Ecosystem Service Assessment of TIDE Estuaries

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1 Summary

Ecosystem services (ES) link nature with human well-being. The economy, health and survival depend upon natural resources. Health problems, natural disasters and high costs for technical replacement of natural regulating functions increase the need to adopt a broader view and strategy on resource use.

The Ecosystem services approach offers a pragmatic, rational approach to nature management and an opportunity to sustainably manage natural capital for human benefits. The societal demand for regulating services to cope with growing risks of lowered ecosystem functioning is growing, especially in coastal zones and estuaries.

TIDE presents an overview of demand and supply of ES in four North Sea estuaries (Elbe, Weser, Humber, Scheldt), including maps of many estuarine ecosystem services.

ES demand in the four estuaries is very similar, due to the fact that these estuaries are both ecological as socio-economic very similar. A remarkable difference is the lower demand for sedimentation-erosion regulation by biological mediation, extreme water current reduction and landscape maintenance services in the Humber estuary, due to its naturally extreme turbidities and fluid mud conditions, combined with lower dredging requirements compared to the other estuaries.

The supply by habitat is also comparable among estuaries, and most service supplies are also similar along the salinity gradient. Using the scores of supply importance by habitats, trade-offs and synergies, historical value estimates, and impacts of estuarine management measures on ES are provided. The provision of bundled ecosystem services requires the entire gradient of habitats. Many services, essential for regulation and support of the estuarine system, are provided by habitats with lower direct provisioning service supplies, such as marshes, mudflats and shallow water habitats. Steep intertidal habitats, where ecological functioning is hampered, provide the least ecosystem services.

The TIDE results can be used in different fields of estuarine management.

- Improvement of knowledge on ES in general, addressing of knowledge gaps and further pooling of expertise.
- For the implementation of measures: which habitats should be maintained/ restored in order to stimulate certain ES, or for obtaining the maximum supply of the entire bundle of ES.
- For decision making processes: which ES at which location are important or less important for the vision on a certain estuary or for the respective society/residents.
- For estuarine governance: synergies and conflicting aims (with other processes) can be deduced.

There are however important challenges in the related ecological research, in the valuation of ES as well as in the governance to obtain a sound ecosystem based planning and management. However, the current knowledge and this ES assessment provide ample reasons to avoid negative effects from single-benefit directed estuarine measures in the future. The methodology, relying almost entirely on participation by estuarine management experts and involved scientists, has proven to yield useful results, and the ecosystem service supply matrix could be used to map ecosystem services in similar estuaries.

2 Introduction

2.1 Ecosystem Services

"Ecosystems are capital assets which, when properly managed, can yield a flow of vital services" (Daily, 2000)

Ecosystem services link ecosystems with human well-being. Our economy, health and survival depend entirely, albeit often indirectly, upon natural resources (Millenium Ecosystem Assessment, MA 2005). Together with population growth and growing per capita consumption rates, the demand for natural resources increased, and the impact of this consumption pattern became more and more clear: natural resources, supposed to be infinitely and freely available, are becoming scarce or degraded (MA 2005). Health problems, natural disasters and high costs for technical replacement of natural regulating functions have increased the need to adopt a broader view and strategy on resource use.

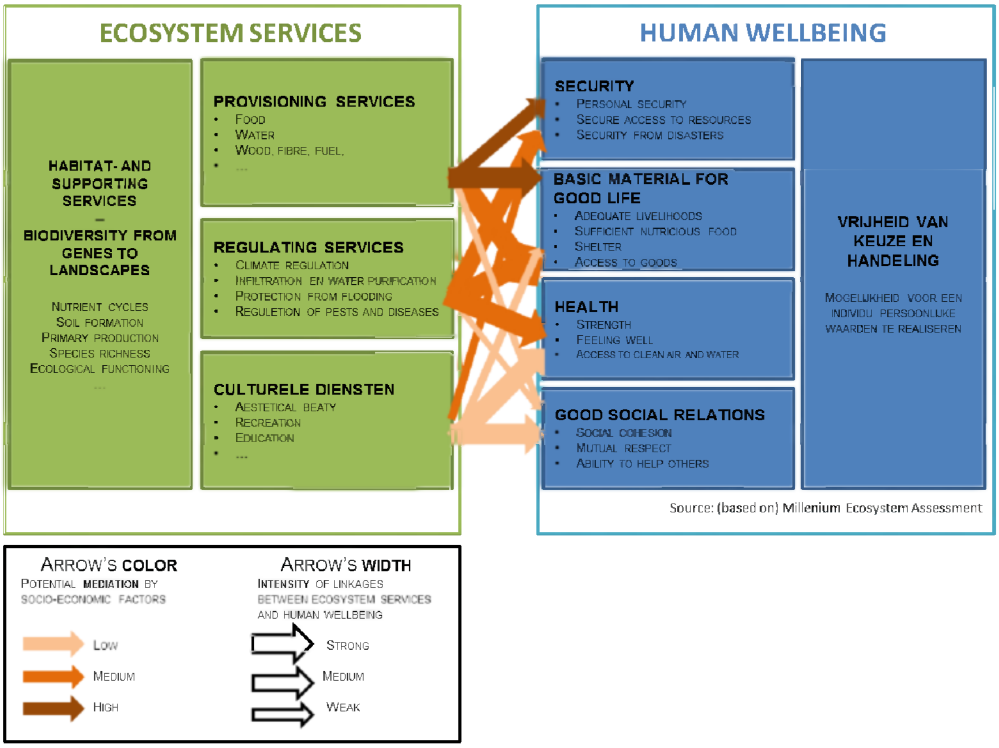


Figure 1 Ecosystem services link ecosystems to human well-being. Based on MA 2005.

Since the publication of the Millennium Ecosystem Assessment in 2005 the concept of ecosystem services has caught widespread attention (MA 2005; www.maweb.org). Ecosystem services are defined as 'the benefits which people derive from nature' (Costanza, 1997; MA, 2005). Fisher et al. (2009) consider ecosystem services to be '*the aspects of ecosystems, utilized actively or passively, to produce human well-being*'. This definition includes ecological phenomena that are used or consumed, directly or indirectly, by humans.

A benefit to human wellbeing, generated by an ecosystem service, mostly requires a human investment (e.g. drinking water requires a pumping installation and a distribution system). The service itself however originates from an ecosystem *function*, being the set of structures and processes which eventually produce the service. Sometimes, several more or less separated functions are appropriate to describe the supply in intermediate services.

Structures and processes are not exclusive to one single service: they contribute to several services and often exhibit trade-offs. For instance, anoxia (lack of oxygen) is a condition in an estuary that is generally considered as negative for provision of many services (e.g. food web support, service: fish provision) related to primary production, but on a microbial scale, it provides the necessary conditions for improved nitrogen removal (service: water purification). As such, every single service is connected directly and indirectly to an intertwined web of structures and processes, finally supported/insured by the functioning and resilience of the entire ecosystem. Understanding of this functioning is thus essential to manage the services and benefits derived from them.

The field of ecosystem services aims to classify, describe and assess the natural assets, their supply functions, quantification, valuation and management. Ecosystem services are now generally categorized in provisioning (food, water,..), regulating (flood control, air purification,..), and cultural (recreation, aesthetic experiences,..) services. All of those are eventually generated, supported and ensured by ecosystems in all their diversity (supporting services or broadly defined biodiversity) (Figure 1, MA 2005, TEEB 2010).

2.2 Ecosystem Services in Estuaries

Estuaries and coastal marine ecosystems are cited among the most productive biomes of the world, and serve important life-support systems also for human beings (Day et al 1989, Costanza et al 1997). Estuaries support many important ecosystem functions: biogeochemical cycling and movement of nutrients, purification of water, mitigation of floods, maintenance of biodiversity, biological production (nursery grounds for commercial fish and crustacean species) etc. (Daily et al 1997). An extensive overview can be found in Table 1.

Many estuaries, as is the case with the four TIDE estuaries, are of tremendous economic and social importance as they are the main trade hub for international shipping, attracting industrial production and transport companies, providing labor and economic growth. Typically, estuarine ecosystems are some of the most heavily used and threatened natural systems globally (Lotze et al. 2006, Worm et al. 2006, Halpern et al. 2008, Barbier et al. 2011), and their deterioration due to human activities is intense and increasing (Barbier et al. 2011). This degradation has a direct impact on the services delivered by estuaries, and thus threatens the well-being of people as well as the economic activities itself.

Due to the fact that estuaries are disappearing worldwide, assessing and valuing the ecosystem services is critically important for improving their management and for designing better policies (Barbier et al. 2011). Yet, as the review by Barbier et al (2011) has shown, many of these values are non-marketed, and efficient management of such ecosystem services requires explicit methods to measure this social value.

2.3 Key questions and general approach

Within TIDE, an approach was developed to tackle a number of key questions concerning ecosystem services in estuaries.

- What are the most important ecosystem services for these estuaries?
- What is the demand for services in each estuary?
- How does this demand vary over time and along the salinity gradient?
- How do habitats differ in supply of ecosystem services?
- What is the spatial variation in that supply?
- How did morphological changes affect ES supply?
- What are potential trade-offs or synergies in supply of ES?
- How can ES be used in habitat conservation/restoration/development?
- How can ES be used to assess estuarine management measures?

Tackling these key questions requires a broad ecosystem service assessment, taking into account the four estuaries entirely and including a broad bundle of services.

Particularly in estuaries, ecosystem functioning is inherently complex, there are many data gaps and management decisions affect a multitude of societal groups, (Granek et al 2010). Also, as pointed out by Barbier et al (2011), many of the important estuarine benefits have not been estimated reliably, and even for those services that have been valued, only a few dependable studies have been conducted.
A service is supplied by an intertwined web of structures and processes, finally supported/insured by the resilience of the entire ecosystem. Quantifying the supply of all services requires delineation of the all processes and structures involved and linking all these to measured or measurable units per service, which was impossible within the scope of TIDE.
Therefore, the ecosystem service assessment in TIDE aimed at providing a broad overview for inter-estuarine comparison and general conclusions on NW European estuaries in general, this meant that the ecological complexity and biophysical supply had to be captured and evaluated in a more generally applicable way. Rather than focusing on functional description and quantifications of detailed fragments of this whole picture, the choice was made to involve about 30 professional estuarine experts in obtaining a more general, but complete semi-qualitative overview to tackle the research questions.

Involving professionals in the ecosystem service assessment allows to increase the awareness of ecosystem services in estuaries, and is in line with the development of an ecosystem based estuarine management (e.g. Granek et al 2010). Ideally, technical information from natural and social scientists, experiential knowledge of people familiar with the ecosystem, and information on the benefits that different individuals and groups receive from goods and services provided by the ecosystem would flow to policy makers and managers to help guide policy formulation and implementation (Granek et al 2010).

The approach of this study:

- Focuses on comparing a broad bundle of services rather than on the detailed assessment of a few single services, well-known supply functions or case studies.
- Is based on experiential knowledge of people familiar with the system to provide a broad assessment in semi-quantitative units rather than quantitative data using diverse units and suffering from knowledge gaps.
- Involves professional experts from the TIDE regional working groups, conveying the importance and potential of ecosystem service based management to professionals active in estuarine management.

The work within the TIDE project provides a broad overview of ecosystem service demand and supply in the four TIDE estuaries, but it is only the first step towards *capturing the value* of ecosystem services (TEEB 2010). This capturing can be obtained by seeking solutions to overcome the current undervaluation of many ES, using economically informed policy instruments, which are based on local quantifications and assessments. These should take into account biophysical and ecological underpinning as well as social and economic values of the specific local context.

The approach for this study was as follows:
Firstly, the important ecosystem services for TIDE estuaries are distinguished from a "longlist" of estuarine services, and the **variation in demand** ("societal importance") is assessed along estuaries, salinity zones and for historical, present and future time steps.
Secondly, the "**ecosystem service supply**" results are presented. ES supply is compared for the different along the estuaries and basic underlying **processes and structures** are pointed out. A **historical ES supply** evolution through habitat change is estimated. An indicator for **trade-off risk** generated by differential supply of ES by habitats is discussed. In the Measures report, (see report "Management measure analysis and comparison"), the expected effect of **estuarine management measures** on ES supply was estimated. In our report, the **synergies in ES supplies** (which ES supplies are increasing together) occurring from these measures are discussed.
Finally, key questions are answered and **recommendations for research, policy and practice** are provided in the conclusion section.

3 TIDE ES - Assessment methodology

In the following sections, the detailed methodology for the demand and supply surveys is explained. The survey reliability (consistence and accordance) is assessed. and the limitations of the survey methodology as well as the validity of the results for future use are determined.

3.1 From "ES longlist" to key ecosystem services

Initially, a "longlist" of services was identified based on literature and estuarine expert involvement (table 1). The "TIDE longlist", comprises 46 services, of which 15 provisioning, 25 regulating and 5 cultural services. The category “supporting service” (benefit: insurance of all services; see 2.1) was defined as *total amount of abiotic and biotic diversity at all levels (gene-landscape), regardless of rarity or vulnerability.* All services were briefly defined and main benefits mentioned (see Table 1)

Evidently, not all of these services have the same societal relevance. Some services are supplied in larger quantities than others. Also, differences between historical times, present and future supply will occur, and supply variations among and within estuaries prevail. When drafting this list, the explicit goal was to obtain a list containing al services mentioned in literature or by experts. Consequently, this list contains some redundancies, as well as mixtures between intermediate and final services.

CATEGORY	NR	SERVICES	BENEFITS	Short description
PROVISIONING SERVICES	1.1	Food: Plants	Food	presence and use of edible plants, including agricultural production for direct food consumption
	1.2	Food: Animals	Food	presence and use of edible animals, including livestock growth and fodder production
	1.3	Water for household use	drinking water	provision and use of water for household use meeting the quality standards for drinking water
	1.4	Water for industrial use	improved industrial production	provision and use of water for e.g. cooling water, rinsing water, water for chemical reactions
	1.5	Water for agricultural use	improved agricultural production	provision and use of water for e.g. irrigation water, freezing prevention for fruit trees, drinking water for cattle,..
	1.6	Water for energy use	renewable energy production	provision and use of water for tidal or dam water turbines
	1.7	Water for navigation	Shipping	presence and use of water for shipping purposes
	1.8	Raw materials: Renewable soil materials: sand	building material	provision and use of sand from dynamic environments which are renewed within a few generations (100 y)
	1.9	Raw materials: Renewable soil materials: clay	building material	provision and use of clay from dynamic environments which are renewed within a few generations (100 y)
	1.10	Raw materials: Platform	building platform for housing, roads, infrastructure,…	presence and use of stable and safe environments for building of infrastructure: housing, roads,..
	1.11	Raw materials: Plants	building material, fibre, fuel	presence and use of forests, energy and fibre crops
	1.12	Raw materials: Animals	building material, fibre, fuel	presence and use of animals for fur, leather, gelatine,…
	1.13	Genetic resources	various improved provisioning services	presence and use of typical varieties and cultivars of species, adapted to a specific environment
	1.14	Medicinal resources	human health	presence and use of plants/organisms used in herbal medicine, medicinal tea,...
	1.15	Ornamental resources	Wellbeing	presence and use of organisms for decorative purposes
REGULATING SERVICES	2.1	Air quality regulation: Removing harmful particles	human health	adsorption of fine dust and pollutants on leaf surfaces of forests,…
	2.2	Air quality regulation: Air-water exchange	human health	influence of evaporation and evapotranspiration, condensation on air quality
	2.3	Air quality regulation: Biogeochemical reactions due to activity of organisms	human health	respiration and photosynthesis, exudation of chemicals by degradation reactions,…
	2.4	Climate regulation: Carbon sequestration and burial	human health, avoided costs caused by extreme events or disturbance, ensured provisioning services	buffering carbon stock in living vegetation, burial of organic matter in soils
	2.5	Climate regulation: Water thermodynamic regulation	human health, avoided costs caused by extreme events or disturbance, ensured provisioning services	cooling effect of vegetation, uptake of solar energy for photosynthesis and evapotranspiration,

	2.6	Climate regulation: Heat exchange regulation	human health, avoided costs caused by extreme events or disturbance, ensured provisioning services	effect of direct reflection, storage, transport, radiation of solar heat by various soil and water bodies
	2.7	Regulation extreme events or disturbance: Flood water storage	human health, avoided costs caused by extreme events or disturbance, ensured provisioning services	storage of storm or extreme spring tides in natural or flood control habitats
	2.8	Regulation extreme events or disturbance: Peak discharge buffering	human health, avoided costs caused by extreme events or disturbance, ensured provisioning services	storage of peak discharge floods in natural or flood control habitats
	2.9	Regulation extreme events or disturbance: Water current reduction	human health, avoided costs caused by extreme events or disturbance, ensured provisioning services	reduction of water current by physical features or vegetation
	2.10	Regulation extreme events or disturbance: Wave reduction	human health, avoided costs caused by extreme events or disturbance, ensured provisioning services	reduction of wave height by physical features or vegetation
	2.11	Regulation extreme events or disturbance: Sound buffering	human health	reduction of noise disturbance by presence of natural buffers
	2.12	Water quantity regulation: drainage of river water	ensured platform, food, water other provisioning services	drainage of the catchment by the river
	2.13	Water quantity regulation: prevention of saline intrusion	various ensured provisioning services	countering of saline tidal wave by fresh water discharge
	2.14	Water quantity regulation: dissipation of tidal and river energy	various ensured provisioning services, avoided maintenance costs	buffering of average flood and discharge variations in the river bed
	2.15	Water quantity regulation: landscape maintenance	various ensured services	formation and maintenance of typical landscapes and hydrology
	2.16	Water quantity regulation: transportation	Shipping	discharge and tidal input for shipping, including water use for canals and docks
	2.17	Water quality regulation: transport of pollutants and excess nutrients	improved water quality, various ensured services	transport of pollutants from source, dilution
	2.18	Water quality regulation: reduction of excess loads coming from the catchment	improved water quality, various ensured services	binding of N, P in sediments and pelagic food web
	2.19	Erosion and sedimentation regulation by water bodies	avoided damage or maintenance costs, various ensured provisioning services	sediment trapping and gully erosion by variable water currents and topography
	2.20	Erosion and sedimentation regulation by biological mediation	avoided damage or maintenance costs, various ensured provisioning services	sediment trapping and erosion prevention by vegetation, effects of bioturbation
	2.21	Biological regulation of soil processes and soil formation	various ensured provisioning services	soil microbial activities important for agriculture or water quality regulation processes, bioturbation
	2.22	Prevention of establishment of harmful invasive species	various ensured provisioning services	presence of resilient natural populations able to withstand invasion
	2.23	Reduced spread of diseases	various ensured provisioning services, human health	presence of resilient and equilibrated natural populations avoiding excessive population growth of disease-carrying vector species, importance for human health or agriculture
	2.24	Pollination	various ensured provisioning services	presence of pollinators and importance for agricultural production
	2.25	Pest control	various ensured provisioning services	presence of predators for problematic pest species impacting agricultural production
HABITAT SERVICES	3.1	"Biodiversity"	insurance of all services	total amount of abiotic and biotic diversity at all levels (gene-landscape), regardless of rarity or vulnerability
CULTURAL & AMENITY SERVICES	4.1	Aesthetic information	Wellbeing	appreciation of beauty of organisms, landscapes,…
	4.2	Opportunities for recreation & tourism	Wellbeing	opportunities and exploitation for recreation & tourism
	4.3	Inspiration for culture, art and design	Wellbeing	appreciation of organisms, landscapes,… as inspiration for culture, art and design
	4.4	Spiritual experience	Wellbeing	appreciation of organisms, landscapes,… on a spiritual level
	4.5	Information for cognitive development	Wellbeing	use of organisms, landscapes for (self-) educational purposes

Table 1: Longlist of estuarine ecosystem services for the four TIDE estuaries. Category (TEEB 2010), benefits and short definition is added.

