary). Based on this information we assume a safety benefit for the integrated plan of €100 million for 100 years, or around €4 million per year (annuity 100 years, interest 4%). The flood protection benefit is equal for all scenarios as all scenarios are developed as flood control area.

Sedimentation and erosion

The sediment volume stored in the intertidal habitats was already calculated in the calculation of C, N and P burial. The sedimentation rates for high marshes, bare tidal flat and low marshes used to calculate the sediment volume are based on knowledge from the pilot Lippenbroek project in the Scheldt estuary: 0.005 m/y for high marshes and 0.02 m/y for bare tidal flats and low marshes. This gives a volume of 50 m³/ha/y for high marshes and 200 m³/ha/y for bare tidal flats and low marshes. Since sediment storage forms a trade-off with flood water storage (more sediment storage means less capacity for flood water storage), initiatives to limit the sedimentation rate were undertaken in the polders of Kruibeke because flood water storage is considered as the most important function in this case. On the other hand, sedimentation is crucial for marsh development and in case of sea-level rise for vertical accretion to keep up with the increasing water level. The monetary value of sediment storage in the Polders of Kruibeke is maximum 0.5 million €/y (scenario S1 CRT) (Figure 41).

FIGURE 41.
Monetary benefits for sedimentation regulation in the Polders of Kruibeke project, for 8 scenarios.



8.3.3 CULTURAL ECOSYSTEM SERVICES

Recreation

The touristic and recreation potential of the project was studied to estimate the number of visitors (ANTEA group and IDEA Consult, 2012). Benefits from additional recreation are not added in the analysis because of two reasons: first because it is difficult to estimate the added value (although literature studies exist but the results are very local specific), and second because it is difficult to estimate differences between land use types. Therefore we decided that any estimate of recreation benefits would not give additional information to compare scenarios, since the estimate would be the same for all scenarios.

8.3.4 BIODIVERSITY

An important objective of the Polders of Kruibeke project is the contribution to the Habitat and Bird Directive targets (e.g. creation of estuarine nature and wet meadows). However, societal benefits from habitat creation and an increase/ shift in biodiversity are not included in the monetary assessment due to a lack of scientifically sound methods. However, the contribution of the project towards targets in the Habitat- and Bird Directive (HD and BD) is crucial for decision makers and the management of the Scheldt river. Because this project is still under construction, no monitoring data is available yet on the presence of fauna and flora. Habitat types that are created are estuary (tidal habitat), wet meadows and alder brook forest.

8.4. DISCUSSION AND CONCLUSION

All scenarios generate additional ES benefits apart from the flood safety benefit (sum of all benefits are higher than the flood safety benefits, Figure 42). Nevertheless, we see differences between scenarios. Scenario S1: CRT (tidal) (creating an intertidal wetland area) generates the highest benefits and scenario S4: FCA agriculture the lowest. The different scenarios show a clear distinction in which ES that will be delivered. Some highlights: air quality regulation is highest for scenario S3: FCA marsh forest (trees can capture more fine dust compared to lower vegetation), climate regulation is negative for scenario S1: CRT (tidal) (high potential for methane emission in mudflats), denitrification is highest for scenario S1: CRT (tidal) (high denitrification potential in mudflats). When comparing the four different agricultural scenarios (with differences in classic or organic practice and with or without a pumping system to regulate groundwater level), the ES benefits are almost equal (Figure 43). The highest benefit is found for the organic scenario without pumping system (the lower food benefit is compensated by a reduced loss from nitrogen leaching).

FIGURE 42.
ES benefits per scenario (construction scenarios: reference compared to S1-S4).

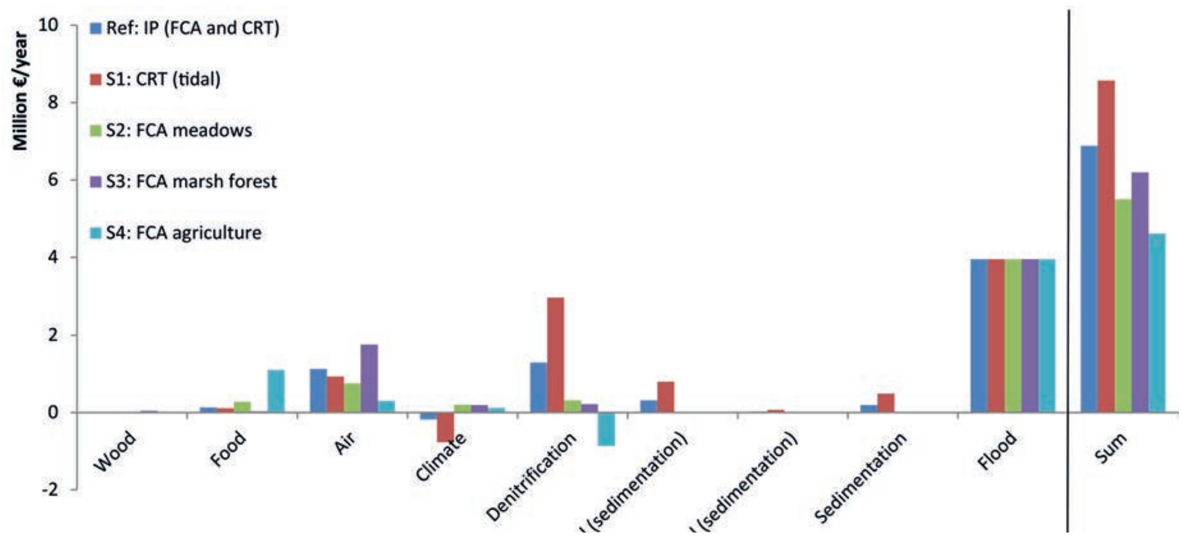


FIGURE 43.
ES benefits for four agricultural scenarios: S4 (classic practice, with pump), S5 (classic practice, without pump), S6 (organic practice, with pump), S7 (organic practice, without pump).