3.2 Expert survey reliability: theory

In TIDE, the ES assessment is entirely based on expert surveys and inventories. A first survey, implying 27 estuarine users and stakeholders from regional working groups of all four estuaries, was used to determine the focal ecosystem services, demand of ecosystem services, and trends in these services. A second survey, implying 12 professional experts in estuarine functioning, was used to provide information on the supply of ES.
In the ecosystem service based management (EBM) approach of Granek et al (2010), "*the benefits that make services relevant to human wellbeing*" are regarded as "*end-use demand*". Although we do not quantify the material demand for a certain amount of service or benefit, and consequently this cannot be an economic demand for a certain quantity of service, the assigned value can be regarded as a representation of a societal demand of a given service relative to other services. *"By definition, an ecosystem service is only a service, if there is a benefit. This means, there must be a certain demand by people to use a particular service. [These demands] can be derived from statistics, modeling or interviews […] [and] transferred to a scale similar to the one used for ecosystem services supply [..].*(Burkhard et al 2012). This is an important concept since it finally determines priorities for conservation and restoration of service providing units.
As *"values may be assigned heterogeneously by people over the landscape" (Norton and Hannon, 1997 in Bryan et al 2010)*, it is essential to account for local variability in this demand value. We adapted the survey approach in order to account for spatial (estuaries, salinity zones) as well as temporal aspects. The surveys were performed for every estuary, along four common salinity zones, and for historical (ca. 1900), present and future (ca. 2050) times.

An essential but often overlooked aspect in using expert data are the scientific checks of consistency and agreement among raters (or rater groups, in this case estuarine regional groups), the argumentation of validity by comparing results to other data sources or observed patterns as well as describing the experts' basic background. This is crucial before interpreting results of the survey, but also to verify whether data can be extrapolated to other systems or if the survey -as a tool- is reliable.
Within the TIDE approach, both statistical procedures, assessment of general patterns and argumentative confidence are verified.

Statistical reliability

Cronbach's Alpha

In statistics, Cronbach's alpha (Cronbach 1951) is a coefficient of reliability. It is commonly used as a measure of the internal consistency or reliability of a test score for a sample of examinees. Cronbach's alpha statistic is widely used in the social sciences, business, nursing, and other disciplines. A commonly accepted rule of thumb for describing internal consistency using Cronbach's alpha is as follows (George et al 2003, Kline 1999):

Cronbach's alpha	Internal consistency
α ≥ 0.9	Excellent
0.8 ≤ α < 0.9	Good
0.7 ≤ α < 0.8	Acceptable
0.6 ≤ α < 0.7	Questionable
0.5 ≤ α < 0.6	Poor
α < 0.5	Unacceptable

Some professionals (Nunally 1978) as a rule of thumb, require a reliability of 0.70 or higher (obtained on a substantial sample) before they will use an instrument.

Intraclass correlation coefficient (ICC)

Another statistic which is prominently used for assessment of consistency or reproducibility of measurements made by different observers, is the intraclass correlation coefficient (abbreviated ICC, Koch 1982). ICC can be applied when quantitative measurements are made on units organized into groups. It describes how strongly units within the groups resemble each other. While ICC is a correlation, unlike most other correlation measures it operates on groups, rather than on paired observations. ICC might thus be a more appropriate evaluation of the TIDE survey methods, which clearly assessed grouped data (estuaries, zones, habitats).
The test can be performed in several ways depending on the conditions (see R package irr version 0.82). When considering which form of ICC is appropriate for an actual set of data, one has to take several decisions (Shrout & Fleiss, 1979):

- Should only the subjects be considered as random effects ('"oneway"' model) or are subjects and raters randomly chosen from a bigger pool of persons ('"twoway"' model). We have chosen a twoway model.
- If differences in judges' mean ratings are of interest, interrater '"agreement"' instead of '"consistency"' should be computed. We have performed both.
- If the unit of analysis is a mean of several ratings, unit should be changed to '"average"'. In most cases, however, single values (unit='"single"') are regarded. As the score was a consensus (debated mean) of expert groups, the former is the case in our survey.

Omega-H

Finally, it has been shown that alpha (or ICC) can return high values even when several unrelated latent constructs are measured (e.g., Cortina, 1993; Cronbach, 1951; Green et al 1977; Revelle, 1979; Schmitt, 1996; Zinbarg et al 2006), such as our different estuaries could be considered. It is only appropriately used when the items measure different areas within a single construct. When more than one construct is measured, the coefficient omega_hierarchical (omegaH) is more appropriate (McDonald, 1999; Zinbarg et al, 2005).
Let us clarify this for the TIDE surveys. If our estuaries are considered different (functioning) systems, alpha (and ICC) are not appropriate. However, if they are

similar entities of "the industrialized estuary", the omegaH should yield about the same result as alpha and ICC.
OmegaH is a much more complex procedure involving factor analysis, which is a field of statistics related to principle component analysis. To find omega it is necessary to do a factor analysis of the original data set, rotate the factors obliquely, do a Schmid-Leiman transformation, and then find omega. In de R package psych (version 1.0-85), McDonalds provides the code to do this.

Traceability and argumentative confidence

When surveying for societally relevant answers, a broad survey is appropriate. However, apart from the number of respondents (which logically is as big as possible), their affinity is the key issue. It is essential to include stakeholders from different sectors. This is called segmentation. Theoretically, the number of respondents should be increased until a saturation point (no more differing 'stakes') is reached. In anonymous surveys, the number of representatives per sector is also important. In open group surveys, consensus scorings can be obtained, and the number of respondents per sector is far less important than their authority and expertise level.
When surveying for specialized information or scientific knowledge to fill data gaps and obtain scientifically supported qualitative statements, the number of respondents is irrelevant. Two specialists will generate data with a much higher confidence level than a hundred laymen which are no experts in the matter concerned. However, checks on confidence of this kind of surveys are crucial (Van Crombrugge 2002). Miedema (1988) and Van Ijzendoorn (1988) distinguish technical and argumentative confidence. Confidence points towards the exact determination of the possibility to repeat a certain aspect of the research. Argumentative confidence is the non-quantitative indication of repeatability of the research process whenever exact repeatability cannot be determined (Van Ijzendoorn et al. 1986). For this kind of research, "traceability" is a more adequate term to evaluate confidence (Smaling 2004).This traceability accounts for the collection as well as for the analysis of the data. A well-known example of this kind of semi-quantitative research confidence evaluations is the IPCC research and their uncertainty approach, in which accordance of evidence is one of the features evaluated.
For the TIDE surveys, maximal transparency on survey questions, respondents and analyses is provided, as well as cross-checks of emerging patterns with physical reality.

3.3 TIDE Survey methodology & reliability

Survey one: Demand survey

Objectives

In order to select focal ecosystem services and obtain an estimate of service demand, the value (sensu Costanza 2000: appraised value or importance for society) of these services was qualitatively assessed. This corresponds to the concept of assigned values (Brown, 1984; Lockwood, 1999) as applied by Bryan et al (2010). As advised by Granek et al (2010) this implied decision makers and the public.

The first basic objective was to determine which ecosystem services were important to be considered in TIDE, to narrow down the further research to the relevant services.
The second objective was to obtain a qualitative estimate of the importance of the ecosystem services, comparable over space (estuaries, salinity zones) and time.

Questions

Respondents were asked to score the importance of 46 ecosystem services for every salinity zone in their estuary, for past, present and future times. Salinity zones were based on the zonation report (see report Zonation of the TIDE estuaries). Past and future were defined as ca. 1930 and ca. 2050 respectively. The scoring values were:

Score	Description
1	don't know
2	unimportant ecosystem service
3	less important
4	important
5	very important

The survey thus yielded 48 ecosystem service lists (four estuaries, four zones, three time steps), each containing 46 scores. The respondent groups were asked to provide a debated consensus scoring per estuary.

Reliability of the survey

Reliability of the survey was evaluated by checking consistency and accordance of survey results between estuaries. Although a high accordance adds to the confidence that can be put in the results, a low accordance could well be the result of differences in score interpretation or resulting from actual differentiation in importance among estuaries.
Visually, this can be evaluated by the mean, standard error and standard deviation of scores per service (Figure 2). Standard error never exceeds categories, standard deviation rarely exceeds one category. This rather high observed accordance adds a third argument to the confidence in results of the first survey.

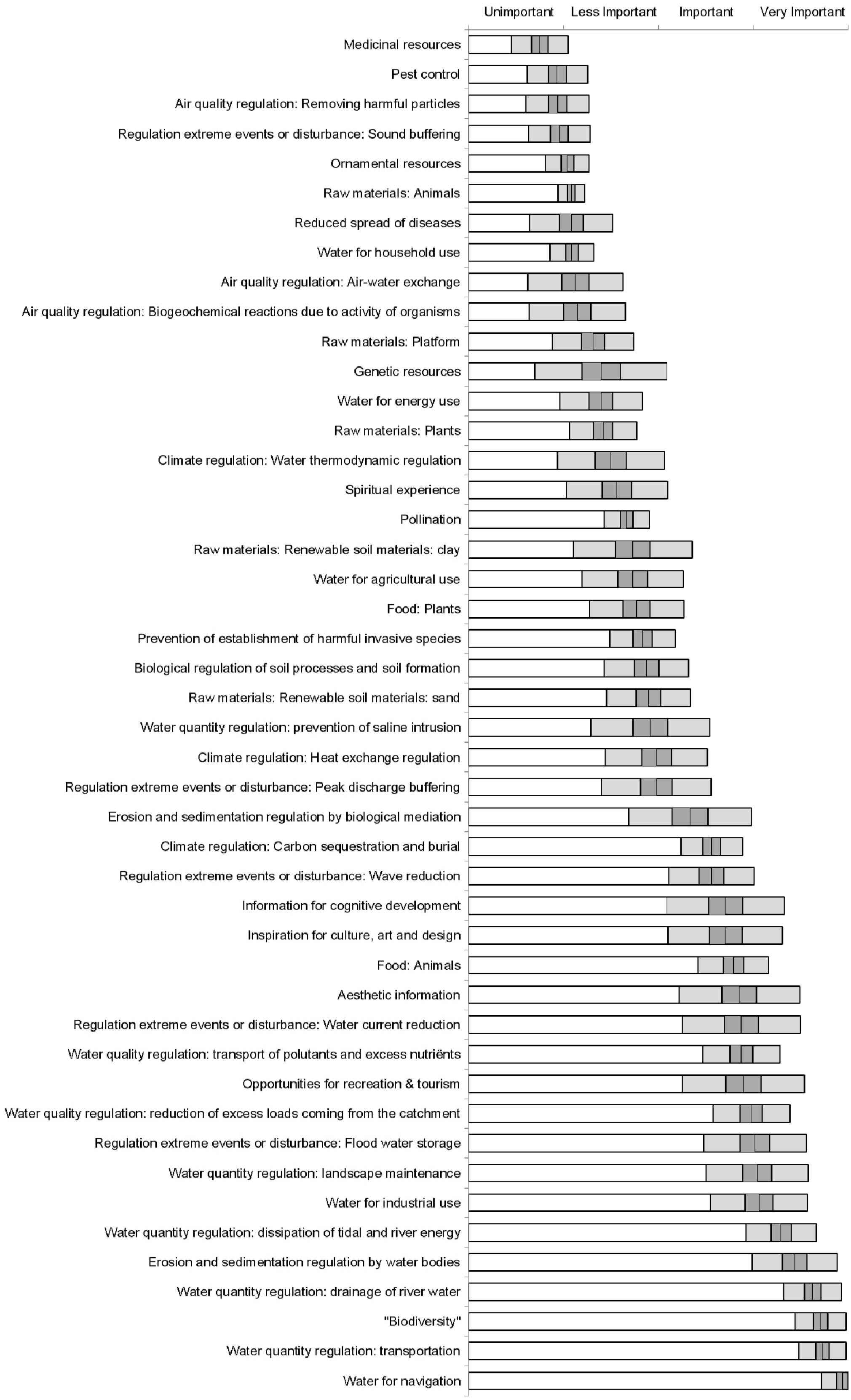


Figure 2: Importance score of all ecosystem services. Dark grey bars represent standard error over all estuaries and zones, lighter bars standard deviation.

Statistically, the demand survey has an **acceptable** reliability (**alpha = 0.798**), inter-estuarine consistence (**ICC-c = 0.798**; F-Test F(183,549) = 4.95 , p = 6.39e-48; 95%-CI 0.746 < ICC < 0.842) and agreement (**ICC-A = 0.792**; F-Test F(183,459) = 4.95 , p = 7.75e-44; 95%-CI 0.737 < ICC < 0.838). Estuaries have also a high similarity in ES-demand (**Omega-H = 0.77**)

Respondents and their affiliations

As the confidence and legitimacy of the results clearly depends on the representativeness of the respondents, this survey was conducted in the regional working groups in each estuary. "*These groups consisted of several experts being very familiar with the characteristics of the [...] estuary. In this context it was the aim to bring people with different expertise together, e.g. ecology, hydrology, sediment management, engineering, experience in the implementation of various European directives, etc.. Furthermore the experts should come from different institutions [...]*" (pers.comm Kirsten Wolfstein).
The number of respondents per consensus group ranges widely (3 – 9), and their expertise level from student to professor or engineer. Their experiences vary from coordination of navigation projects, to estuarine ecology research, morphological modeling, drafting of conservation plans, polluted sediment remediation, etc. For the first survey, respondents' affiliations and expertise are depicted in appendix I.

Additionally, a basic check was performed to verify whether affinities of the respondents are sufficiently broad. The respondents assigned their own personal or professional affinity to three categories ('transport', 'safety' and 'ecology', fig…). This test indicated a reasonable representation of basic issues in estuarine management for all estuaries, except for the "safety" aspect which is not represented in the Elbe. Also, the Scheldt group was very small. However, earlier tests indicate this did not influence inter-estuarine consistency or accordance of scorings.

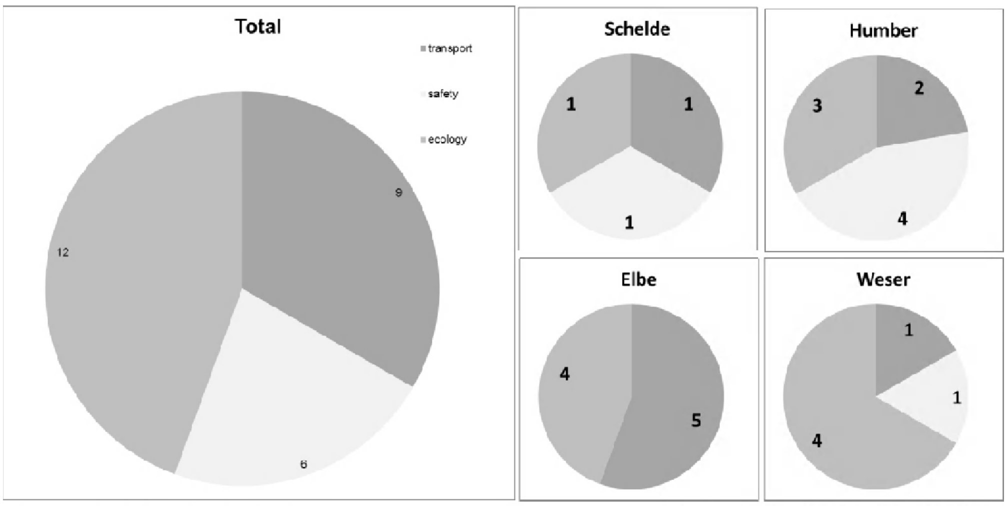


Figure 3: Affinity of different regional working groups and overall affinity distribution. Number represents the number of persons scoring the highest priority for a certain category.

Conclusions demand survey reliability

Based on the acceptable level of consistence, accordance and the similarity among expert groups scorings, the broad selection of stakeholders, their expertise and their differentiation over estuarine topics; the results of the demand survey can be assigned a high confidence, despite large differences in group size. The legitimacy of this demand survey would surely benefit from a repetition with an even broader selection of stakeholders, including non-technical experts and broader user groups.

Survey two: habitats and supply of ecosystem services

Objectives

The first objective was to obtain a qualitative supply score for every service by every habitat; "how important is habitat x in delivery of ES y?".
The second objective was to obtain this information over different salinity zones.
The third objective was to obtain qualitative scorings on the state of the habitats concerning ES, more precisely on overall functional quality (to deliver the bundle of services) and current (decades) trend of the habitats, again in each zone and estuary.

Questions

The approach of Burkhard et al (2010, 2012) was adapted for use in the TIDE estuaries. Similarly to their approach, a habitat x ecosystem service matrix was created. For this analysis, six habitat types were distinguished and described (see report "Interestuarine comparison: hydro-geomorphology"). Compared to the four TIDE habitats, two low-dynamic habitats were distinguished since these exhibit different functioning. The conditions were that these habitat categories should:

- cover the entire estuarine gradient
- allow mapping in all four TIDE estuaries
- be explicitly and clearly described
- be easily understandable by a broad selection of stakeholders
- form ecologically distinguishable functional units

These six habitats were defined as physiotopes based on elevation and slope (see 3.2 and report "Interestuarine comparison: hydro-geomorphology") These habitats were regarded as *service providing units* (Luck et al 2003, 2009) and used as a basis for scoring the supply of ecosystem services. It should however be kept in mind that these are categories distinguished within a continuous gradient when observing sharp shifts in supply values. Since habitats are regarded per zone there are ecological differences within them along the salinity gradient.

Marsh habitat	above mean high water (MHW)
Intertidal steep habitat	Between MHW and MLW, slope > 2.5%
Intertidal flat habitat	between MHW and MLW, slope < 2.5%
Subtidal shallow habitat	between MLW and 2m beneath MLW
Subtidal moderately deep habitat	between 2m and 5m beneath MLW
Subtidal deep habitat	>5m beneath MLW

This allows to obtain a common habitat definition along the estuaries and salinity gradient.
The habitat x ES matrix consisted of 6 habitat types and 20 ecosystem services (120 intersections) and was scored for each salinity zonation in each estuary yielding in total 16 matrices of 120 scorings each (1920 combinations).

Score	Habitat has…in supply of ES
1	no importance
2	very low importance
3	moderate importance
4	Important
5	Essential importance

Additionally, functional quality of habitats and current (decades) trend was scored along estuaries and zones using following respective questions (for every habitat, zone and estuary):

Score	Description: This habitat has…
1	very bad supply quality in this zone
2	bad supply quality in this zone
3	moderate supply quality in this zone
4	good supply quality in this zone
5	very good supply quality in this zone

Score	Description: This habitat is…
1	quickly disappearing in this zone
2	decreasing in this zone
3	stagnant in this zone
4	increasing in this zone
5	quickly increasing in this zone

Reliability of the supply survey

Visually, accordance can be tentatively evaluated on fig. 4: standard deviation of ES supply scores per habitat and among zones and estuaries rarely exceeds more than one score category. Although this is implies large variation (e.g. from moderate to low), this indicates that there is no large disagreement on importance of habitats in ES delivery.

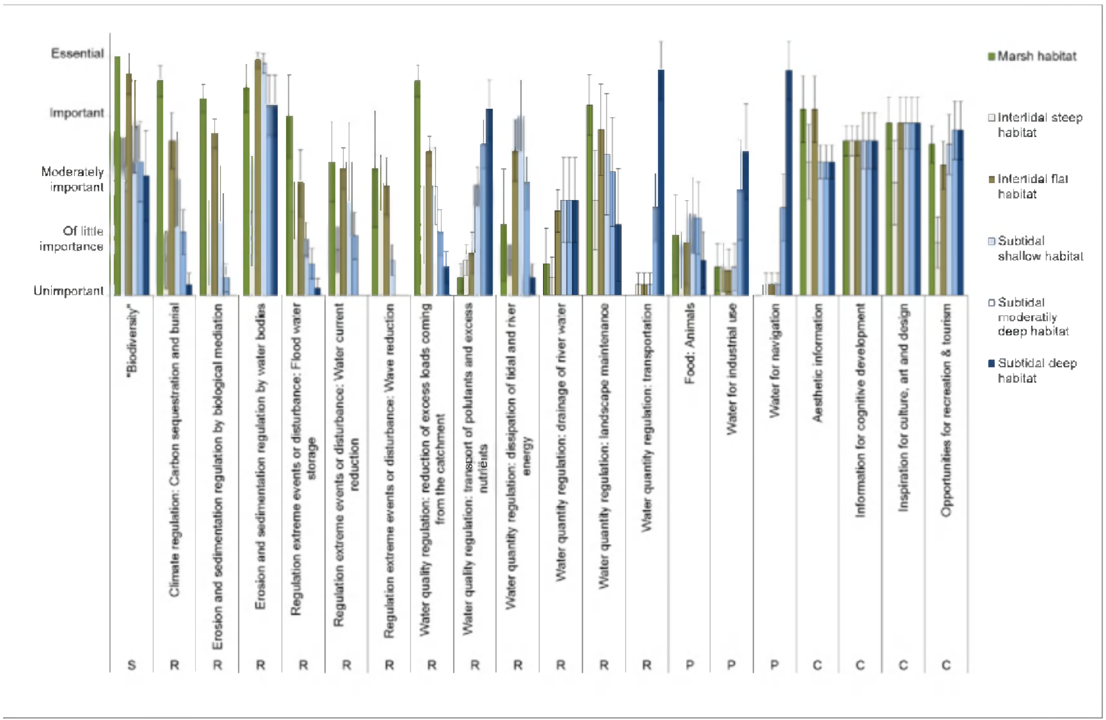


Figure 4: Scoring of habitat supply of ecosystem services. Scoring axis interpreted as "this habitat is … for delivery of ES x". Error bars show standard deviation over all estuaries and zones. Service categories are indicated (P=provisioning; R=regulating; C=cultural; S=Supporting/Habitat)

The supply survey has an **acceptable** reliability (**alpha = 0.7479**), inter-estuarine consistency (**ICC-C = 0.748**; F-test F(479,1437) = 3.97 p = 5.2e-90; 95%-CI = 0.709 < ICC < 0.783) and accordance (**ICC-a = 0.71**; F-test F(479,1437) = 3.97 p = 1.44e-15; 95%-CI 0.613 < ICC < 0.779) (R package multilevel version 2.3) Omega Hierarchical (**Omega-H = 0.73** ; 3 factors, minimum residual OLS factor solution) not only confirms the previous tests, but also indicates that the estuaries can be regarded as similar in supply, which adds to the validity of the data used.

Quality and trend habitat surveys have a '**questionable**' and '**unacceptable**' consistency (**alpha 0.687** and 0.**157** respectively).

<u>Respondents and expertise</u>

The respondent group for the supply survey consisted of a smaller professional expert group of 12 people, locally selected based on professional knowledge, acquaintance with the ES concept and direct (field) involvement in the estuary (see appendix II).

<u>Evaluation of physical reality of patterns from supply scores.</u>

By performing a principal component analysis (PCA), variability in scores along the spatial units (zones, habitats) of all 20 ecosystem services is evaluated using two axes which display the maximal variation. The pattern which emerges can be evaluated to learn whether scorings represent a physical reality. For the supply scores, result of this PCA analysis is shown in fig…

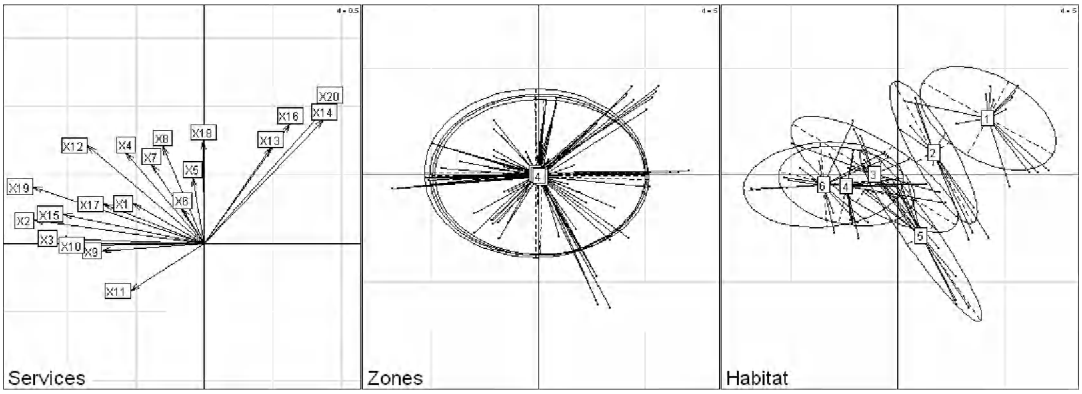


Figure 5: Principal component analysis on supply scores. Left panel: ecosystem service vectors loadings on the two axes (=meaning of the axes), middle panel: salinity zone variation (1: fresh, 2: Oligo, 3: Meso, 4: Polyhaline zone); right panel: habitat variation in supply scores. (1: Subtidal deep, 2: Subtidal moderately deep, 3: Subtidal shallow, 4: Intertidal flat, 5: Intertidal steep, 6: Marsh)

From this analysis, two main conclusions were drawn: (1) Scores did not differ between salinity zones. This shows that only few services are perceived to be delivered differently over the salinity gradient (see 5.5, but also that inter-zone variations in habitat surfaces did not influence scorings (e.g. proportion of marsh surface differs between zones, which could have influenced importance scorings).This again means scores can be applied in mapping further calculations involving surface. (2) The habitats display a distinct functional pattern along the tidal gradient (marsh to subtidal deep from left to right along first component). This confirms that supply scores represent a physical understanding of the system. Results are further discussed in section 5.

Conclusions supply survey reliability

The supply survey has an acceptable reliability, consistency and agreement (alpha, ICC and McDonalds scores >0.7) regardless the severity of the applied statistical procedure. The results indicate that scores were given for habitat supply importance regardless their local surface and can considered to be based on a physical understanding of the system.
However, the quality and trend scores are to be approached with great caution and data are not further used in TIDE calculations. Although estuaries are similar in ES supply, the differences in quality and trend might be very large between estuaries, yielding these low consistencies. Yet, it is not possible to distinguish differences between respondent groups for this question from existing inter-estuarine differences. Internal double checks or different rater groups within estuaries would have been needed for this.

Conclusion: valid use of results of the surveys

Use within TIDE

The data of the demand and supply survey are used within the TIDE project to derive general patterns and perform comparisons at the scale of salinity zones.

Also, screenings of estuarine measures are performed, using the general conclusions from the surveys. This screening however is strictly indicative. When scaling down to actual local contexts, e.g. for quantifying or valuing services of a specific measure, data have to be used with much caution. Actual local demand as well as supply might differ from the average scores assigned to the zone level. This means that a different set of focal ES might be selected as being important locally, and that supply of services by habitats is increased or hampered by specific local features. The data and derived maps should be interpreted as such, and not be used as a basis for specific local management decisions. However, as test results above have proven, the survey methodology yields reliable results on large (estuary) scale.

Linking ES with scientific evidence

Survey data should be regarded as *perceived* importance of services and habitat supply. This perception, although consistent among respondents of different estuaries and fields of scientific expertise, is still a perception as is, dependent on the personal expertise and variable scientific background of the respondents. This is why statistical and argumentative checks are indispensable to interpret the results.
As respondents did not argument their choices for scorings, it is hard to evaluate the amount of scientific evidence available for each score. The amount of evidence can vary from "*absent"* to "*abundant*", and the accordance of evidence can vary from "*generally accepted"* to "*scientific dispute"*.
Determining the *amount and agreement of scientific evidence* behind these perceptions is necessary to integrate system understanding among different expertise fields, determine knowledge gaps and discussion points for further fundamental research and increase rooting of ecosystem service research in natural sciences.

Use of survey method and results in similar estuaries

The survey data are valid for evaluation of spatial patterns on the salinity zone scale and indicative screenings of potential trade-offs and synergies, potential effects of measures on overall ES bundle delivery and deriving general supply scores for ES bundles per habitat. The 'acceptable' level of inter-estuarine accordance between estuaries suggest that these data could be representative for other estuaries, provided they are similar to the TIDE estuaries. Moreover, the survey methodology is a valid tool to be applied in order to obtain proper assessments.

4 Results: demand survey for ecosystem services in four EU estuaries

4.1 Which are the key ecosystem services?

Within the project consortium, 20 ecosystem services which scored on average higher than 'less important', were selected as "focal" (Granek et al 2010) ecosystem services for further research within TIDE (see Table 2). There were only few 'unknown' scorings, and these mainly occurred along the Humber for some cultural services.

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

Table 2: selection of important ecosystem services for consideration in TIDE estuaries, and the service categories they belong to.

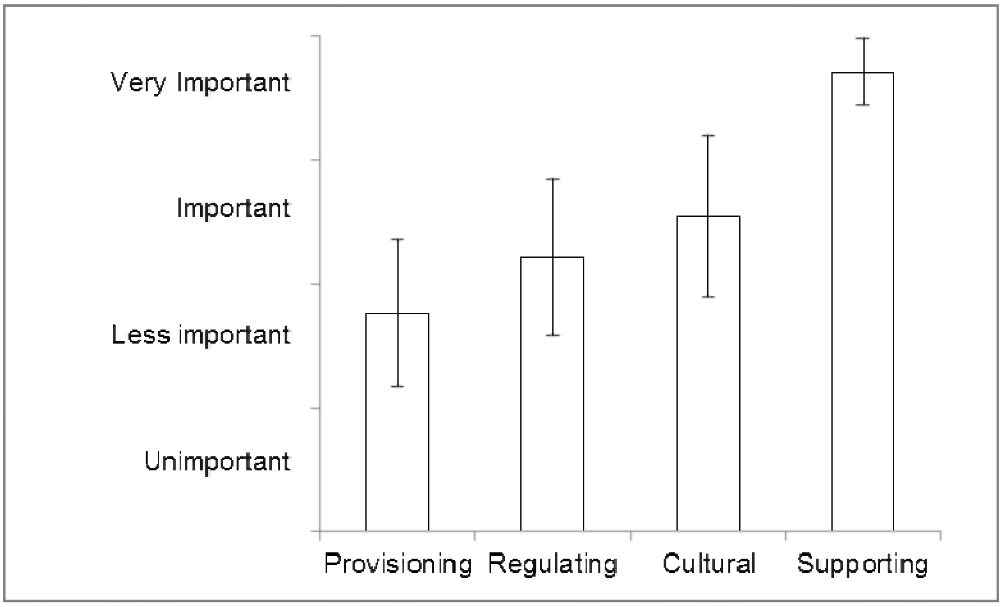


Figure 6: Fig Importance scoring of ecosystem services from all four estuaries and zones per service category, with standard deviations of scorings.

The results show that supporting, cultural and regulating services' importance is well recognized, and regional working groups recognize the dependence of the estuarine use on supporting services.

4.2 Spatial aspects of ES demand

The inter-estuarine or inter-zone variance of scores is plotted, together with the % contribution of the respective zone/estuary. This allows to evaluate which scores caused the higher variances.

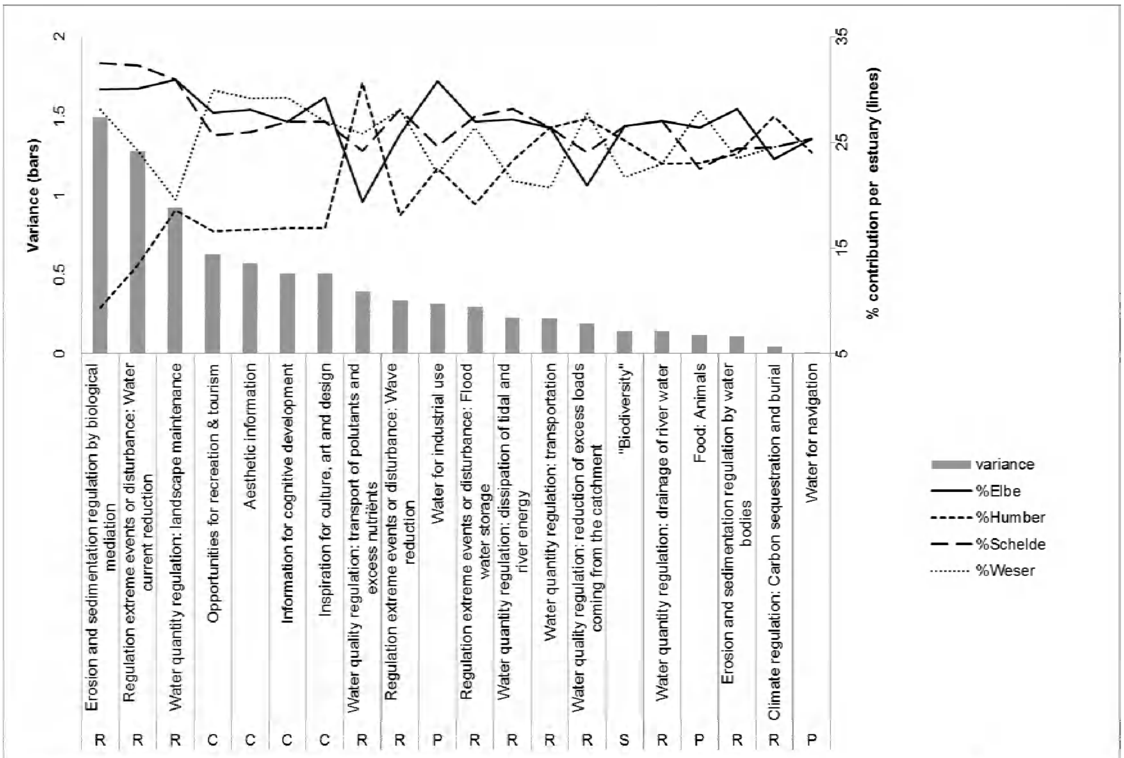


Figure 7: Ecosystem service importance score variance between estuaries (score units 1-5), and relative score differences between estuaries (per ES: % of summed estuary scores to total summed scores). Service categories are indicated (P=provisioning; R=regulating; C=cultural; S=Supporting/Habitat)

The main inter-estuarine variations are caused by lower importance scoring of all cultural and some regulating services in the Humber, and lower scoring of ‘landscape maintenance’ in the Weser. In these analysis, ‘unknown’ scores are added as zero, instead of leaving them out of the average. This assumes very low demand when demand is unknown by the regional working group. This occurred for very few services.

The lower scoring of three regulating services (biological mediation of sedimentation and erosion, water current reduction and landscape maintenance) in the Humber could reflect the exceptional features of this estuary compared to the others: extremely high turbidities, almost ‘fluid mud’ conditions on tidal flats and lack of rigid subtidal structures and marsh habitats (see report “Interestuarine comparison: hydro- geomorphology”).

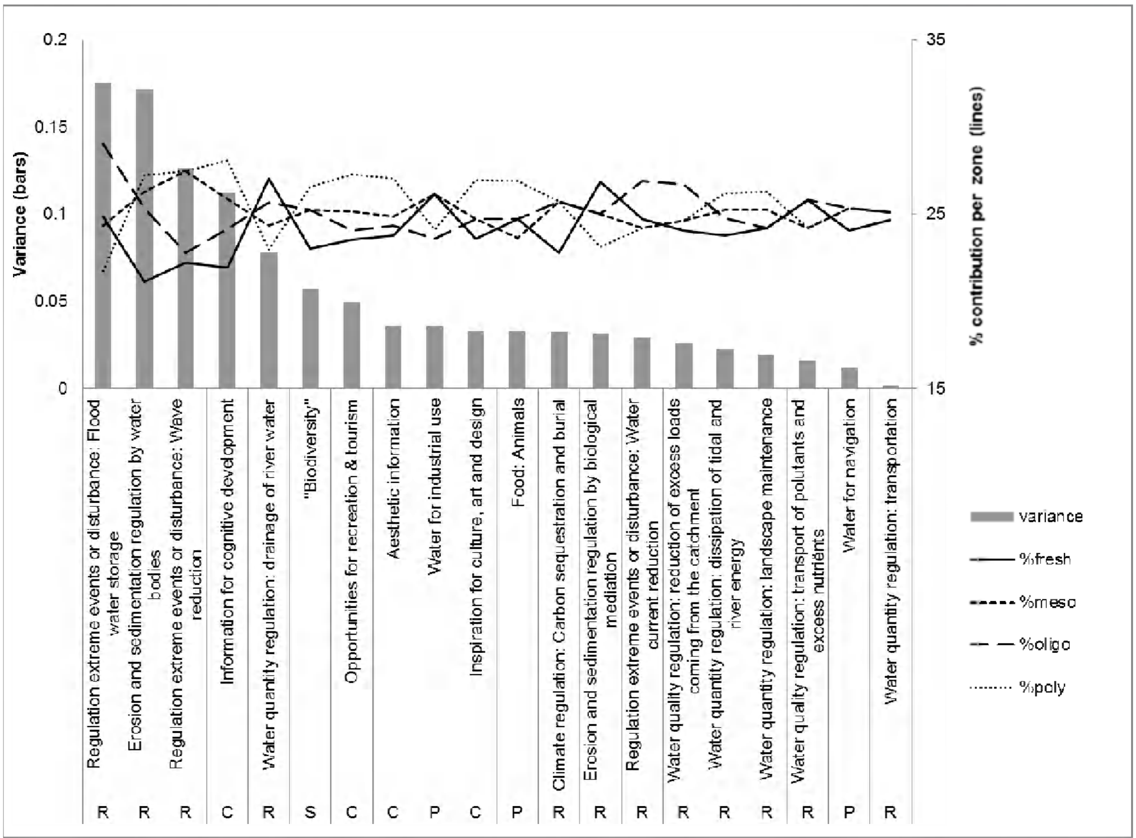


Figure 8: Ecosystem service importance score variance between salinity zones (score units 1-5), and relative score differences between salinity zones (per ES: % of summed estuary scores to total summed scores). Service categories are indicated (P=provisioning; R=regulating; C=cultural ; S=Supporting/Habitat)

Salinity zones were defined in four zones: freshwater zone, oligohaline, mesohaline and polyhaline zone. This allowed to obtain a similar, comparable zonation over all four TIDE estuaries. However, this also reduced the detail of estuaries with more elaborate zonation schemes of the report "Zonation of the TIDE estuaries" (e.g. the Elbe contains three freshwater zones and the Scheldt ten zones), which were averaged within the four comparable zones. In some single cases the merge of the freshwater zones can lead to results which differ from the result obtained by the expert group; this will be indicated for the particular cases.
Variations between salinity zones are generally very low. Only about four services exert small variations in demand along the salinity gradient. In these cases, the fresh and oligohaline zones separate from the meso- and polyhaline zones. Three of these higher demands can be linked to the specific features of the upper reaches of estuaries: higher flood risk, vulnerability for high turbidities induced by tidal pumping and wave erosion of habitats and infrastructures in confined upper reaches.