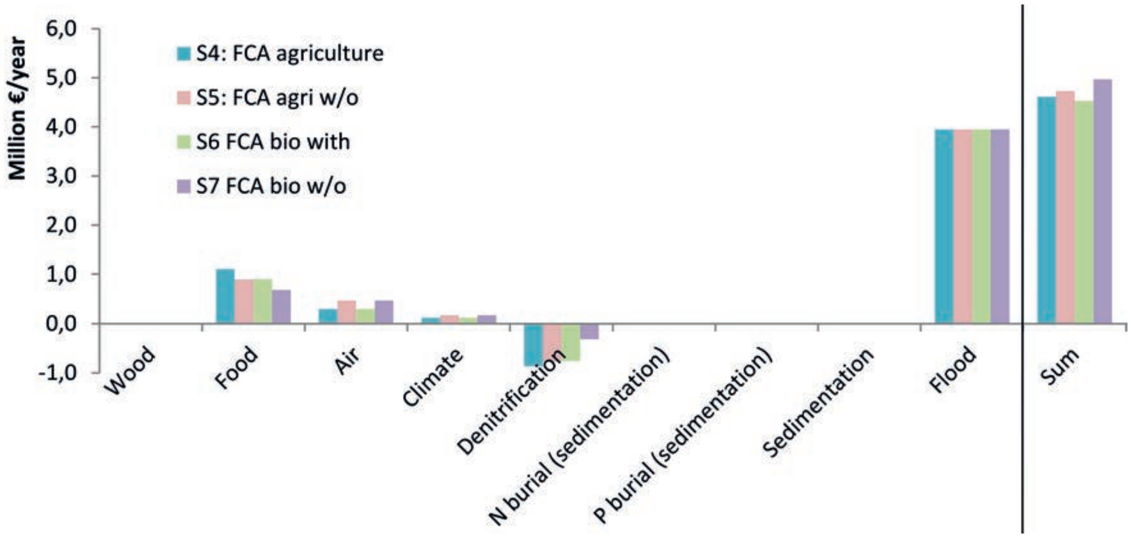
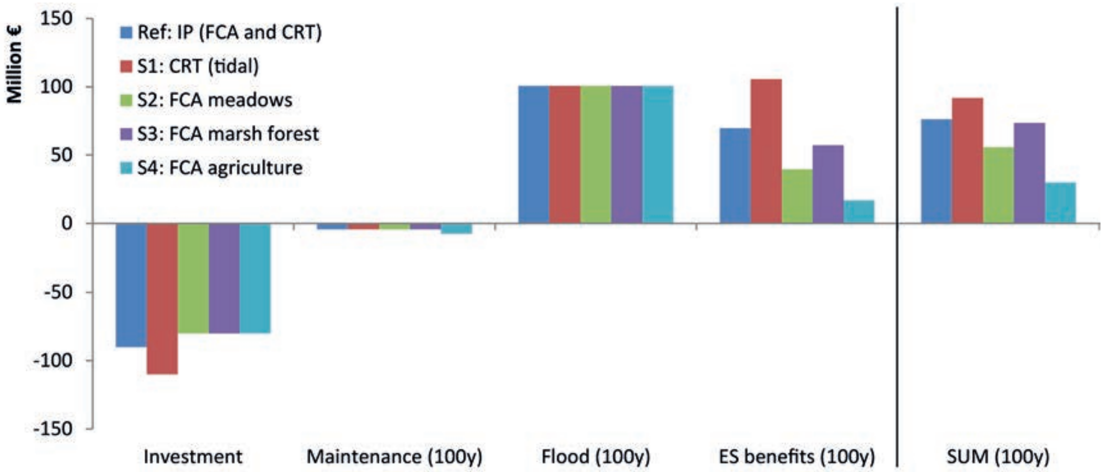


FIGURE 44.
Costs and benefits per scenario.



When comparing the investment and maintenance cost with the ES benefits between the different construction scenarios, all scenarios give a positive net results (Figure 44). Without counting for the additional ES benefits (only flood prevention benefit), most scenarios are only slightly beneficial due to the high investment cost.

The ecosystem services assessment of the Polders of Kruibeke project shows that the project is much more beneficial for society then otherwise would have been concluded (when only looking to the flood safety benefit). Furthermore the development of the project (different scenarios) does make a difference in which ES will be delivered. The scenario where the full project area is developed as a FCA-CRT to create a tidal wetland shows the highest added value (Figure 45).

The results of the economic benefits as shown in Figure 44 are on its own not sufficient to make final decisions on which development alternative to choose. It is important to put this result in the wider context and to check for which ES are actually needed in the area (which ES could also be delivered elsewhere and which ES are really depending on the project) and which habitats and species are needed in the area according to European legislation and local plans. Furthermore, the ES assessment that we presented is not complete since not all ES are included (e.g. contribution to the silica cycling, turbidity reduction in the Scheldt river (linked to primary production), nursery function, …).

FIGURE 45.

Summary of the ES effects of the Kruibeke project. Flood protection (indicated in black) is the main project benefit considered in the initial project evaluation. All additional ecosystem services effects are indicated in green (if positive) or red (if negative).