4.3 Temporal aspects of ES demand

The inter-temporal variance of scores is plotted, together with the % contribution of the respective time steps. This allows to evaluate which scores caused the higher variances.

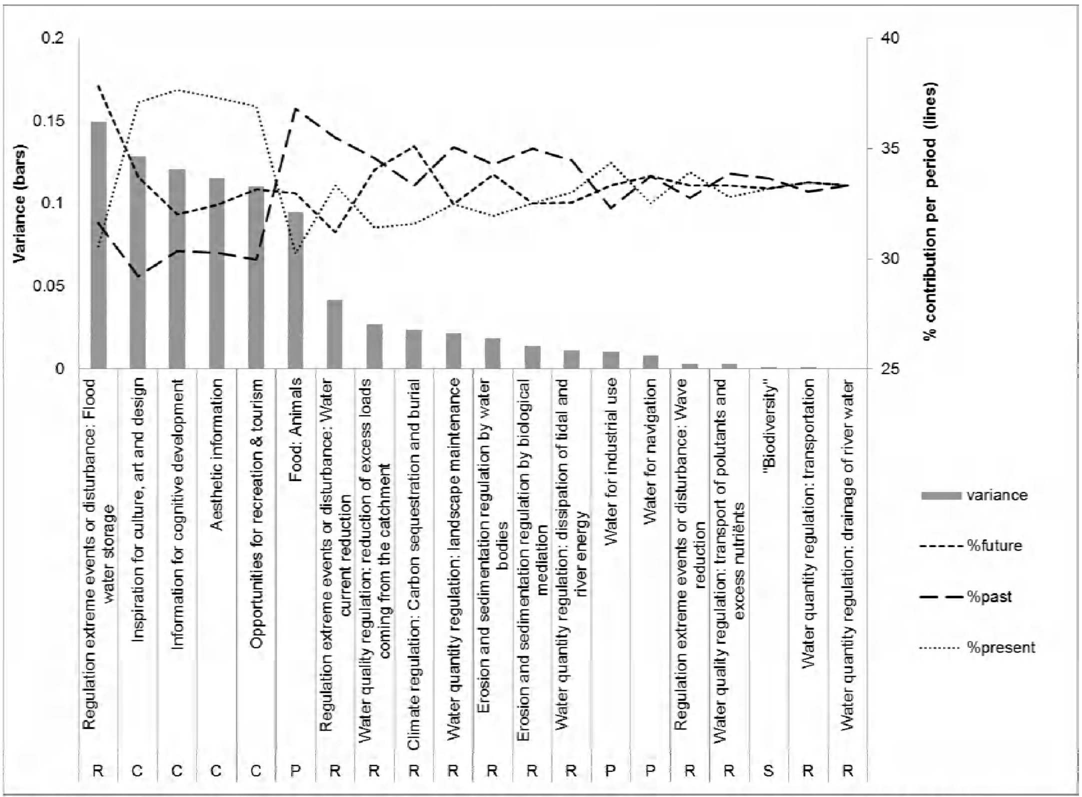


Figure 9: Ecosystem service importance score variance between time periods (score units 1-5), and relative score differences between time periods (per ES: % of summed estuary scores to total summed scores). Indicative historical reference was beginning of 20th century, future 2050. Service categories are indicated (P=provisioning; R=regulating; C=cultural; S=Supporting/Habitat)

Temporal variance is generally very low. The highest variance is observed in the flood control service. This is considered to gain importance, (~demand increase) considering climate change and sea level rise. Higher 'present' values of cultural services are logic since the scoring of cultural services importance in past and future is hard, thus containing unknowns. In the variance plot containing all services (not shown), high future scores for regulating service "Climate regulation" and provisioning service "Platform for infrastructure building" and "Water for agricultural use" are observed, concurring with future developments of climate change and continuing growth of human infrastructures. The future scorings are not used in further analysis, and historical demand scores were applied in the historical analysis exercise (see section 6).

5 Supply of ecosystem services in four EU estuaries

5.1 ES supply by habitats

Ecosystem services are supplied by ecosystem functions. These functions are the collection of structures (species, water bodies, soil entities,…) and processes (primary production, sedimentation and marsh formation, tidal pumping,…) which are linked to the supply of the service. Also, some services consist of several functionally separated 'intermediate' services, such as 'water purification' which consist of 'denitrification', 'immobilization of pollutants' etc (Figure 10).

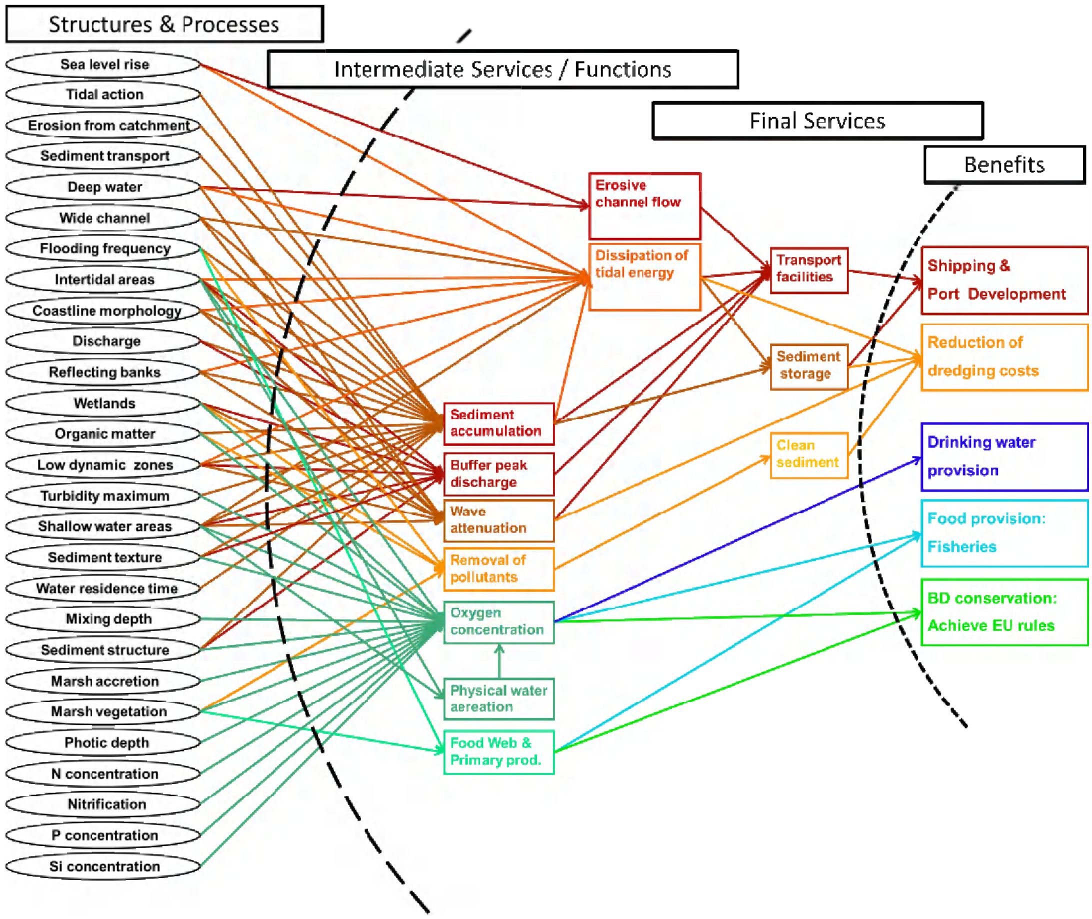


Figure 10: Illustration of supply of several benefits of ecosystem services by interacting structures and processes in the ecosystem.

A common unit however in the functional understanding of the estuarine system is 'the habitat', which is a well described part of the ecosystem which is distinguished by its physical and/or ecologic properties.
From the survey results (Figure 11), typical "subtidal" services (Provisioning service "*water for navigation*" and the underlying "*Water quantity regulation: transportation*" as well as "*Water for industrial use*"), typical "intertidal" services (regulating services concerning carbon, excess nutrient loads, and related to reduction of flood risks and wave/water current reduction) as well as services (most) delivered by a broad range of habitats can be distinguished.

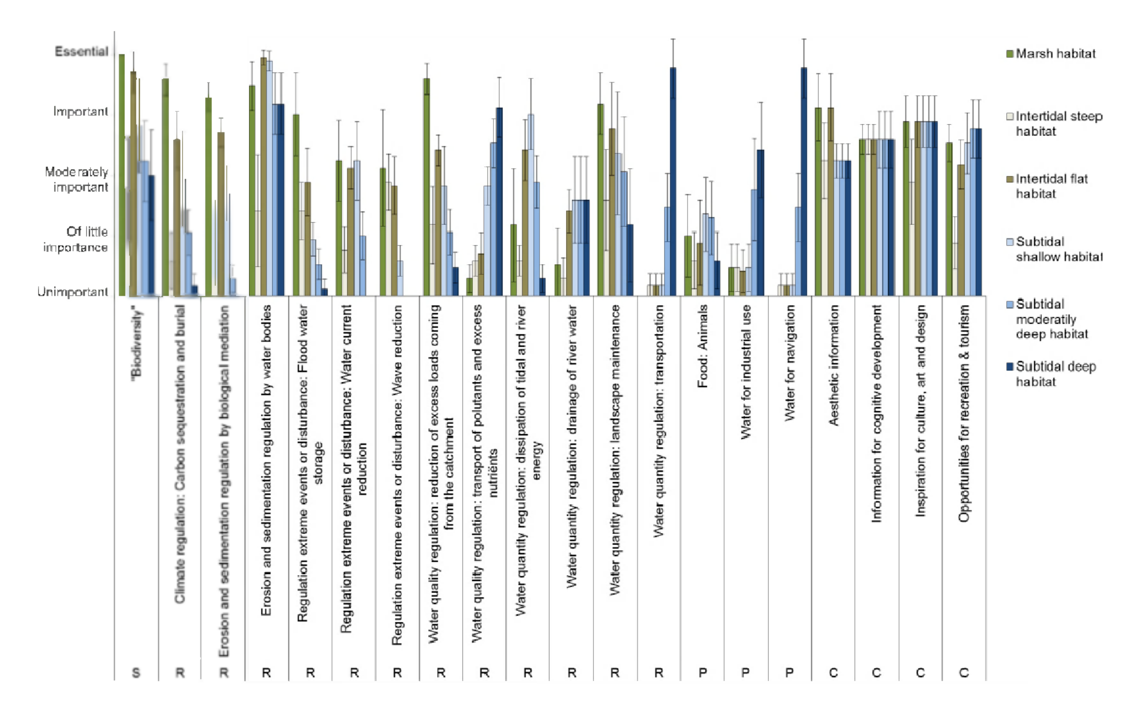


Figure 11: Scoring of habitat supply of ecosystem services. Scoring axis interpreted as "*this habitat is … for delivery of ES x*". Error bars show standard deviation over all estuaries and zones. Service categories are indicated (P=provisioning; R=regulating; C=cultural ; S=Supporting /Habitat)

5.2 Determining conservation objectives with ES

Mostly, benefit transfer methods based on reviews of monetary values are applied to demonstrate the societal value of ecosystems in monetary terms. These values are not linked to *local* ecological and socio-economic realities and do not have the order of detail required to base local decisions upon. However, they are relevant for discussion as they provide us with the order of magnitude of societal benefits which are at stake.

In the recent review of de Groot et al (2012), a monetary value is compiled for different biomes, based on a compilation of existing local valuation studies around the world. Although these monetary values are based on an extensive and up to date literature study, they do not offer adequate data to analyze separate, local ecosystem services. Every ecosystem has its specificities, and in order to address ecosystem services, the *local* demand and supply of ecosystem services should be addressed on the appropriate scale.

Such an approach was taken in the Scheldt estuary. With a length of 160 km, flowing from Gent in Flanders to Vlissingen in the Netherlands, it is one the largest European estuaries with a complete gradient from marine over brackish to fresh water tidal habitats, the latter being very rare on a European scale. The Scheldt catchment is one of the most densely populated in Europe and heavily impacted by human activities. Changes in land use and water management altered the hydrology and lead to a larger variability of fresh water discharges to the estuary. Buffering of peak flows is reduced, while extensive water abstraction strongly reduces the flows during dryer periods, both changing the water residence time, a crucial parameter determining ecological functioning. Large inputs of nutrients, pollutants and suspended solids resulted in serious problems of water and sediment pollution. The geomorphology changed due to land reclamation for agricultural and industrial development, infrastructural works to improve and maintain the fairway to the harbours and sea level rise, causing coastal squeeze, the trapping of tidal marshes and mudflats between the sea walls and the rising sea. This reduced the capacity to absorb tidal energy and as a result the tidal range in Antwerp increased by nearly one meter over the last century, causing serious safety problems.

The loss of habitats (along with pollution of the remaining ones) not only reduced biodiversity, but also ES such as the nursery function, fisheries, nutrient retention and flood protection. The capacity to absorb the increasing loads of nutrients has declined, resulting in bigger loads towards the coastal sea, increasing the risks of eutrophication. During this century, the magnitude and frequency of floods are likely to increase due to climate change induced high rainfall and rising sea levels, increasing the risk on flooding. This means the amount of areas at risk of flooding will further increase. There has also been a rise in the vulnerability to flooding due to the increase in the number of people and economic assets located in flood risk zones.

While little experience exists with defining conservation objectives (CO's) in compliance with the Habitat Directive, its importance became clear after the Court of Justice's case on the Cockle fisheries in the Wadden Sea: the CO's should be the main reference point to judge whether an effect is significant or not. This point of view places CO's at the centre of the appropriate assessment in terms of article 6.3 of the Habitat Directive. CO's have to describe the desirable state of the ecosystem and can be formulated qualitatively or quantitatively e.g. a desired population size or habitat area. These objectives are mostly formulated from a structural point of view and do not really suit the ecosystem approach that was put forward by IUCN and adopted by the Convention on Biodiversity as a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. It is based on the application of appropriate scientific methodologies focused on different levels of biological organization which encompass the essential processes, functions and interactions among organisms and their environment. It also recognises that humans are an integral component of ecosystems.

This approach is essential in economically important areas such as estuaries. Major infrastructural works were planned in the Scheldt: the deepening of the fairway to the harbour of Antwerp and the Sigmaplan to protect the land from storm floods coming from the North Sea. As the whole estuary, both in the Netherlands and Flanders, is protected by the EU habitat directive, infrastructural works should not have a significantly negative impact on the conservation objectives (CO's). However, these objectives were not yet accurately defined for the Scheldt estuary.

In the Scheldt, therefore, a methodology was developed to define CO's that allow a more strategic, integrated and sustainable approach to objectives settings and decision making.

The analysis of the Scheldt measures in view of Natura 2000 is based on the contents of the Long Term Vision for the Scheldt estuary for 2030 (LTV) and Development plan 2010 (Ontwikkelingsschets – OS). These bilateral agreements fit in the long term cooperation between both neighbor states. The overall target of the long term vision is about the conservation of the physical characteristics of the estuary and the optimal balance between safety, accessibility and environmentally. Regarding the environmental aspect, this means specifically the sustainable preservation in 2030 of a large diversity of habitats with associated species communities. Therefore, ecological objectives were developed regarding the naturalness aim from the Long Term Vision:

- A large diversity in estuarine habitat (marshes, mudflats, shallow water and sandbars in fresh, brackish and saline water) with sustainable associated life communities;
- Space for natural dynamical physical, chemical and ecological processes. Maintenance of the multiple-channel system in the Westerschelde;
- The water quality may not be a limiting factor anymore.

Firstly, based upon data on presence and trends in the numbers of different characteristic and relevant species and based on knowledge of habitat selection, densities etc., population targets were defined and translated to a surface of habitats necessary. Next a required amount of ES desired or needed from the system was defined. To protect the land against flooding a certain amount of water must be stored during storm tides. Based on hydrodynamic models this volume was translated in the surface of flood control area needed, given a politically agreed level of safety. To reduce the nutrient load towards the coastal sea, the surface of tidal marshes needed to provide a significant nitrogen sink was calculated using an ecological model. Basic research proved that tidal marshes are essential in delivering dissolved silica to the estuary and in this way play a crucial role in sustaining pelagic primary production. Based on this knowledge the surface of tidal marshes necessary to prevent a shift towards blooms of blue-green toxic algae was derived. Similar calculations were done for the various relevant ES. However, the delivery of ES is not only dependent on the surface of habitats but also on habitat quality. Therefore, objectives were set for several environmental parameters (e.g. water and soil quality). All of this information was finally compiled in CO's for the estuary described both in terms of population sizes and in terms of the amount of ecosystem services required for a sustainable development. ES in turn were translated in the necessary surface of habitats and required environmental quality.

From a biodiversity point of view, objectives are set primarily as a number of individuals. For instance we can argue that a CO is to have a population of 10.000 Oystercatchers in the estuary during winter. Based on basic knowledge of feeding ecology we know that the average density of Oystercatchers on the tidal flats is about 5/ha, given an average biomass of cockles present. This can then easily be translated into a required surface of tidal flats needed, being 10.000/5 = 2000 ha. This can be done for all species for which we make CO's.

Much more interesting it become however if we define also CO for ES. This can be done in many different ways. A CO can be for instance the safety level. The objective is that an area is only flooded with a storm occurring only once in 500 years. We know from such a storm that the high water levels are 8 m and that such a volume of water must be accommodated at that time. If we know that we need to store x million m³ we can again translate this into a surface of habitat. Another example is the reduction of pollutants. A certain load of a pollutant, let's say N, is entering the estuary. Because we want to reduce the eutrophication of the North Sea, we can allow only a certain load leaving the estuary towards the North Sea. The difference between input in the estuary and output to the estuary is the amount that should be stored/transformed in the estuary. As we know that tidal marshes are a sink for N and we know how much N can be stored/transformed per ha marsh we can calculate how much surface of marshes we need to remove this load. In this way we are making very functional conservation objectives.

The advantages of defining the CO's in such a comprehensive and systemic manner are huge. Not only does it put the emphasis on protecting and restoring species and habitats, but to a very large extent it also emphasizes the fundamental problems of the system (such as increasing tidal energy) that negatively affects both the ecology and economy of the system. The ES-approach is also an opportunity to link the various environmental legislations (Bird and Habitat-, Water Framework-, flood directive etc.). This enables a truly integrated approach and makes it much easier to negotiate with all of the different stakeholders.

A cost benefit analysis, taking into account the ES, clearly proved the overall economic benefits of the integrated plan versus sectorial plans. In view of the increasing risk of flooding complementary measures are needed along the Scheldt River to achieve an acceptable protection level. A technological option (storm barrier) was compared with dike heightening and controlled inundation areas.

AS such, a concrete application of considering multiple ES in estuarine management combining conservation goals, safety, recreation and biogeochemical functioning took place. An innovative site restoration technique of controlled reduced tides was elaborated and tested in a pilot project and is now being implemented along the entire estuary, Involving the building of over 1500 hectares of flooding area.

In the cost benefit analysis including ecosystem services, two kinds of floodplains were taken into account: a system where the existing land use is maintained (mostly agriculture) and a tidal system that delivers multiple ES.

- Regulating services were quantified through the OMES-model. This ecosystem model was developed for the Scheldt estuary in order to study the possible impact of different water management strategies on the ecosystem. This model was based on a monitoring program for all major groups (plankton, benthos, avifauna, fish, and littoral vegetation), carried out by different universities and institutes, and simulated major ecosystem processes, such as the C, N and P cycles. The OMES-model makes distinctions between the impact of riverine wetlands in the fresh water, brackish and salt zone of the river.
- The flood control service was quantified by a large hydrodynamic model. Based on land use data, damage factors and replacement values for houses, household furniture, roads, industry, crops and

other damage categories the flood damages in the inundated area were estimated.

- A Contingent Valuation study was performed to value the recreational value of new floodplains.

Results of the cost benefit analysis show that an intelligent combination of dikes and floodplains can offer higher net benefits (596 Million Euros) at lower costs (132 Mio.Eur, payback period 14 years) compared to more drastic measures as a storm surge barrier near Antwerp (net benefits 339 Mio.Eur, Costs 387 Mio.Eur, payback period 41 years).
The hydrodynamic modelling also indicated that floodplains are necessary to ensure safety levels in the longer term in the Scheldt basin. Dike heightening only would cause a shift in flooded areas but does not suffice to importantly reduce flood risk. Additionally results showed that the benefits of the controlled reduced tidal areas (RTA) exceeded benefits of the controlled inundation area (CIA) with agricultural use. Based on these results, the Dutch and Flemish governments approved the integrated management plan consisting of the restoration of approximately 2500 ha of intertidal and 3000 ha of non-tidal areas, the reinforcements of dikes and the necessary dredging to improve the fairway to Antwerp.

This example demonstrates that ecosystem services can form the basis of an approach to obtain an integrated management including industry and port development, agriculture, conservation goals, recreation etc. Currently, a guidance document is developed to describe a methodology for monetary valuation of ecosystem services in estuaries which is based on best available data and state-of-the-art insights (Liekens et al 2013)

5.3 ES supply maps

Maps of every service and estuary were created by using average supply scores of each habitat and zone (Table **3**), and the mapping of habitats following the analysis in (see report “Interestuarine comparison: hydro- geomorphology”, see also 3.2).
Since there is a high consistency among estuaries’ supply scores, one single average estuary score matrix was constructed. This score matrix incorporates all expert scores. As such, maps can be compared to assess distribution of ES along the longitudinal gradient of the estuaries. The TIDE ES maps provide an inventory of ecosystem services in four industrialized estuaries, based on habitat-specific supply scores per salinity zone, and involving local and site-specific scientific expertise. Inter-estuarine variation in scores is assessed in section 5.5.
Salinity zones were defined in four zones: freshwater zone, oligohaline, mesohaline and polyhaline zone. This allowed to obtain a similar, comparable zonation over all four TIDE estuaries. However, this also reduced the detail of estuaries with more elaborate zonation schemes (eg the Elbe contains three freshwater zones and the Scheldt 10 zones), which were averaged within the four comparable zones. In some single cases the merge of the freshwater zones can lead to results which differ from the result obtained by the expert group; this will be indicated at the particular cases.
In the following section, maps per ecosystem service are provided, together with short explanations and description of some of the basic structures and processes involved. Each of these factsheets provides an overview of supply of the ecosystem service throughout the TIDE estuaries. Applied and relevant ecological research for estuarine management should focus on further description and centralization of ecological functions and mechanistic understanding per service, including available parameter and modeling data, as well as assessment of uncertainty and data needs.

	S	R												P			C								
	Supporting & Habitat services	Climate regulation: Carbon sequestration and burial	Erosion and sedimentation regulation by biological mediation	Regulation extreme events or disturbance: Water current reduction	Regulation extreme events or disturbance: Flood water storage	Regulation extreme events or disturbance: Wave reduction	Water quality regulation: reduction of excess loads coming from the catchment	Water quality regulation: transport of polutants and excess nutriënts	Water quantity regulation: dissipation of tidal and river energy	Water quantity regulation: drainage of river water	Water quantity regulation: landscape maintenance	Water quantity regulation: transportation	Erosion and sedimentation regulation by water bodies	Water for industrial use	Water for navigation	Food: Animals	Information for cognitive development	Inspiration for culture, art and design	Aesthetic information	Opportunities for recreation & tourism	Supporting & Habitat services	Regulating services	Provisioning services	Cultural services	All services
Freshwater zone																									
Marsh habitat	5	4	4	3	4	3	5	2	2	2	4	1	4	2	1	3	4	4	4	3	5	3	2	4	3
Intertidal flat habitat	5	3	4	3	3	3	3	2	3	3	3	1	5	1	1	2	4	4	4	3	5	3	1	4	3
Intertidal steep habitat	3	2	2	2	3	3	2	2	2	2	2	1	2	2	1	2	4	3	3	2	3	2	2	3	2
Subtidal shallow habitat	4	3	3	3	2	2	3	3	3	2	3	1	5	2	1	2	4	4	3	3	4	3	2	4	3
Subtidal moderatily deep habitat	3	2	1	2	2	1	2	3	3	2	2	3	4	3	3	2	4	4	3	4	3	2	3	4	3
Subtidal deep habitat	3	1	1	1	1	1	2	4	1	2	1	5	4	3	4	2	4	4	3	4	3	2	3	4	3
Oligohaline zone																									
Marsh habitat	5	5	4	4	5	4	4	2	3	2	4	2	5	2	1	3	4	4	4	4	5	4	2	4	4
Intertidal flat habitat	5	4	3	3	4	3	3	2	4	2	4	2	4	2	2	2	4	4	4	3	5	3	2	4	3
Intertidal steep habitat	4	2	2	2	3	3	2	2	2	2	2	2	3	2	2	2	4	3	3	3	4	2	2	3	3
Subtidal shallow habitat	4	3	3	3	2	2	3	3	4	3	4	2	5	2	2	3	4	4	3	3	4	3	2	4	3
Subtidal moderatily deep habitat	4	2	2	2	2	1	2	4	3	3	3	3	4	3	3	3	4	4	3	4	4	3	3	4	3
Subtidal deep habitat	4	1	2	2	2	1	2	5	2	3	2	5	4	4	5	2	4	4	3	4	4	3	4	4	3
Mesohaline zone																									
Marsh habitat	5	4	4	3	3	3	4	2	3	2	4	2	4	2	1	2	4	4	4	4	5	3	2	4	3
Intertidal flat habitat	5	4	3	3	2	3	3	2	4	2	4	2	4	2	1	2	4	4	4	4	5	3	2	4	3
Intertidal steep habitat	4	2	2	2	2	3	2	2	2	1	2	2	2	2	1	2	4	3	3	3	4	2	2	3	2
Subtidal shallow habitat	4	3	3	3	2	2	3	3	4	3	4	2	4	2	1	3	4	4	3	4	4	3	2	4	3
Subtidal moderatily deep habitat	4	2	2	2	2	1	2	4	3	3	3	3	4	3	3	3	4	4	3	4	4	3	3	4	3
Subtidal deep habitat	4	1	2	2	2	1	2	5	2	3	2	5	4	4	5	2	4	4	3	4	4	3	4	4	3
Polyhaline zone																									
Marsh habitat	5	4	4	3	3	3	4	3	3	2	4	2	4	2	1	2	4	4	4	4	5	3	2	4	3
Intertidal flat habitat	5	4	3	3	2	4	3	2	4	2	4	2	4	2	1	2	4	4	4	4	5	3	2	4	3
Intertidal steep habitat	4	2	2	2	2	3	2	2	2	1	2	2	2	2	1	2	4	3	3	3	4	2	2	3	2
Subtidal shallow habitat	4	3	3	3	2	2	3	3	4	3	4	2	4	2	1	3	4	4	3	4	4	3	2	4	3
Subtidal moderatily deep habitat	4	2	2	2	2	1	2	4	3	3	3	3	4	2	2	3	4	4	3	4	4	3	2	4	3
Subtidal deep habitat	4	1	2	2	2	1	2	5	2	3	2	5	4	4	5	2	4	4	3	4	4	3	4	4	3

Table 3: average score matrix for estuaries similar to the TIDE estuaries.

5.3.1 Provision of food

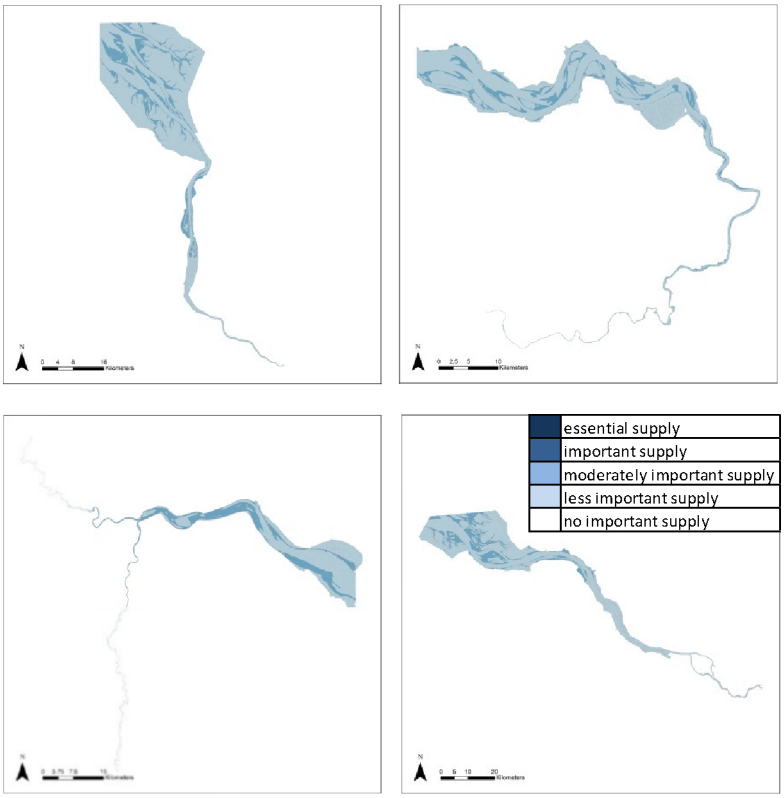


Figure 12: Provision of food in the Weser, Scheldt, Humber and Elbe estuary, based on average habitat-specific supply scores per salinity zone, and involving local and site-specific scientific expertise.

Service	Benefit	Short definition
Food: Animals	Food	presence and use of edible animals, including livestock growth and fodder production

Substantial food provision in estuaries is mainly regarded as historical. Livestock grazing and fodder production on the highly fertile marshes was a common practice, with crops in the freshwater zones and extensive grazing in brackish and salt marshes. Also, direct fishing and shellfish breeding inside estuaries occurred more commonly in history. The higher scores for marshes in the freshwater and oligohaline zone reflect this supply. Although agricultural practices abide in some areas, they have disappeared in many others due to excessive pollution and market shifts. However, estuaries are still regarded highly important as foraging, breeding or spawning ground for commercial fish species which spend part of their live cycle in fresh or brackish water. This is reflected in the higher scores of shallow and moderately deep subtidal areas.

Structures & processes

Food provision is strongly driven by ecological habitat quality and biodiversity. Shallow areas with low hydrological stress (currents, waves, erosion), opportunities for shelter and high benthic productivity are essential, as well as the presence of a full gradient in habitats which are well connected. This service

has its main feedback to the supporting & habitat services, positively (increased biodiversity) as well as potentially negatively (e.g. overfishing, habitat modification for increased shellfish productivity).
Quantification and pricing (Liekens et al 2013B) can be performed by estimating the market prices for animals and crops grown in estuarine ecosystems. It is to be noted that, in general, the current benefits (monetary benefits in particular) obtained from biodiversity resources do not often reflect sustainable extraction or production patterns. The external costs related to this issue are not taken into account. The estimated value of the biodiversity resource based on market price is equal to the quantity of sold resource x (market price – costs related to production). Liekens et al (2013B) suggest taking the standard gross margin as indicator.

5.3.2 Provision of water for industrial use

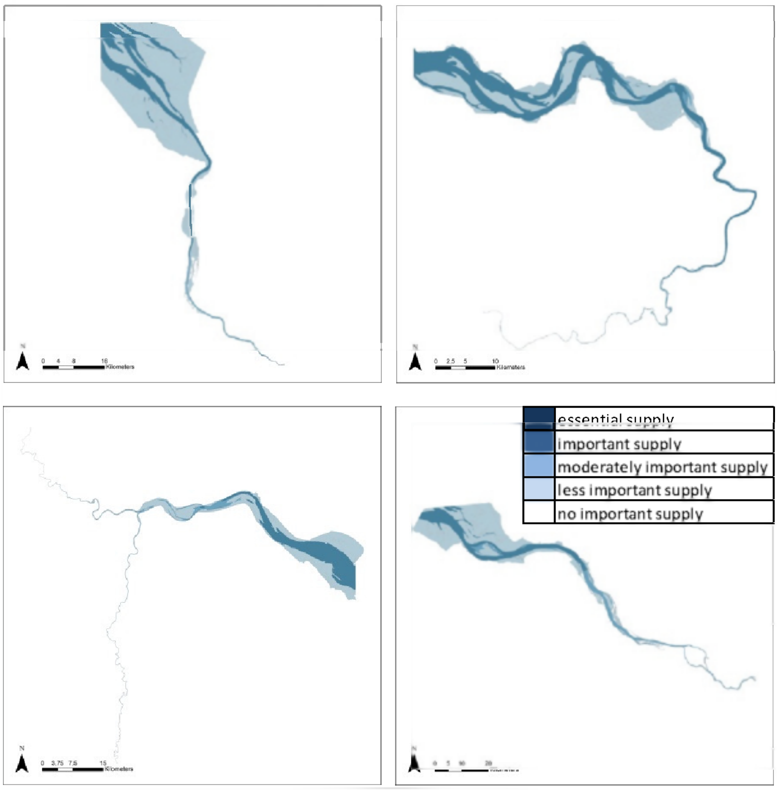


Figure 13: Provision of water for industrial use in the Weser, Scheldt, Humber and Elbe estuary based on average habitat-specific supply scores per salinity zone, and involving local and site-specific scientific expertise.

Service	Benefit	Short definition
Water for industrial use	improved industrial production	provision and use of water for e.g. cooling water, rinsing water, water for chemical reactions

Requirements for industrial use water are not as stringent as for provision of e.g. drinking water, although some industries require fresh water. However, often large amounts are needed in relatively short timespans, which requires the presence of adequate volumes at all times. Deep subtidal habitats are therefore important, and since *most* industrial activities are often concentrated towards the mouth of estuaries, these deep habitats get a higher score in poly- and mesohaline zones. Using the score matrix does reveal habitat-driven differences, but some specific estuarine supply aspects are lost. For instance, in the Elbe, this service was scored higher in freshwater and oligohaline zones, where most industrial activities are located. These inter-estuarine differences are represented in detail section 5.5. Also, the estuary-specific zonation scores were averaged in the four common zones.

Structures and processes

This service is mainly physically driven. Main driving factors are the presence of deep water habitat (adequate volumes) as well as the quantities provided by discharge and tidal influx. However, the use of this service impacts on supporting / habitat services since returning of cooling water (often with increased temperatures and algicides) could impact the ecosystem locally: increased productivity or changes in algal community composition, or local microclimate conditions altering composition of higher trophic levels. An important process is the residence time and the volume of the water in the zone where the cooling water is released. This determines the concentration or heating impact.

As an indicator, the volume (m^3) water directly taken from the estuary for processing and cooling by industrial sector in the estuary can be used, while the costs of losing or replacing natural water supply or finding an alternative for it can be used as an estimate for its value (Liekens et al 2013B). In addition, opportunity costs, i.e. loss of income foregone due to the loss of water supply, can also be used as an indication for the value.