Scenario integrated plan

Tidal wetland (zone 4)
- Flood protection
- Food production
- Climate regulation
- Water quality regulation
- Air quality regulation
- Sediment burial
- Recreation
- Biodiversity

Marsh forest (Alder brook forest) (zone 2)
- Flood regulation
- Food production
- Wood provision
- Climate regulation
- Water quality regulation
- Air quality regulation
- Recreation
- Biodiversity

Wet meadows (zone 1,3)
- Flood regulation
- Food production
- Climate regulation
- Water quality regulation
- Air quality regulation
- Recreation
- Biodiversity

Dike
- Flood regulation
- Food production
- Climate regulation
- Water quality regulation
- Air quality regulation
- Recreation
- Biodiversity

ES	Total effect
Fish production	
Agricultural production	+
Wood production	
Water production for potable water	
Water provision for transportation	
Climate regulation	-
Water quality regulation	+
Air quality regualtion	+
Flood protection	+
Sedimentation and erosion regulation	+
Recreation	
Heritage	
Cognitive development	
Biodiversity	

Habitat types and land uses
Main project target
positive/negative ES benefits

9. GOVERNANCE, DISCUSSION AND CONCLUSION

While classic environmental impact assessments focus on the potential negative effects of a dredging project on nature and society, taking an ecosystem services perspective allows to look at both the negative effects as well as new opportunities that may arise as secondary benefits. By targeting a variety of ecosystem services from the conceptualisation phase of a project and optimizing its design for additional benefits, innovation efforts shift away from 'avoiding damage' to 'creating opportunities'.

An ecosystem service assessment provides information and data to include in the traditional cost-benefit analysis of projects. Monetary valuation of ecosystem services is useful to make a full environmental cost-benefit analysis and weigh the investment cost with environmental and socio-economic benefits. This means that projects that are more expensive and less beneficial for the main aim of the project could still be identified as most beneficial after considering changes in ecosystem services and its socio-economic relevance. This enables a better comparison between project alternatives, taking into account subtle differences to the environment. It will also depict the alternatives that properly contribute to the environment and not just compensate negative effects.

Monetary valuation techniques are however not available for all ecosystem services. A qualitative assessment of all effects (in non-monetary terms) is therefore always added to give some nuance to the monetary outcome. With this approach, also other considerations could be added in the evaluation: e.g. when targets should be considered such as habitat and biodiversity targets, whether certain habitats are easier or more difficult to replace, … . When these aspects are taken into account during the design of the project, this could be used in the selection of the project location to avoid problems at a later stage (e.g. less critical habitats, easier to compensate).

We did not compare the benefits with the investment cost of projects, although it is possibility to get a feeling whether the ecosystem service benefits are substantial in comparison with the investment cost (cfr. case Polders of Kruibeke). Furthermore, ecosystem services do not incorporate all possible effects of projects, but only those that follow directly or indirectly from adaptations to the ecosystem.

Taking ecosystem services into account from the designing phase of a project allows to generate added value that might otherwise be missed out on, avoid destruction that is impossible to mitigate and create support from different stakeholders.

10. LIST OF FIGURES

11. LIST OF TABLES

12. REFERENCES

AGIV, 2001. Vector Version of the Soil Map of Flanders (Vectoriële versie van de Bodemkaart Vlaanderen). AGIV, IWT, Laboratory for Soil Science, University of Ghent.

AGIV, 2011. Digital Elevation Model Flanders 25m. Flemish Government Ministry of Environment, Nature and Energy. AWZ Administration and AMINAL Administration Water Division.

Alongi, D. M., G. Wattayakorn, J. Pfitzner, F. Tirendi, I. Zagorskis, G. J. Brunskill, A. Davidson, and B. F. Clough. 2001. Organic carbon accumulation and metabolic pathways in sediments of mangrove forests in southern Thailand. Marine Geology 179:85-103

ANTEA group and IDEA Consult, 2012. Polders van Kruibeke, toeristisch-recreatieve basispositionering. in opdracht van Waterwegen en Zeekanaal nv. Antwerpen. 18pp.

Beaumont N.J., Austen M.C., Atkins J.P., Burdon D., Degraer S., Dentinho T.P., Derous S., Holm P., Horton T., van Ierland E., Marboe A.H., Starkey D.J., Townsend M. and Zarzycki T. (2007). Identification, definition and quantification of goods and services provided by marine biodiversity: Implications for the ecosystem approach. Marine Pollution Bulletin 54 (2007) 253–265

Beleidsevaluatie Zandmotor 2013. 34p. Te downloaden via www.dezandmotor.nl

Berendsen E. et al. (2005). Rapport verkenningsfase Project Zande n Ze(e)ker – de zandmotor bij Ter Heijde. 70p.

Bollen, B., 2012. Optimalisation of Soil Suitability Map Based on Soil Texture and Hydrology (Optimalisatie van de bodemgeschiktheidskaart op basis van de drainage en textuurklasse). Agriculture and Fisheries Department, Sustainable Agricultural Development Division, Flemish Government.

Bouillon, S., A. V. Borges, E. Castañeda-Moya, K. Diele, T. Dittmar, N. C. Duke, E. Kristensen, S. Y. Lee, C. Marchand, J. J. Middelburg, V. H. Rivera-Monroy, T. J. Smith, and R. R. Twilley. 2008. Mangrove production and carbon sinks: A revision of global budget estimates. Global Biogeochemical Cycles 22:GB2013.

Brion N., Baeyens W., De Galan S., Elskens M. and Laane R. (2004). The North Sea: source or sink for nitrogen and phosphorus to the Atlantic Ocean? Biogeochemistry 2004, Volume 68, Issue 3, pp 277-296

Broekx, S., E. Meynaerts, and P. Vercaemst. 2008. Milieukostenmodel Water voor Vlaanderen. Berekeningen voor het stroomgebiedbeheerplan 2009. Finaal rapport 2009/RMA/R/146. Studie uitgevoerd in opdracht van het Vlaams Gewest. Page 128. VITO.

Broekx, S., De Nocker, L., Liekens, I., Poelmans, L., Sates, J., Van der Biest, K., Meire, P., Verheyen, K., 2014. Estimate of the Benefits Delivered by the Flemish Natura 2000 Network. Flemish Government Nature and Forestry Agency, p. 217.