5.3.3 Provision of water for navigation

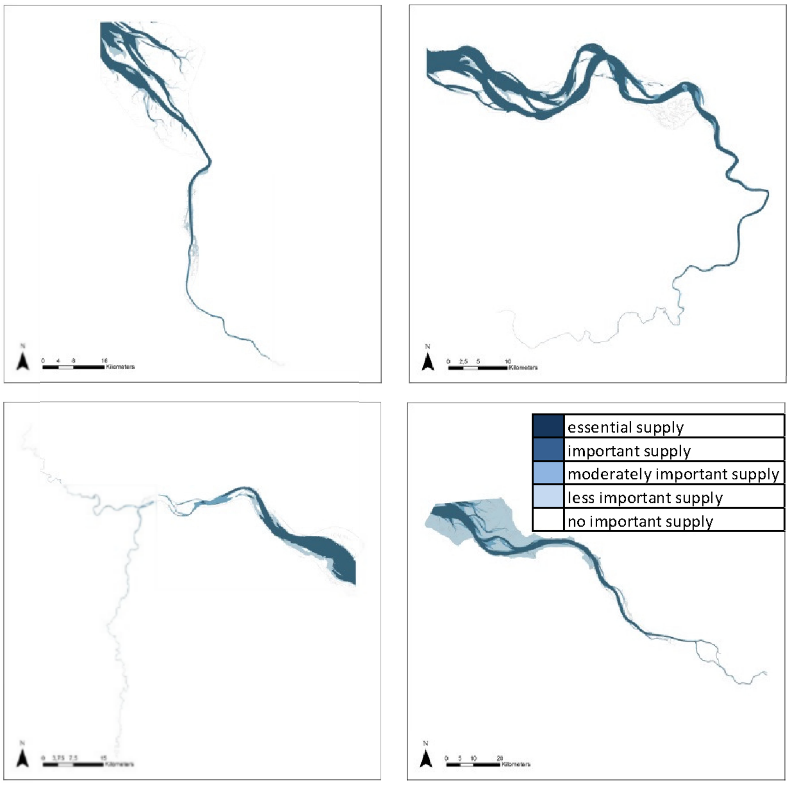


Figure 14: Provision of water for navigation in the Weser, Scheldt, Humber and Elbe estuary based on average habitat-specific supply scores per salinity zone, and involving local and site-specific scientific expertise.

Service	Benefit	Short definition
Water for navigation	Shipping	presence and use of water for shipping purposes

Requirements for navigation use water are straightforward. Water bodies require adequate depths and width, while complex and dynamic morphology as well as sedimentation of these habitats might increase costs for shipping. Scores are highest for deep and moderately deep subtidal habitats, while shallow areas are less important (mainly recreational navigation). Using the score matrix reveal habitat-driven differences, but some specific estuarine supply aspects are lost. For instance, in the Elbe, this service was scored lower in the freshwater zone upstream of the harbour, compared to the other estuaries. These inter-estuarine differences are represented in detail section 5.5. Notice, that the estuary-specific zonation scores were averaged in the four common zones. In this case it has to be noticed that for instance in the Elbe, the freshwater zone 1 upstream of the harbour (see report “Zonation of the TIDE estuaries”)had a lower score as the zones 2 and 3 downstream the harbour.

Structures and processes

This service is mainly physically driven. Main driving factors are the presence of deep water habitat (adequate volumes) as well as the quantities provided by discharge and tidal influx. However, the use of water for navigation has an impact on supporting / habitat services since dredging and disposal of sediments (often causing increased turbidities or availability of pollutants) could impact the ecosystem locally: direct impacts on benthic communities, decreased light availability and primary productivity or changes in algal community composition, or local conditions altering composition of higher trophic levels. This engenders an impact on all services depending on supporting and habitat services (see section 5.4).

The value of water for navigation is estimated by the prevented costs made by ships not being able to make use of the full loading capacity functions. It is assumed that the costs exist out of more trips to the deliver address or by transport the rest load by another mode: train or truck (Liekens et al 2013B).

5.3.4 Climate regulation: C-sequestration & burial

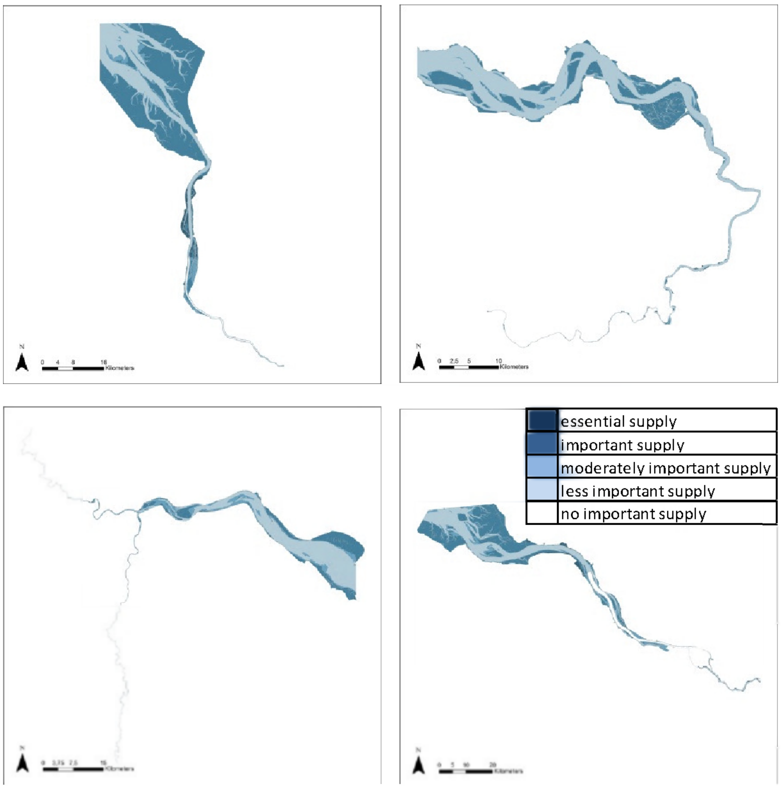


Figure 15: Carbon sequestration and burial in the Weser, Scheldt, Humber and Elbe estuary based on average habitat-specific supply scores per salinity zone, and involving local and site-specific scientific expertise.

Service	Benefit	Short definition
Climate regulation: Carbon sequestration and burial	human health, avoided costs caused by extreme events or climate disturbance, ensured provisioning services	buffering carbon stock in living vegetation, burial of organic matter in soils

As carbon sequestration and burial is linked to biological productivity and sedimentation/burial of sediments; marshes and intertidal areas have the highest scores. Other habitats can also store carbon if they silt up. Inter-estuarine differences among zones and habitats are represented in detail section 5.5.

Structures and processes

Carbon sequestration and burial has both biological and hydrological drivers. Uptake of carbon in the estuarine food web (linked to productivity of algae and vegetation) and long-term sedimentation into deeper soil layers are the main drivers. The fate of this carbon is long term burial or sequestration and potential uptake. This decides whether carbon is removed from the atmosphere on the long term.
Carbon sequestration and burial is only one of the estuarine functions related to climate regulation. It can be regarded as an intermediate service delivering the final service of climate regulation. Other intermediate services include direct cooling effect of water bodies, cooling effects of vegetation, processes related to

production of methane and other greenhouse gasses etc. These are all related and should be addressed together.

In Liekens et al (2013B), an extensive literature review on this topic can be found. Here, some basic processes are described:
Estuarine ecosystems are extremely productive biologically (Bianchi, 2007), with net primary production rates among the highest of the world. Consequently, these systems play globally an important role as carbon sinks (Chmura et al., 2003).
Sediment carbon is oxidized by microbial mediation to other species, including, among others, carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O). Production of these gases is potentially important since they are greenhouse gases (GHGs), all with a different Global Warming Potential. GWPs are measures of the contribution towards global warming and integrate a gas' radiative absorption ability, its atmospheric residence time, the frequency of radiation which it absorbs and any indirect effects by feedbacks (Forster et al., 2007). Over a 100 year frame the GWPs of CO2, CH4 and N2O are 1, 25 and 298 respectively (Forster et al., 2007); meaning that 1 tonne of N2O would affect global warming as much as 198 tonnes of CO2. These GWPs are in fact carbon dioxide equivalents (CO2eq). Applying these GWPs to the GHG flux data, and converting the C burial into CO2 equivalents allows this data to be directly compared, permitting the calculation of net CO2eq-fluxes.
Carbon is sequestered when the net effect of all CO2eq-fluxes is negative; this occurs when more carbon enters a system, than the amount of carbon that will leave the system.

C sequestration = C-burial + (CO2+CH4+N2Ofluxes) (+ long lasting biomass)

Short-term carbon sequestration occurs in biomass, long-term carbon storage would be based on carbon removed over app 100 years (Crooks et al., 2010) and therefore only sequestration in sediments is taken into account.
Long lasting biomass might be an important long-term carbon pool too, especially when it concerns trees (mangroves,...). Hereto also belowground biomass has to be accounted for. Furthermore, due to sea level rise, sedimentation is an ongoing process and so is the sequestering capacity.

5.3.5 Flood water storage

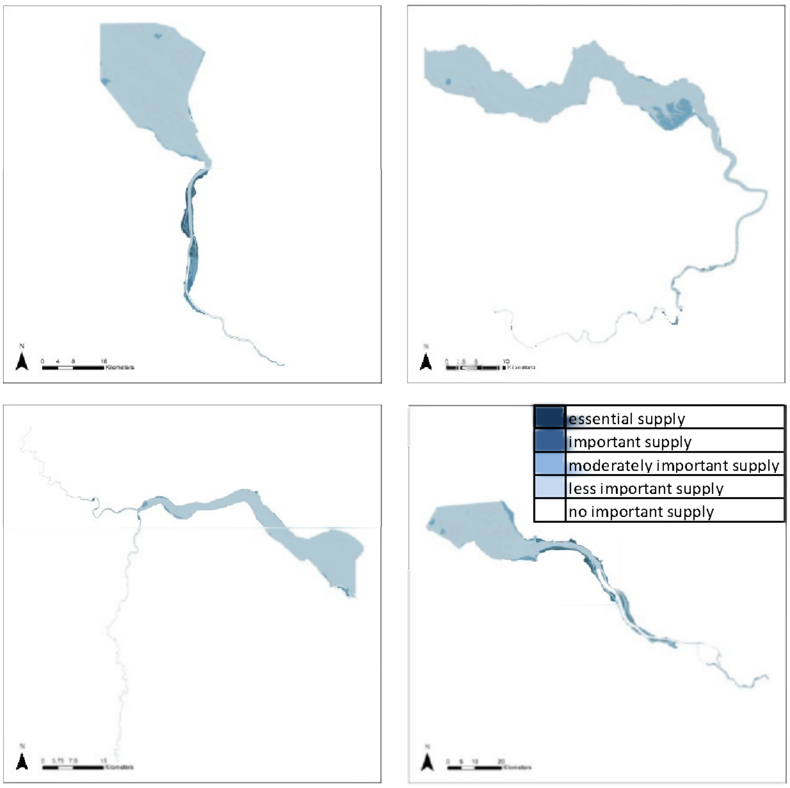


Figure 16: Flood water storage in the Weser, Scheldt, Humber and Elbe estuary based on average habitat-specific supply scores per salinity zone, and involving local and site-specific scientific expertise.

Service	Benefit	Short definition
Regulation extreme events or disturbance: Flood water storage	human health, avoided costs caused by extreme events or disturbance, ensured provisioning services	storage of storm or extreme spring tides in natural or flood control habitats

Flood water storage is beneficial as the water volume which causes flooding of properties is stored in areas where the damage is lower or zero. This is reflected in the highest scores for marsh habitat in upstream zones. Large differences between estuaries occur, as marsh habitats are much more abundant (relatively) in the Weser (and to a lesser extent in the Elbe), while in the Humber and Scheldt, these are very small in surface. In the poly- en mesohaline zone subtidal habitats play a role as determining factor for the amount of water coming into the estuarine funnel, and direct storage above marshes is moderately important (except for the large ‘Land van Saeftinghe’ area in the mesohaline zone of the Scheldt). Inter-estuarine differences among zones and habitats are represented in detail section 5.5.

Structures and processes

This service is entirely physically driven. The shape and volume of the estuary in the poly- and mesohaline zone determines the volume and speed of the tidal wave, while the extent of intertidal and mainly marsh habitat (which is close to critical elevation for flooding) determines the amount of flood water potentially

stored. Complex interactions with water quantity-influenced services exist, as the tidal propagation influences sedimentation-erosion balances. However, there are also potential synergies with habitat and supporting services, as marshes or flooding areas can be essential biodiversity hotspots.
Concerning quantification, Liekens et al (2013B) note that services related to disturbance prevention or moderation reduce flood risk. The benefits of flood alleviation comprise the flood damage averted in the future as a result of schemes to reduce the frequency of flooding or reduce the impact of that flooding on the property and economic activity affected, or a combination of both. This is reflected in less material and immaterial damages. It is not possible to translate the assessment methods into easily applicable indicators that can be applied in different estuaries. However, the principles of this method are accepted internationally. Liekens et al (2013B) refer to *FHRC 2010 the benefits of flood and Coastal Risk management: a handbook of assessment techniques 2010* for a stepwise approach to assess the benefits of flood prevention.

5.3.6 Water current reduction

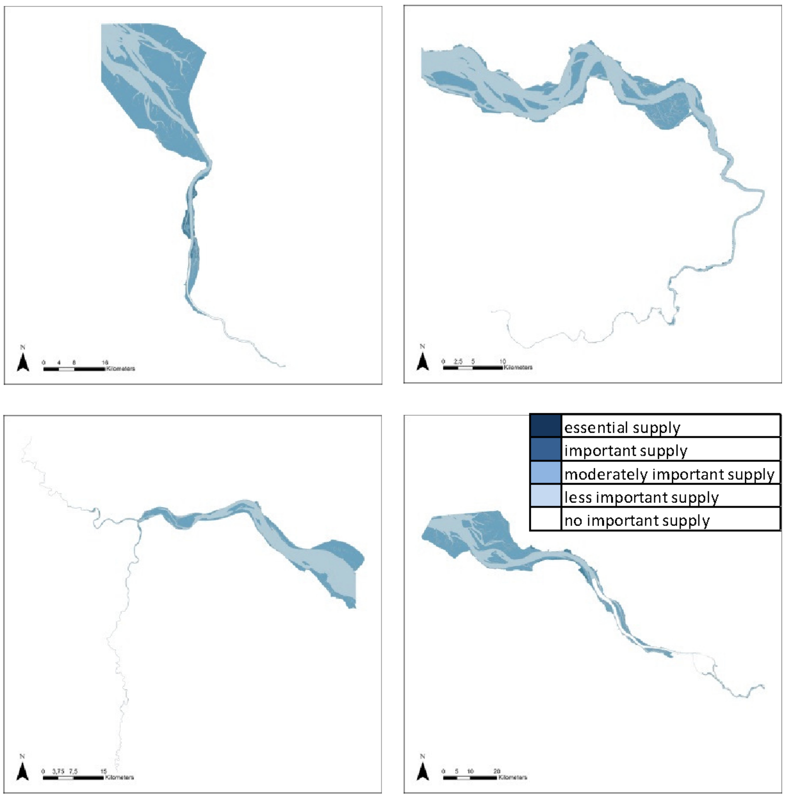


Figure 17: Water current reduction in the Weser, Scheldt, Humber and Elbe estuary based on average habitat-specific supply scores per salinity zone, and involving local and site-specific scientific expertise.

Service	Benefit	Short definition
Regulation of extreme events or disturbance: Water current reduction	human health, avoided costs caused by extreme events or disturbance, ensured provisioning services	reduction of water current by physical features or vegetation

Intertidal habitats and shallow zones are scored as more important for reducing water currents than other habitat types. Water current reduction takes place at different levels: morphological structures reduce water current in subtidal (except in the freshwater area, where this is less important) as well as intertidal habitats. Reduction of this current decreases shear stress and incoming tidal volumes. On intertidal habitats, and especially on marshes, organism structures (vegetation) are also known to strongly reduce water current. This reduces erosion of protective natural or technical infrastructures. Inter-estuarine differences among zones and habitats are represented in detail section 5.5.

Structures and processes

Reduction of water current as an ecosystem service, is physically driven, but on marshes, biological structures also exert this physical role. Apart from direct damage to infrastructures, excessive water currents also cause potential excessive erosion in the estuarine system, disturbed benthic population dynamics, high turbidity and hence impacts on primary production of the algal community. It interacts with all ecosystem services linked to water quantity.

5.3.7 Wave reduction

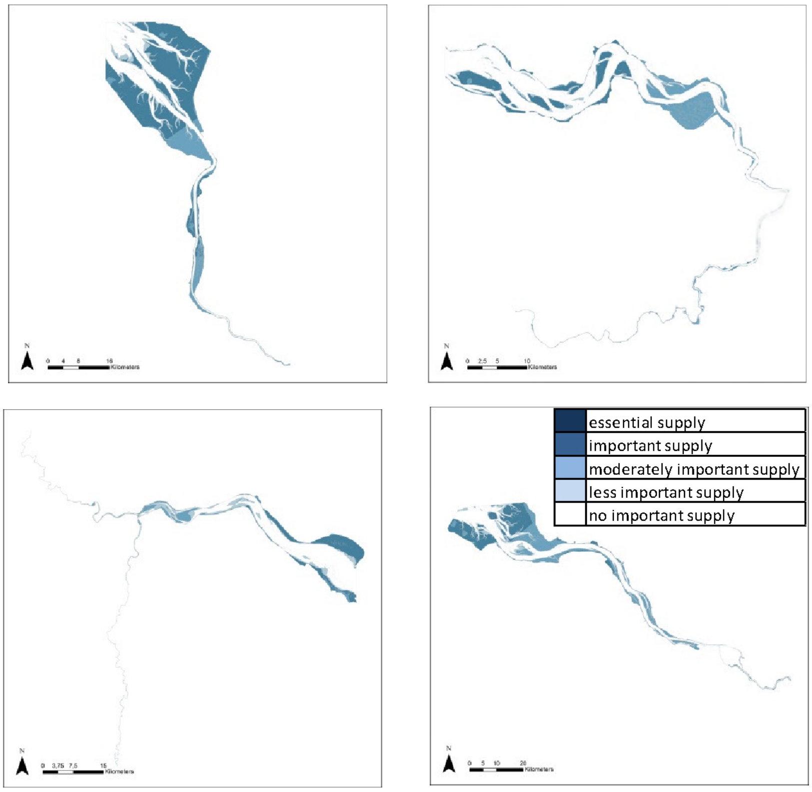


Figure 18: Wave reduction in the Weser, Scheldt, Humber and Elbe estuary based on average habitat-specific supply scores per salinity zone, and involving local and site-specific scientific expertise.

Service	Benefit	Short definition
Regulation of extreme events or disturbance: Wave reduction	human health, avoided costs caused by extreme events or disturbance, ensured provisioning services	reduction of wave height by physical features or vegetation

Intertidal areas and shallow zones get the higher scores. Reduction of waves decreases erosion of marsh edges and protective infrastructure. Inter-estuarine differences among zones and habitats are represented in detail section 5.5.

Structures and processes

Wave reduction is a service which is physically driven, but on marshes, biological structures also exert this physical role. Wave reduction is a physical process. Waves, generated by wind or ships, are attenuated by physical structures or organisms, mainly vegetation. Apart from direct damage to infrastructures, excessive waves cause potential excessive erosion in the estuarine system, which consequences as disturbed benthic population dynamics, high turbidity and hence impacts on primary production of the algal community. It interacts with all ecosystem services linked to water quantity.