Byun, D. W., and K. L. Schere, 2006: Review of the governing equations, computational algorithms, and other components of the Models-3 Community Multiscale Air Quality (CMAQ) Modeling System. Appl. Mech. Rev., 59, 51-77

Cardno and Sydney ports corporation. 2013. Port Botany post construction environmental monitoring: annual report 2013

CEDA 2013. Ecosystem Services and Dredging and Marine Construction. Central Dredging Association (CEDA).

Çinar, M. E., T. Katağan, F. Koçak, B. Öztürk, Z. Ergen, A. Kocatas, M. Önen, F. Kirkim, K. Bakir, G. Kurt, E. Dağli, S. Açik, A. Doğan, and T. Özcan. 2008. Faunal assemblages of the mussel Mytilus galloprovincialis in and around Alsancak Harbour (Izmir Bay, eastern Mediterranean) with special emphasis on alien species. Journal of Marine Systems 71:1-17.

Coates D., Deschutter Y., Vincx M. and Vanaverbeke J. (2013). Macrobenthic enrichment around a gravity based foundation. Chapter 13 of Degraer et al. (2013c).

Coates D., Deschutter Y., Vincx M. and Vanaverbeke J. (2014). Enrichment and shifts in macrobenthic assemblages in an offshore wind farm area in the Belgian part of the North Sea. Marine environmental research Volume: 95 Issue 9916, p 1-12

Coombes, M. A., E. C. La Marca, L. A. Naylor, and R. C. Thompson. 2015. Getting into the groove: Opportunities to enhance the ecological value of hard coastal infrastructure using fine-scale surface textures. Ecological Engineering 77:314-323.

Coppens, G., Elsen, F., Ver Elst, F., Bries, J., 2007. Bepalen van nitraatresidu en bemestingsadvies voor een selectie van landbouwpercelen gedurende het voorjaar van 2007 en opmaken van een bodembalans. Studie door Bodemkundige Dienst van België vzw in opdracht van VLM.

Cox, T., T. Maris, P. De Vleeschauwer, T. De Mulder, K. Soetaert, and P. Meire. 2006. Flood control areas as an opportunity to restore estuarine habitat. Ecological Engineering 28:55-63

CPB 2006. Maatschappelijke kosten-batenanalyse van de Westerschelde Containerterminal, een 'second opinion'.

Dafforn, K. A., M. Mayer-Pinto, R. L. Morris, and N. J. Waltham. 2015. Application of management tools to integrate ecological principles with the design of marine infrastructure. Journal of Environmental Management 158:61-73.

de Boer, W. P., P. C. Roos, S. J. M. H. Hulscher, and A. Stolk. 2011. Impact of mega-scale sand extraction on tidal dynamics in semi-enclosed basins: An idealized model study with application to the Southern North Sea. Coastal Engineering 58:678-689.

de Groot, S. J. 1986. Marine sand and gravel extraction in the North Atlantic and its potential environmental impact, with emphasis on the North Sea. Ocean Management 10:21-36.

de Jong, M. F., M. J. Baptist, R. van Hal, I. J. de Boois, H. J. Lindeboom, and P. Hoekstra. 2014. Impact on demersal fish of a large-scale and deep sand extraction site with ecosystem-based landscaped sandbars. Estuarine, Coastal and Shelf Science 146:83-94.

De Mesel I., Kerckhof F., Rumes B., Norro A., Houziaux J.S. and Degraer S. (2013). Fouling community on the foundations of wind turbines and the surrounding scour protection. Chapter 12 of Degraer et al. (2013c).

De Nocker L., Broekx S., Demeyer R., Simoens I., Turkelboom F., Provoost S. and Van der Biest K. (2015). Evaluatie van de socio-economisch impact van het FLANDRE project op de lokale economie, bevolking en het herstel van de ecosysteemdiensten. Studie in opdracht van Agentschap Natuur en Bos. Draft-versie mei 2015.

de Nooij M. and Rosenberg F. (2008). Maatschappelijke kosten-batenanalyse voor de planstudie versterking zwakke schakel Scheveningen. Studie iov. Provincie Zuid-Holland. 68p.

De Vos, B., 2000. Achtergrondsinformatie bij het bodemgeschiktheidsprogrammavoor boomsoorten BoBo, edited by I. v. B. e. W. IBW.

De Witte, B., L. Devriese, K. Bekaert, S. Hoffman, G. Vandermeersch, K. Cooreman, and J. Robbens. 2014. Quality assessment of the blue mussel (Mytilus edulis): Comparison between commercial and wild types. Marine Pollution Bulletin 85:146-155.

Deek A., Emeis K. and van Beusekom J. (2012). Nitrogen removal in coastal sediments of the German Wadden Sea. Biogeochemistry 108: 467-483

Degraer S., Baeye M., Botteldooren D. et al. (2013a). Environmental impacts of offshore windfarms in the Belgian part of the North Sea. Learning from the past to optimize future monitoring programmes. Executive summary of Degraer et al. (2013c).

Degraer S., Brabant R. and Rumes B. (eds.) (2013c). Environmental impacts of offshore wind farms in the Belgian part of the North Sea: Learning from the past to optimize future monitoring programmes. Royal Belgian Institue of Natural Sciences, Operational Directorate Natural Environment, Marine Ecology and Management Section. 239 pp.

Degraer S., Kerckhof F., Reubens J., Vanermen N., De Mesel I., Rumes B., Stienen E., Vandendriessche S. and Vincx M. (2013b). Not necessarily all gold that shines: appropriate ecological context setting needed! Chapter 17 of Degraer et al. (2013c).

Demey, A., Baeten, L. & verheyen, K. (2013). Opbouw Methodiek Prijsbepaling Hout. 'KOBE-rapport van het Agentschap voor Natuur en Bos en Inverde.

DHV 2010. Projectnota/ MER Aanleg en zandwinning. Zandmotor Delflandse kust. 372p.

Duarte, C. M., I. J. Losada, I. E. Hendriks, I. Mazarrasa, and N. Marba. 2013. The role of coastal plant communities for climate change mitigation and adaptation. Nature Clim. Change 3:961-968.

Dulfer W., van Gelder C., Marx S. en de Wilde C. (2014). Hoe bruikbaar is de zandmotor? Eerste tussentijdse verkenning naar de haalbaarheid en bruikbaarheid van de pilot Zandmotor 2011-2013. 32p.

EC 2011. Our life insurance, our natural capital: an EU biodiversity strategy to 2020. European commission.

Ecorys 2006a. Maatschappelijke kosten-batenanalyse van de Westerschelde Containerterminal.

Ecorys 2006b. Maatschappelijke kosten-batenanalyse van de Westerschelde Containerterminal, Addendum Provincie Zeeland.

ESM 2006. Strategische Milieu Beoordeling/Milieu Effect Rapport Westerschelde Container Terminal. Actualisatie 2006. Exploitatiemaatschappij Schelde Maas (ESM)

ESM 2009. Natuurcompensatie Westerschelde Container Terminal. Startnotitie milieueffectrapportage. Exploitatiemaatschappij Schelde-Maas.

Essink K. (2005). Bodemfauna en beleid. Een overzicht van 35 jaar bodemfauna onderzoek en monitoring in Waddenzee en Noordzee. 154p.

Eyre B.D. and Maher D. (2011). Mapping ecosystem processes and function across shallow seascapes. Continental Shelf Research 31: 162-172

Fraser, C., P. Hutchings, and J. Williamson. 2006. Long-term changes in polychaete assemblages of Botany Bay (NSW, Australia) following a dredging event. Marine Pollution Bulletin 52:997-1010

Gacia, E., C. M. Duarte, and J. J. Middelburg. 2002. Carbon and nutrient deposition in a Mediterranean seagrass (Posidonia oceanica) meadow. Limnology and Oceanography 47:23-32.

Gómez-Baggethun E., Gren A., Barton D.N., et al. (2013). Chapter 11 - Urban Ecosystem Services. In: Elmqvist T., Fragkias M., Goodness J., Güneralp B., Marcotullio P.J., McDonald R.I., Parnell S., Schewenius M., Sendstad M., Seto K.C. and Wilkinson C. (eds.) (2013). Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities. A global assessment. 754p.

Gonçalves, D. S., L. M. Pinheiro, P. A. Silva, J. Rosa, L. Rebêlo, X. Bertin, S. Braz Teixeira, and R. Esteves. 2014. Morphodynamic evolution of a sand extraction excavation offshore Vale do Lobo, Algarve, Portugal. Coastal Engineering 88:75-87.