5.3.8 Drainage of river water

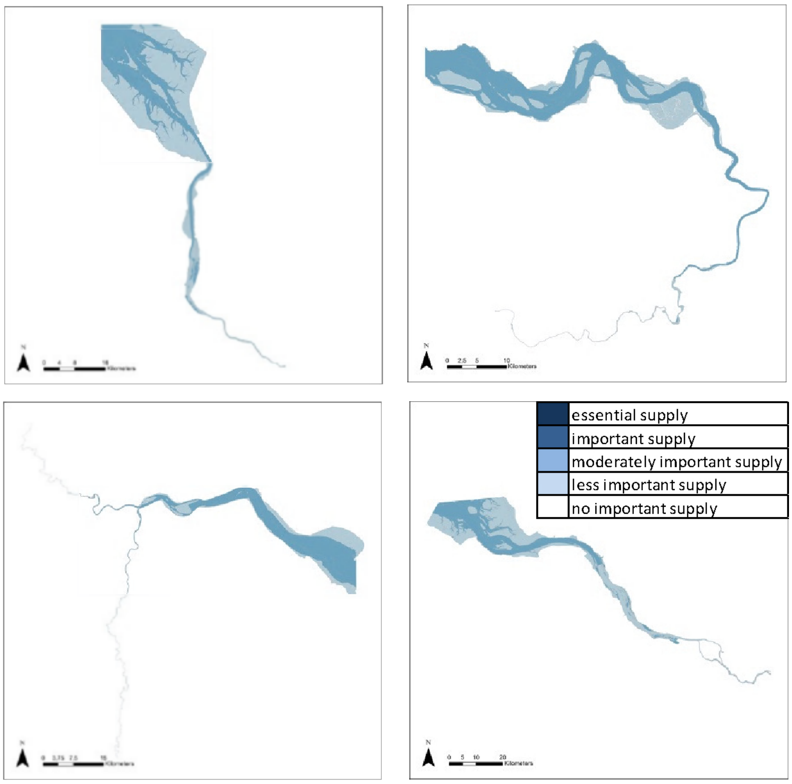


Figure 19: Drainage of river water in the Weser, Scheldt, Humber and Elbe estuary based on average habitat-specific supply scores per salinity zone, and involving local and site-specific scientific expertise.

Service	Benefit	Short definition
Water quantity regulation: drainage of river water	ensured platform, food, water other provisioning services	drainage of the catchment by the river

Drainage of river water is a basic but essential process of evacuating water from the catchment, which guarantees basic activities performed in the estuarine valley. Especially, evacuation of the river water after a storm tide is very important as storm tides are often coinciding with heavy rainfall (and potential high discharges from the catchment), and emptying the estuary is essential to prevent flooding by consequent surges. It is provided by the deep subtidal habitat mainly, but also other habitats play their role as temporary discharge buffers. Inter-estuarine differences among zones and habitats are represented in detail section 5.5.

Structures and processes

Drainage of river water is physically driven. It consists of the connection of the catchment with the estuary, the buffering potential of discharge in intertidal areas, and the evacuation of water out of the estuary in between tides. It interacts with all ecosystem services linked to water quantity. Optimal drainage requires an open and free flow, but on the other hand this might increase the tidal volume coming in (see section 0, 0). Tidal amplitude and tidal asymmetry and its links with morphology are essential drivers.

5.3.9 Dissipation of tidal and river energy

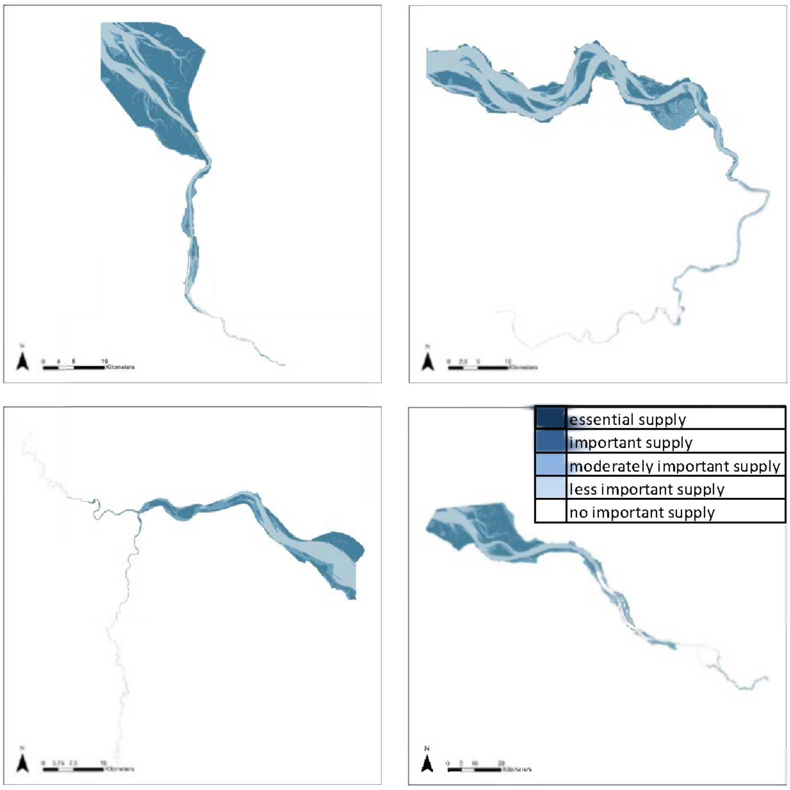


Figure 20: Dissipation of tidal and river energy in the Weser, Scheldt, Humber and Elbe estuary based on average habitat-specific supply scores per salinity zone, and involving local and site-specific scientific expertise.

Service	Benefit	Short definition
Water quantity regulation: dissipation of tidal and river energy	various ensured provisioning services, avoided maintenance costs	buffering of average flood and discharge variations in the river bed

This service is very similar to flood protection, but while flood protection is linked to extreme events and storm flood volumes (highest intertidal habitats), dissipation is the regulating process for everyday tidal volumes. Too high river or tidal energies exert continuous hydrological stress on habitat & supporting services and on infrastructures, mainly through excessive water currents and erosion. Dissipation occurs in shallow areas and intertidal areas. Inter-estuarine differences among zones and habitats are represented in detail section 5.5.

Structures and processes

This ecosystem service is almost entirely physically driven. The shape and volume of the estuary in the poly- and mesohaline zone determines the volume and speed of the tidal wave, while the extent of intertidal habitats determine the amount of energy potentially dissipated. Complex interactions with water quantity-influenced services exist, as the tidal propagation influences sedimentation-erosion balances. However, there are also potential synergies with habitat and supporting services, as intertidal areas can be essential biodiversity hotspots.

5.3.10 Landscape maintenance

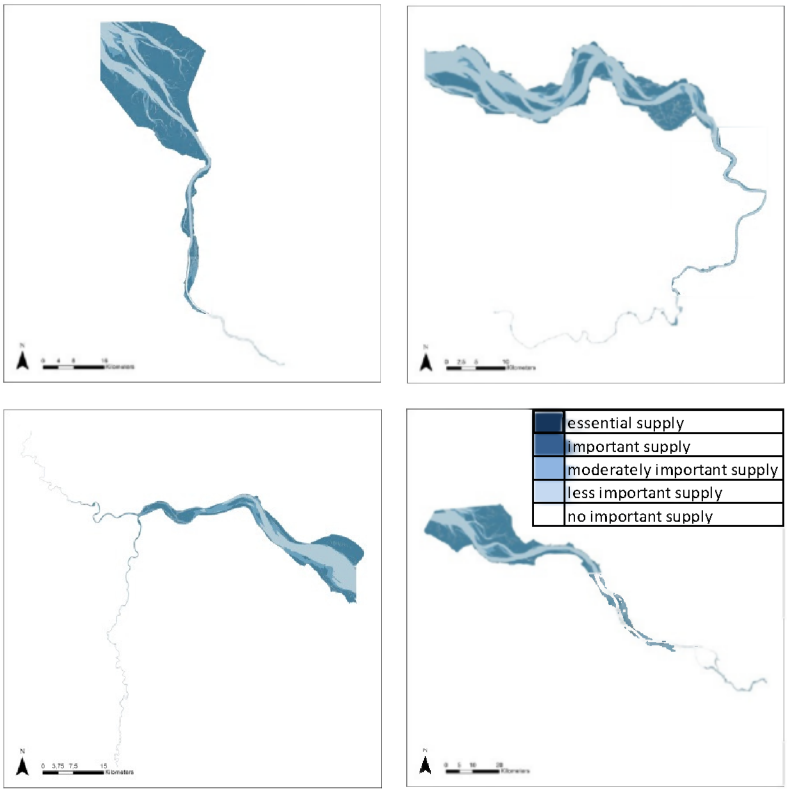


Figure 21: Landscape maintenance in the Weser, Scheldt, Humber and Elbe estuary based on average habitat-specific supply scores per salinity zone, and involving local and site-specific scientific expertise.

Service	Benefit	Short definition
Water quantity regulation: landscape maintenance	various ensured services	formation and maintenance of typical landscapes and hydrology

This service describes the ensemble of natural processes which ensure an equilibrium in sedimentation (= formation of new habitats) and erosion (= decrease in older habitats). Essential are sedimentation areas in shallow water and intertidal flats, which allow emergence of new habitats at young succession stages, which are often lacking from highly dynamic zones. However, the erosion of tidal marshes is an evenly important process. Overall, this service can be regarded as an intermediate service to many final services. Its delivery could be evaluated by assessing the long-term trends in habitats ratio's and equilibria between marsh formation and erosion. Inter-estuarine differences among zones and habitats are represented in detail section 5.5.

Structures and processes

This service is driven by sedimentation erosion processes and thus mediated by morphological as well as biological processes and structures. Morphology and water quantity related services are strongly interacting, but the presence of complete gradients and specific habitats is essential for the biological and morphological functioning of the estuary. These processes generally play a role in any habitat, but most importantly in the shallow water and intertidal habitats.

5.3.11 Water quantity regulation for navigation

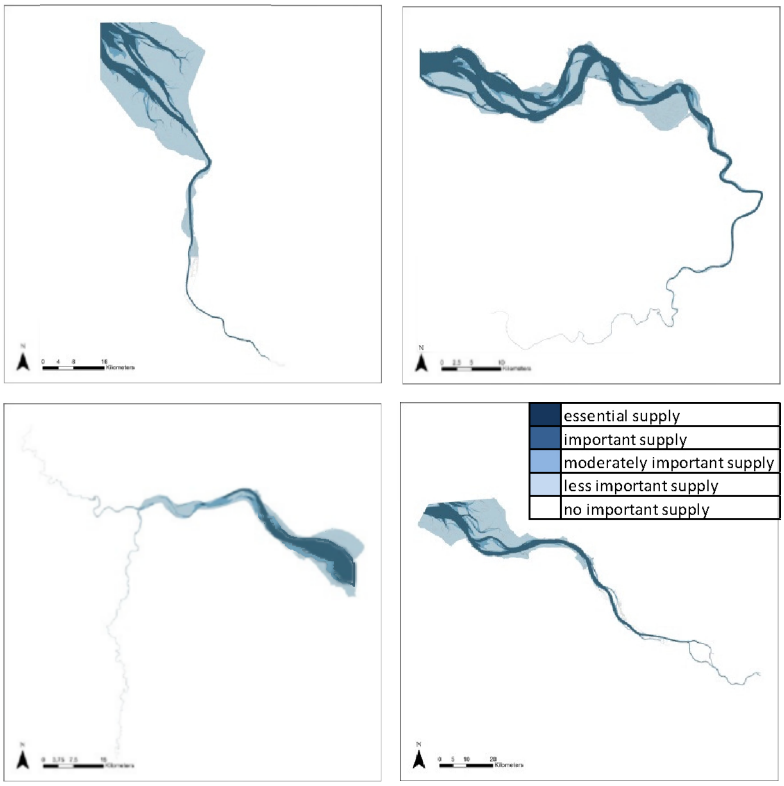


Figure 22 Water quantity regulation for navigation in the Weser, Scheldt, Humber and Elbe estuary based on average habitat-specific supply scores per salinity zone, and involving local and site-specific scientific expertise.

Service	Benefit	Short definition
Water quantity regulation: transportation	Shipping	discharge and tidal input for shipping, including water use for canals and docks

Requirements for navigation use water are straightforward. Water bodies require adequate depths and width. This is an intermediate service for the final provision of water for navigation (section 0). The complex and dynamic morphology is regulated by water quantity and morphology aspects, which can cause erosion as well as sedimentation of the fairway, which might increase (dredging) costs for shipping. Scores are highest for deep and moderately deep subtidal habitats where these processes impact directly on accessibility, while shallow areas are important as sedimentation areas. Inter-estuarine differences among zones and habitats are represented in detail section 5.5. Notice, that the estuary-specific zonation scores were averaged in the four common zones. In this case notice that for instance in the Elbe, the freshwater zone 1 upstream of the harbour (see report "Zonation of the TIDE estuaries") has a lower score as the zones 2 and 3 downstream the harbour.

Structures and processes

This ecosystem service is mainly physically driven. Main driving factors are the water quantities provided by discharge and tidal influx and the morphology of the fare way. The service is interacting with supporting & habitat services by direct impacts on benthic communities, light availability and productivity or changes in algal community composition, or local conditions altering composition of higher trophic levels.

5.3.12 Water quantity regulation services

The former four services al relate to regulation of water quantity. Concerning their identification, quantification and valuation, Liekens et al (2013) state that ecosystems, e.g. forests and wetlands, play an important role in the hydrological cycle including regulating the provisioning of water, i.e. “capturing” quantities of water for human or other use (including both surface and ground water). One of the important uses in an estuary is transportation defined as the discharge and tidal input for shipping, including water use for canals and docks. From the ecosystem functioning point of view, water regulation services are based on the combined effects of vegetation and soil characteristics. Vegetation cover maintains certain soil characteristics, e.g. permeability, that enable infiltration of rain water into the ground. Reduced vegetation cover can thus increase surface runoff and decrease infiltration, resulting in lower recharging of the groundwater reserves. In general, all ecosystems use water, e.g. water is required for photosynthesis to take place. Consequently, vegetation cover inherently reduces fresh water quantities and the quantity of water taken up by vegetation increases. Liekens et al (2013) further describe interaction with other services and suggest quantification methods per use category (industry, transport, agriculture,…).

5.3.13 Transport of pollutants and nutrients

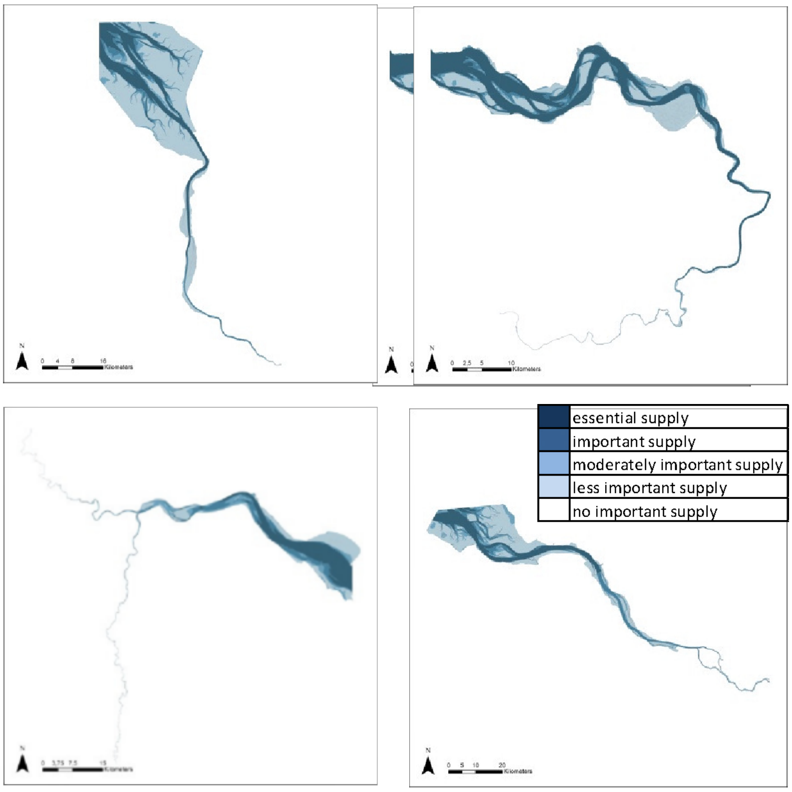


Figure 23 Transport of pollutants and nutrients in the Weser, Scheldt, Humber and Elbe estuary based on average habitat-specific supply scores per salinity zone, and involving local and site-specific scientific expertise.

Service	Benefit	Short definition
Water quality regulation: transport of pollutants and excess nutrients	improved water quality, various ensured services	transport of pollutants from source, dilution

This service describes the basic physical removal of pollutants and excess nutrients out of the system by dissolution in the estuaries water mass and transport towards the sea. The scores are very similar to e.g. drainage of river water with a decreasing importance of habitats higher in the tidal frame. Inter-estuarine differences among zones and habitats are represented in detail section 5.5.

Structures and processes

This service is mainly physically driven. Main driving factors are the water quantities provided by discharge and tidal influx and the morphology of the river. The service is heavily interacting with supporting & habitat services, since excessive loads of nutrients or pollutants will impact benthic communities, algal community composition, or higher trophic levels, and overall functioning of the estuarine ecosystem.

5.3.14 Filter function: Reduction of excess nutrient loads

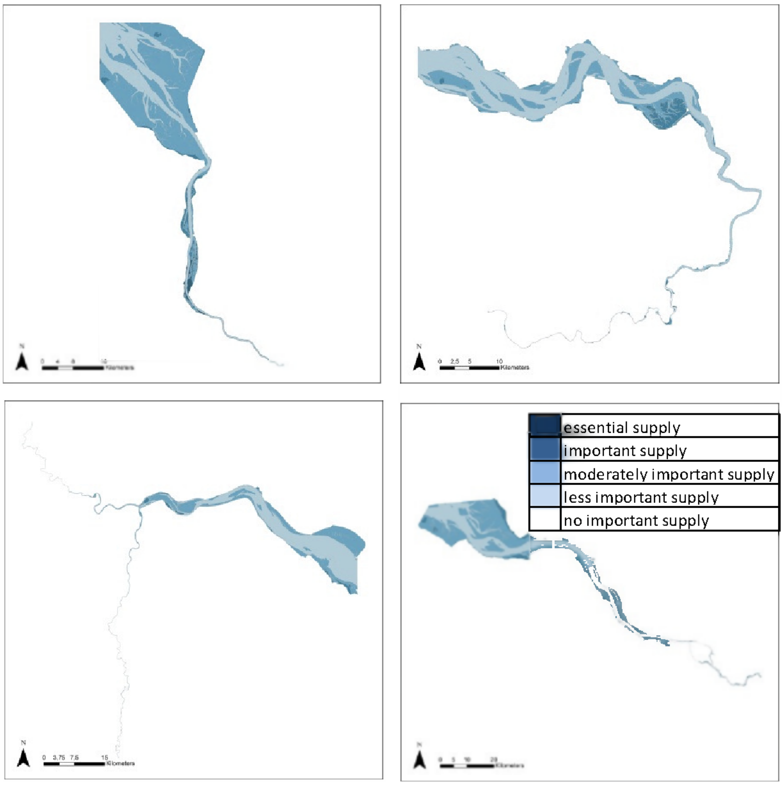


Figure 24: Reduction of excess nutrient loads in the Weser, Scheldt, Humber and Elbe estuary, based on average habitat-specific supply scores per salinity zone, and involving local and site-specific scientific expertise.