Google Scholar (2016). http://scholar.google.be/. Consulted 05/02/2016
Haelters J., Vigin L. and Degraer S. (2013). Attraction of harbour porpoises to offshore wind farms: what can be expected? Chapter 16 of Degraer et al. (2013c).
Heip C., Basford D., Craeymeersch J.A., Dewarumez J.M., Dorjes J.,Dewilde P., Duineveld G., Eleftheriou A., Herman P.M.J., Niermann U., Kingston P., Kunitzer A., Rachor E., Rumohr H., Soetaert K. and Soltwedel T. (1992). Trends in biomass, density and diversity of North Sea macrofauna. ICES Journal of Marine Research 49, 13-22. Heip et al. 1992. In Rumes et al. 2013
IADC 2013. Facts about ecosystem services & dredging. International Association of Dredging Companies (IADC).
Jonkhoff W., Koops O., van der Krogt R.A.A., Oude Essink G.H.P. and Rietveld E. (2008). Economische effecten van klimaatverandering. Overstroming en verzilting in scenario's, modellen en cases. 128p.
Kerckhof, F., Rumes, B., Norro, A., Houziaux, J.-S., Degraer, S., 2012. A comparison of the first stages of biofouling in two offshore wind farms in the Belgian part of the North Sea.
In: Degraer, S., Brabant, R., Rumes, B., (Eds.). 2012. Offshore wind farms in the Belgian part of the North Sea: Heading for an understanding of environmental impacts. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models, Marine Ecosystem Unit. pp. 17-39.
Kubicki, A., F. Manso, and M. Diesing. 2007. Morphological evolution of gravel and sand extraction pits, Tromper Wiek, Baltic Sea. Estuarine, Coastal and Shelf Science 71:647-656.
Lee, S. Y., J. H. Primavera, F. Dahdouh-Guebas, K. McKee, J. O. Bosire, S. Cannicci, K. Diele, F. Fromard, N. Koedam, C. Marchand, I. Mendelssohn, N. Mukherjee, and S. Record. 2014. Ecological role and services of tropical mangrove ecosystems: a reassessment. Global Ecology and Biogeography 23:726-743.
Leonhard et al. 2011. In: Vandendriessche et al. 2013
Liekens, I., S. Broekx, and L. De Nocker. 2012. Manual for the valuation of ecosystem services in estuaries. Report for TIDE financed by EU interreg IVB North Sea Region Programme.
Liekens, I., S. Broekx, and L. De Nocker. 2013. Manual for valuation of ecosystem services in estuaries. Study report in the framework of the Interreg IVB project TIDE. Flemish Institute for Technological Development (VITO), commissioned by Antwerp Port Authority (APA), Mol, Belgium.
Lindeboom et al. (2011). In: Vandendriessche et al. 2013
Liquete C., Piroddi C., Drakou E., Gurney L., Katsanevakis S., Charef A. and Egoh B. (2013). Current Status and Future Prospects for the Assessment of Marine and Coastal Ecosystem Services: A Systematic Review. PlosONE V8, I7, e67737
MAHB, 2012. Environment and Development Challenges: The Imperative to Act. Blue Planet Synthesis paper. Millennium Alliance for Humanity and Biosphere (MAHB).
Marchal, P., M. Desprez, Y. Vermard, and A. Tidd. 2014. How do demersal fishing fleets interact with aggregate extraction in a congested sea? Estuarine, Coastal and Shelf Science 149:168-177.
Maris, T., T. Cox, S. Temmerman, P. de Vleeschauwer, S. van Damme, T. de Mulder, E. van den Bergh, and P. Meire. 2007. Tuning the tide: creating ecological conditions for tidal marsh development in a flood control area. Hydrobiologia 588:31-43.
McGlathery K.J., Sundbäck K. and Anderson I.C. (2007). Eutrophication in shallow coastal bays and lagoons: the role of plants in the coastal filter. Marine Ecology Progress Series 348: 1-18
McLeod, E., G. L. Chmura, S. Bouillon, R. Salm, M. Björk, C. M. Duarte, C. E. Lovelock, W. H. Schlesinger, and B. R. Silliman. 2011. A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO2. Frontiers in Ecology and the Environment 9:552-560.
MEA, 2005. Ecosystems and Human well-being: current state and trends. Millenium Ecosystem Assessment. Page 155. Island press, Washington.
Meersmans, J., van Wesemael, B., Goidts, E., van Molle, M., De Baets, S., De Ridder, F., 2011. Spatial analysis of soil organic carbon evolution in Belgian croplands and grasslands, 1960-2006. Glob. Change Biol. 17, 466-479.
Meire, P., T. Ysebaert, S. Van Damme, E. Van den Bergh, T. Maris, and E. Struyf. 2005. The Scheldt estuary: a description of a changing ecosystem. Hydrobiologia 540:1-11.
Middelburg, J., G. Klaver, J. Nieuwenhuize, and T. Vlug. 1995b. Carbon and nitrogen cycling in intertidal sediments near Doel, Scheldt Estuary. Hydrobiologia 311:57-69.
Middelburg, J., G. Klaver, J. Nieuwenhuize, R. Markusse, T. Vlug, and F. J. A. Nat. 1995a. Nitrous oxide emissions from estuarine intertidal sediments. Hydrobiologia 311:43-55.
Middleton, M. J., J. D. Bell, J. J. Burchmore, D. A. Pollard, and B. C. Pease. 1984. Structural differences in the fish communities of Zostera capricorni and Posidonia australis seagrass meadows in Botany Bay, New South Wales. Aquatic Botany 18:89-109
Mint en Rebel, 2013. Standaardmethodiek voor MKBA van transportinfrastructuurprojecten. Kengetallenboek.

Opdrachtgever Vlaamse Overheid Departement Mobiliteit en Openbare Werken Afdeling Haven- en Waterbeleid. Referentienummer 1379-004-40

Moonen, P., Kint, V., Deckmyn, G., Muys, B., 2011. Scientific Underpinning of a Longterm Plan for Wood Production in Bosland (Wetenschappelijke onderbouwing van een lange termijnplan houtproductie voor Bosland). Final report. Eindrapport opdracht LNE/ANB/LIM-2009/19 Commissioned by the Flemish Government Ministry of Environment, Nature and Energy.

MUMM (2015). IDOD database, Integrated and Dynamical Oceanographic Data management

Nolte S., Müller F., Schuerch M., Wanner A., Esselink P., Bakker J.P. & Jensen K. 2013. Does livestock grazing affect sediment deposition and accretion rates in salt marshes? Estuarine, Coastal and Shelf Science 135 (2013) 296-305

O'Higgins T.G. and Gilbert H.J. (2014). Embedding ecosystem services into the Marine Strategy Framework Directive: Illustrated by eutrophication in the North Sea. Estuarine, Coastal and Shelf Science 140, 146-152

Oosterbaan A. Michel Kiers, Landelijke kaart “potentiële fijnstofinvang door groene vegetaties”, (Alterra Wageningen UR), in Melman, T. C. P. en C. M. van der H. (2011). Ecosysteemdiensten in Nederland: verkenning betekenis en perspectieven. Achtergrondrapport bij Natuurverkenning 2011. Wageningen.DMV 2011

Oosterbaan, A., A. E. G. Tonneijck, and E. A. de Vries. 2006. Kleine landschapselementen als invangers van fijn stof en ammoniak. Alterra Rapport. Alterra Wageningen Universiteit, Wageningen, Nederland. onderzoeksrapport LUWPUBRD_00350279_A502

Oulasvirta, P. and H. Lehtonen. 1988. Effects of sand extraction on herring spawning and fishing in the Gulf of Finland. Marine Pollution Bulletin 19:383-386.

Paalvast, P., B. K. van Wesenbeeck, G. van der Velde, and M. B. de Vries. 2012. Pole and pontoon hulas: An effective way of ecological engineering to increase productivity and biodiversity in the hard-substrate environment of the port of Rotterdam. Ecological Engineering 44:199-209.

PIANC 2005. Dredging: the environmental facts. Where to find what you need to know. International navigation association (PIANC).

PIANC 2011. Working with nature. PIANC position paper.

Polderbestuur, 2015. Communication. Uitgaven Polderbestuur 9150 Kruibeke periode 1990 – 2003.

Provincie Zeeland, 2002. Westerschelde Container Terminal. Herziening van het streekplan Zeeland.

Provincie Zeeland, 2008. Aanleg Westerschelde Containerterminal (WCT) provincie Zeeland. Advies voor richtlijnen voor het milieueffectrapport.

Reubens J. (2013). The ecology of benthopelagic fish at offshore wind farms - towards an integrated management approach, Biology Department, Marine Biology Research Group. Ghent University, Ghent, pp. 237. Reubens et al. 2013 in Rumes et al. 2013

Reubens J., Degraer S. and Vincx M. (2013). Offshore wind farms significantly alter fish community structure – Aggregation of Atlantic cod and pouting. Chapter 11 of Degraer et al. (2013c).

Ruijgrok E., Smale A.J., Zijlstra I.R. et al. (2006a). Kentallen Waardering Natuur, Water, Bodem en Landschap - Hulpmiddel bij MKBA´s. Ministerie van LNV. 1e editie, 263p.

Ruijgrok, 2006b. Westerschelde Containerterminal: Maatschappelijke kosten-batenanalyse onderdeel paleontologie, natuur, landschap en daaraan gerelateerde recreatie.

Rumes B., Coates D., De Mesel I., Derweduwen J., Kerckhof F., Reubens J. and Vandendriessche S. (2013). Dies it really matter? Changes in species richness and biomass at different spatial scales. Chapter 18 of of Degraer et al. (2013c).

Salem, M. E. and D. E. Mercer. 2012. The Economic Value of Mangroves: A Meta-Analysis. Sustainability 4:359.

Scialabba, N.E., Hattam, C., 2002. Organic agriculture, environment and food security. Food and Agriculture Organisation of the United Nations. In Staes B., 2015

Seufert V., Ramankutty N. & Jonathan A.F. 2012. Comparing the yields of organic and conventional agriculture. Nature, V485, p.229-232

Simonini, R., I. Ansaloni, A. M. Bonvicini Pagliai, F. Cavallini, M. Iotti, M. Mauri, G. Montanari, M. Preti, A. Rinaldi, and D. Prevedelli. 2005. The effects of sand extraction on the macrobenthos of a relict sands area (northern Adriatic Sea): results 12 months post-extraction. Marine Pollution Bulletin 50:768-777.

Simonini, R., I. Ansaloni, P. Bonini, V. Grandi, F. Graziosi, M. Iotti, G. Massamba-N'Siala, M. Mauri, G. Montanari, M. Preti, N. De Nigris, and D. Prevedelli. 2007. Recolonization and recovery dynamics of the macrozoobenthos after sand extraction in relict sand bottoms of the Northern Adriatic Sea. Marine Environmental Research 64:574-589.

Skjemstad, J.O., B Cowie, R S Swift, L R Spouncer 2014. Calibration of the Rothamsted organic carbon turn-over model (RothC ver. 26.3), using measurable soil organic carbon pools. Aust. J. Soil Res 2004 Vol 42 (79-88)

Smyth A.R. (2013). Alterations in Nitrogen Cycling Resulting From Oyster Mediated Benthic-Pelagic Coupling. Dissertation thesis, University of North Carolina. 147p.

Stabo, 1998. Sociaal-economische gevolgen voor de land- en tuinbouw van het gecontroleerd overstromingsgebied Kruibeke-Bazel-Rupelmonde. Projectnummer 12410.

Studiebureau c.v Stabo v.o.d., in opdracht van Administratie Land- en Tuinbouw. Leuven. 59pp.
Staes J. (2015). Intermediate results from the ECOPLAN project (Planning for Ecosystem Services). www.ecosysteemdiensten.be
Staes, J., Van der Biest, K., Meire, P., Beauchard, O., Broekx, S., De Nocker, L., Liekens, I., Poelmans, L., Verheyen, K., Panis, J., 2014. Chapter 7: Quantification and Valuation of Ecosystem Services provided by the NATURA 2000 Ecological Network in Flanders (Northern Belgium). PhD Dissertation Jan Staes. ISBN 978 90 5718 074 3. Sydney ports. 2006. Penrhyn Estuary Habitat Enhancement Plan.
Sydney ports. 2009a. Port Botany container terminal expansion. Overview.
Sydney ports. 2009b. Port Botany Expansion. MCOA Annual Environmental Management Report.
Sydney ports. 2011. Port Botany Expansion. MCOA Annual Environmental Management Report.
Sydney ports. 2014. Port Botany Post Construction Environmental Monitoring: Saltmarsh Summary Report, March 2014.
Sydney ports. 2015. Port Botany Post Construction Environmental Monitoring: Seagrass Summary Report, April 2015.
TEEB. 2010. The Economics of Ecosystems and Biodiversity: The Ecological and Economic Foundations.
Thomas H., Bozec Y., de Baar H., Elkalay K., Frankignoulle M., Schietecatte L., Kattner G. and Borges A. (2005). The carbon budget of the North Sea. Biogeosciences, 2, 87–96
Thomson et al. 2006. In: Vandendriessche et al. 2013
Triple E Trust & Natuur en Economie, 2015. Nieuwe natuur, nieuwe kansen. Duurzame financiering als basis voor natuurbeheer in de Polders Van Kruibeke. 32pp.
UNEP, 2009. Water security and ecosystem services: The critical connection. A Contribution to the United Nations World Water Assessment Programme (WWAP). United Nations Environment Programme. Nairobi, Kenya.
UN-Water, 2014. A Post-2015 Global Goal for Water: Synthesis of key findings and recommendations from UN-Water. United Nations (UN) inter-agency mechanism for all freshwater and sanitation related matters (UN-Water).
Update Kennisontwikkeling Zandmotor (2013). Rijkswaterstaat, Nederland. 8p.
URS Australia and Sydney ports. 2003. Port Botany Expansion Environmental Impact Statement – Volume 1. Executive Summary. Sydney Ports Corporation, URS Australia
Uścinowicz, S., W. Jegliński, G. Miotk-Szpiganowicz, J. Nowak, U. Pączek, P. Przezdziecki, K. Szefler, and G. Poręba. 2014. Impact of sand extraction from the bottom of the southern Baltic Sea on the relief and sediments of the seabed. Oceanologia 56:857-880.
Van Braeckel, A., P. Piesschaert, and E. Van den Bergh. 2006. Historische analyse van de Zeeschelde en haar getijgebonden zijrivieren. 19e eeuw tot heden. INBO.R.2006.29. Instituut voor Natuur en Bosonderzoek, Brussel, België.
Van Broekhoven E., Somers L. & Tacquenier B. (2012) Overzicht van de boekhoudkundige resultaten van 749 land- en tuinbouwbedrijven Boekjaar 2010 Landbouwmonitoringsnetwerk, Beleidsdomein Landbouw en Visserij, afdeling Monitoring en Studie, Brussel
Van de Walle, B., C. Boone, and H. Kerrebrouck. 2011. Muren aan de kaai… Saai? Niks van! De Grote Rede 31, 17-22.
Van den Eynde D., Baeye M., Brabant R., Fettweis M., Francken F., Haerens P., Mathys M., Sas M. and Van Lancker V. (2013). All quiet on the sea bottom front? Lessons from the morphodynamic monitoring. Chapter 4 of of Degraer et al. (2013c).
van der Moolen L.N. (2015). An interdisciplinary process based framework for sandy coastal developments – Inspired by the Sand engine project. Thesis for Master of Science in Civil Engineering, TUDelft, 2015.
Van der Ploeg, S. and R.S. de Groot (2010) The TEEB Valuation Database – a searchable database of 1310 estimates of monetary values of ecosystem services. Foundation for Sustainable Development, Wageningen, The Netherlands.
van Gelder-Maas C. (2014). Meten om te weten. Voorstelling tussentijdse evaluatie Zandmotor. Presentatie 31 maart 2014. 18p.
Vandamme, M., G. Bernaersa, and F. Aerts. 2007. Construction of the Deurganckdok in the Port of Antwerp, Belgium. Antwerp Port Authority.
Vandendriessche S., Derweduwen J. and Hostens K. (2013). Between the turbines: soft substrate epibenthos and fish. Chapter 10 of Degraer et al. (2013c).
Vanermen et al. 2013. Attraction of seabirds. Chapter 15 of Degraer et al. (2013c).
Vanermen N., Brabant R., Stienen E., Courtens C., Onkelinx T., Van de walle M., Verstraete H., Vigin L. and Degraer S. (2013). Bird monitoring at the Belgian offshore wind farms: results after five years of impact assessment. Chapter 5 of Degraer et al. (2013c).
Vereniging redt de kaloot, 2009. Aanvullende rapporten MER Aanleg WCT en natuurcompensatie voor de WCT. T.a.v. Provinciale Staten.
Verheyen K., unpublished data
Verwaest T. (2008). De impact van aggregaatextractie op de

kustveiligheid bij storm. 8p.
VLM 2014. Manuring standards 2014. www.vlm.be
Voortgangsrapportage Zandmotor 2014. 9p. www.zuid-holland.nl
W&Z, 2015. Communication. Data overview for the maintenance cost for the pumping system in Kruibeke, 2003-2012. Waterwegen en Zeekanaal.
Waldbusser GG, Steenson RA, Green MA (2011). Oyster shell dissolution rates in estuarine waters: effects of pH and shell legacy. Journal of Shellfish Research 30, 659−669
WBCSD 2012. Biodiversity and ecosystem services scaling up business solutions Company case studies that help achieve global biodiversity targets. World Business Council for Sustainable Development. Atar Roto Presse SA, Switzerland
WBCSD 2016. Biodiversity and ecosystem services scaling up business solutions. World Business Council for Sustainable Development. http://www.wbcsd.org
Web of Science (2016). http://apps.webofknowledge.com/
Wijnen et al. 2002 in Ruijgrok et al. 2006a.
Wint G.R.W. and Robinson T.P. 2007. Gridded livestock of the world 2007, Rome, pp 131.
www.c-power.be. Official C-power website. Consulted May – August 2015
www.esa.org. Official website of the Ecological Society of America. Consulted May – August 2015
www.fossiel.net
www.geologievannederland.nl
www.highroc.eu. Official website of the HIGHROC project (High spatial and temporal resolution ocean colour products and services). Consulted July 2015
www.klimaatatlas.be. Langjarige gemiddelden 1981-2010, website of KNMI, Ministerie van Infrastructuur en Milieu, Nederland
www.marbef.org. Official website of the MARBEF project (Marine Biodiversity and Ecosystem Functioning). Consulted July 2015
www.redwave.nl. Official Redwave website. Consulted June 2015
www.werkgroepgeologie.nl
ZKA Consultants & Planners (2014). Monitor Toerisme en Recreatie Flevoland 2014. 59p.

ECOSYSTEM SERVICES: TOWARDS INTEGRATED MARINE INFRASTRUCTURE PROJECT OPTIMISATION

Annelies Boerema, Katrien Van der Biest and Patrick Meire

Ecosystem management research group (ECOBE)
University of Antwerp, Campus Drie Eiken
Universiteitsplein 1, 2160 Wilrijk
Contact: patrick.meire@uantwerpen.be

ECOBE
016-R190

Final version, September 2016

Commissioned by International Association of Dredging Companies (IADC)
www.iadc-dredging.com

IADC SECRETARIAT Alexanderveld 84 · 2585 DB The Hague · The Netherlands
POSTAL ADDRESS PO Box 80521 · 2508 GM The Hague · The Netherlands
PHONE +31 (0)70 352 33 34 E-MAIL info@iadc-dredging.com
WEBSITE www.iadc-dredging.com