Service	Benefit	Short definition
Water quality regulation: reduction of excess loads coming from the catchment	improved water quality, various ensured services	binding of N, P in sediments and pelagic food web

This service describes the filter function of the estuary by uptake of nutrients and pollutants in the ecosystem (biologically by uptake of organisms, of physically by sedimentation and chemical absorption and immobilization). Highest scores are found on areas where high biological activity coincides with high sedimentation rates. Marshes are particularly important. However, also in the pelagic food web, nutrients are being sequestered. Inter-estuarine differences among zones and habitats are represented in detail section 5.5.

Structures and processes

This service is mainly biologically driven. Main driving factors are the productivity of algal communities and the biologically active layer on subtidal and intertidal sediments. However, hydrology plays an essential role as it determines retention times, flooding frequencies and duration, and evenly important are sediment features and morphology which determine pelagic light climate, intertidal soil porosity and reactivity etc. The service is heavily interacting with supporting & habitat services, since excessive loads of nutrients or pollutants will impact benthic communities, algal community composition, or higher trophic levels, and overall functioning of the estuarine ecosystem.

In Liekens et al (2013B) the importance and complexity of identifying, quantifying and valuing this service is illustrated (see also 5.2.)

5.3.15 Erosion & sedimentation regulation by water bodies

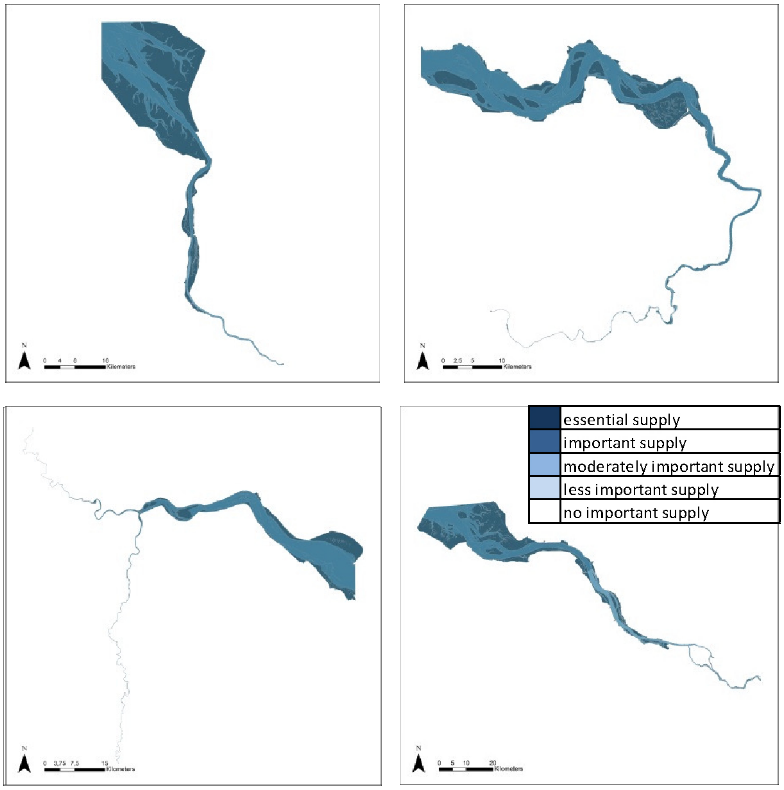


Figure 25: Erosion and sedimentation regulation by water bodies in the Weser, Scheldt, Humber and Elbe estuary, based on average habitat-specific supply scores per salinity zone, and involving local and site-specific scientific expertise.

Service	Benefit	Short definition
Erosion and sedimentation regulation by water bodies	avoided damage or maintenance costs, various ensured provisioning services	sediment trapping and gully erosion by variable water currents and topography

This service is the purely physical regulation of erosion and sedimentation processes occurring in estuaries. All habitats are important, since deep subtidal as well as shallow subtidal and intertidal habitats play essential roles in regulation of sedimentation and erosion. Marshes and tidal flats however are scored highest, as they tend to accumulate sediments, avoiding sedimentation in deep subtidal and providing natural habitat formation. Inter-estuarine differences among zones and habitats are represented in detail section 5.5.

Structures and processes

This service is mainly physically driven. Main driving factors are the position of the habitat in the tidal frame, and the local dynamics and water currents. Processes and structures are linked to the service of landscape maintenance (0).

5.3.16 Erosion & sedimentation regulation by biological mediation

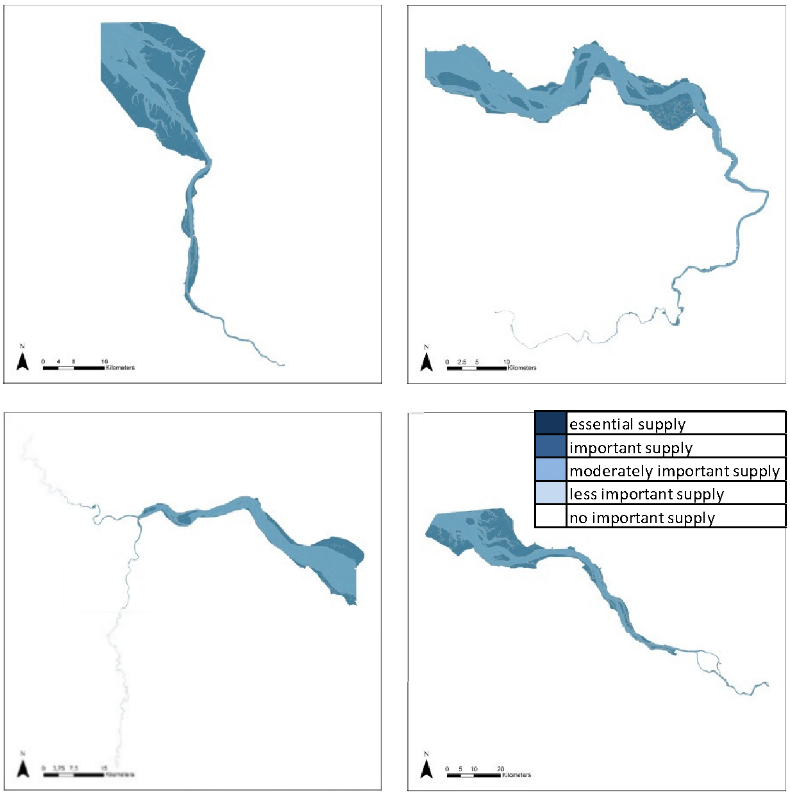


Figure 26: Erosion and sedimentation regulation by biological mediation in the Weser, Scheldt, Humber and Elbe estuary, based on average habitat-specific supply scores per salinity zone, and involving local and site-specific scientific expertise.

Service	Benefit	Short definition
Erosion and sedimentation regulation by biological mediation	avoided damage or maintenance costs, various ensured provisioning services	sediment trapping and erosion prevention by vegetation, effects of bioturbation

This is the biological component of regulation of erosion and sedimentation processes occurring in estuaries. All habitats are important, since biota in deep subtidal (benthic organisms) as well as in shallow subtidal and intertidal habitats play potential roles in regulation of sedimentation and erosion. Marshes and tidal flats however are scored highest, as vegetation plays a major role as ecological engineer by preventing erosion, determining sedimentation-erosion patterns and driving changes in marsh morphology and tidal flat elevation. Inter-estuarine differences among zones and habitats are represented in detail section 5.5.

Structures and processes

This service is mainly biologically driven, and together with its physical counterpart (0), these can be regarded as intermediate services for landscape maintenance (0). These services determine abundance of different structures and gradients and services emerging from them. Main driving factors are the ecological quality of the habitat, the presence and viability of populations of key species, the habitat connectivity and colonization dynamics. Important processes include water current reduction and sediment capturing (in subtidal shallow and intertidal vegetation), bioturbation (e.g. by benthic macrofauna) and increasing resistance against erosion (e.g. benthic algal layers).

5.3.17 Supporting / habitat services

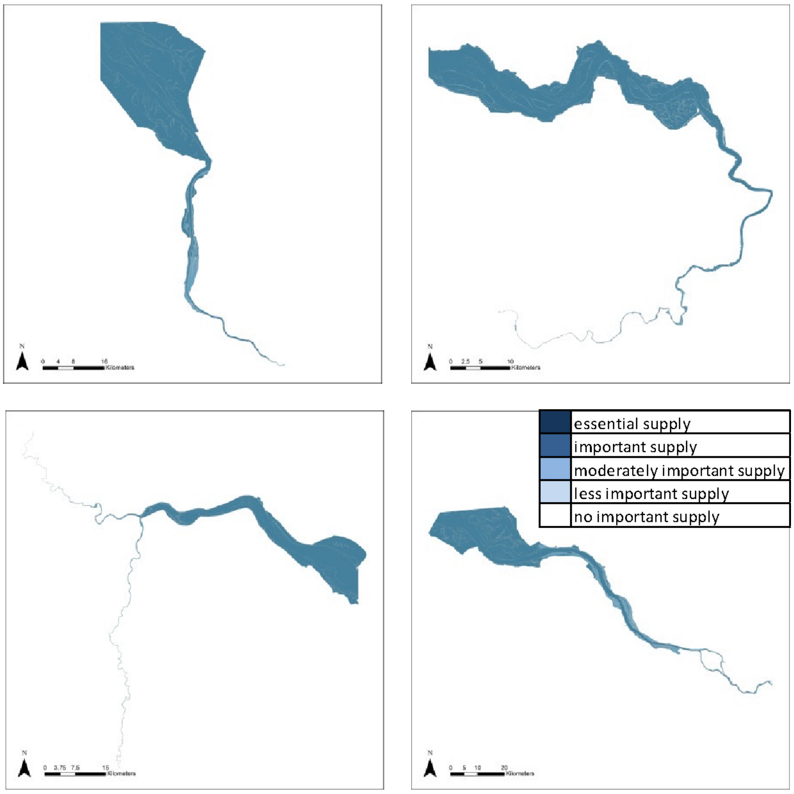


Figure 27: Supporting / habitat services ("biodiversity") in the Weser, Scheldt, Humber and Elbe estuary, based on average habitat-specific supply scores per salinity zone, and involving local and site-specific scientific expertise.

Service	Benefit	Short definition
"Biodiversity"	insurance of all services	total amount of abiotic and biotic diversity at all levels (gene-landscape), regardless of rarity or vulnerability

Biodiversity, broadly defined, contains all processes directly or more indirectly involved in sound ecosystem functioning. Hence the importance of all habitats. Resilience of the ecosystem increases with biodiversity. Resilience of a system is the capacity to recover from impacts, anthropogenic as well as natural. In estuarine ecosystems, this resilience is of key importance since stress (long term) and disturbance (events) are inherently part of the estuarine ecotope. In terms of ecosystem services, resilience can be defined as "*the ability to provide regulating services under varying circumstances*". As estuarine ecosystems are intensively used, and impacts of this use on basic processes are significant, determining the risk of losing this resilience is essential.
Therefore, profound and integrated understanding of the estuarine system and the appearance of thresholds, regime shifts and tipping points is needed, as well as quantification of scientific uncertainties in order to adequately address the precautionary principle. Inter-estuarine differences among zones and habitats are represented in detail section 5.5.

Structures and processes

This service is the ensemble of all biological processes playing at all levels (gene-landscape)

5.3.18 Cultural services

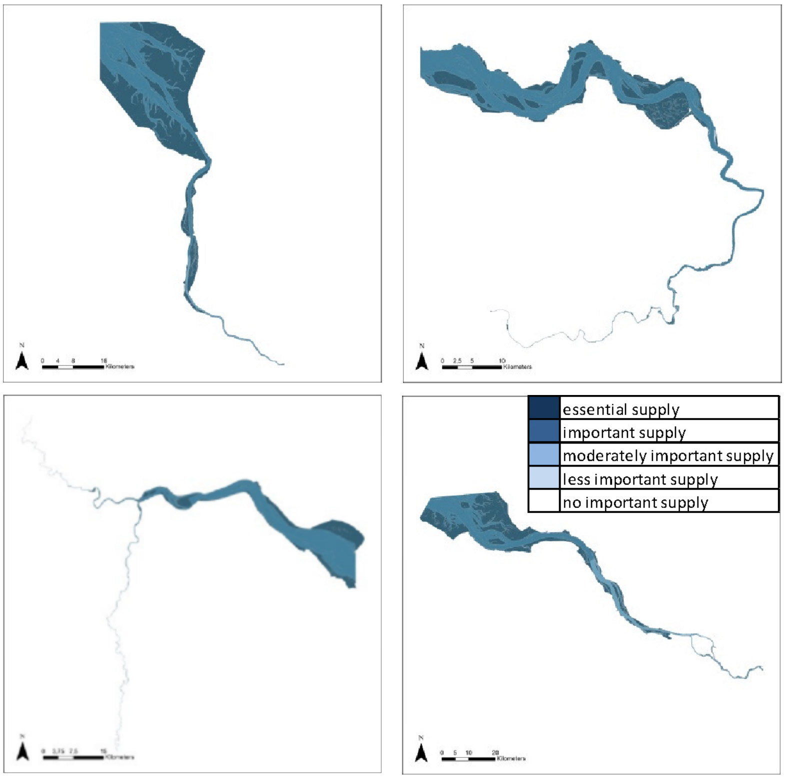


Figure 28: Cultural services in the Weser, Scheldt, Humber and Elbe estuary, based on average habitat-specific supply scores per salinity zone, and involving local and site-specific scientific expertise.

Service	Benefit	Short definition
Aesthetic information	Wellbeing	appreciation of beauty of organisms, landscapes,…
Opportunities for recreation & tourism	Wellbeing	opportunities and exploitation for recreation & tourism
Inspiration for culture, art and design	Wellbeing	appreciation of organisms, landscapes,… as inspiration for culture, art and design
Information for cognitive development	Wellbeing	use of organisms, landscapes for (self-) educational purposes

Most cultural services score high all over habitats. Marshes, as they provide a more accessible and visible biodiversity, score slightly higher for the 'inspiration' service. Inter-estuarine differences among zones and habitats are represented in detail section 5.5.

Structures and processes

These services are driven by the ensemble of abiotic, biotic and human processes and structures in estuaries. Although very valuable and essential for society, they are hard to quantify and capture in decision making.

5.4 Functional ES supply

Following the separate descriptions of structures and processes involved in supply of these ecosystem services, the many interactions and interdependences between them are clear (see also Figure 10). The services described in TIDE are final services, directly linked to benefits, as well as intermediate services, which regulate processes involved in provision of other services. However, these intermediate services can also have direct benefits. All services impact on the main structures and processes which determine the overall functioning of the system, while finally all services are more or less dependent on habitat and supporting functions.

Assuming that all these services have to be provided sustainably, the effect of optimizing structures and processes in function of a (set of) services on the long-term supply of the other services should be estimated. Unavoidably, any use of the estuary will have an impact. The challenge is to assess the risk of this impact to provoke system shifts which cannot be undone. This can only be achieved through building a comprehensive integrated model of the estuary, including quantitative data, verified indicators for ecological functioning and best available estimates, including uncertainties and knowledge gaps as risk factors. An illustrative backbone of such a conceptual model is shown in Figure 29.

From Figure 29, it is clear that all services depend on certain common key drivers, such as discharge and tidal water quantity, morphology, pollution and nutrient loads. These affect services directly, or indirectly by impacting on quality and amount of certain habitats, or with a time lag, when (use of) services impacts future conditions (gray arrows in Figure 29). Adopting a functional approach requires a comprehensive ecological understanding and threshold estimation based on empirical data, through the integration of existing models, data and expertise gathered in TIDE and present in other estuaries.

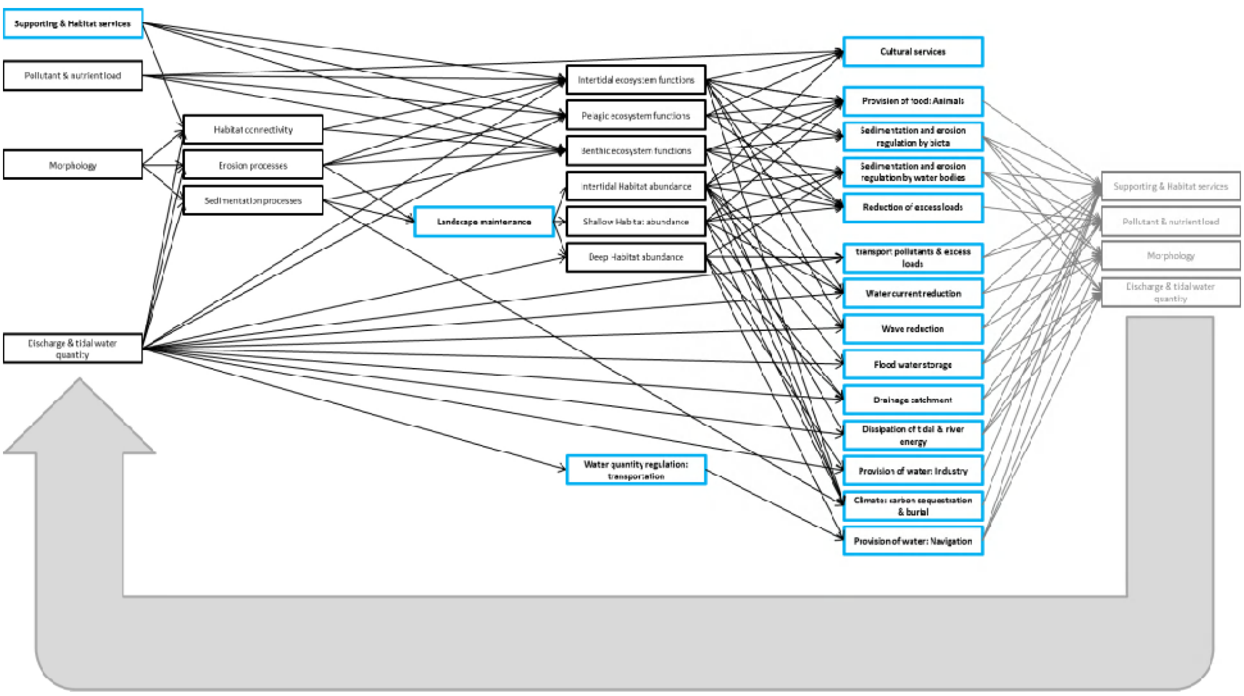


Figure 29: Illustrative scheme of interdependence of TIDE key ecosystem services (blue boxes), habitat abundance, habitat functioning and basic functions in the estuarine system. The grey boxes and arrows arrow represent the feedback of these services on the same drivers which determine their supply.

5.5 Inter- and intra-estuarine ES supply patterns

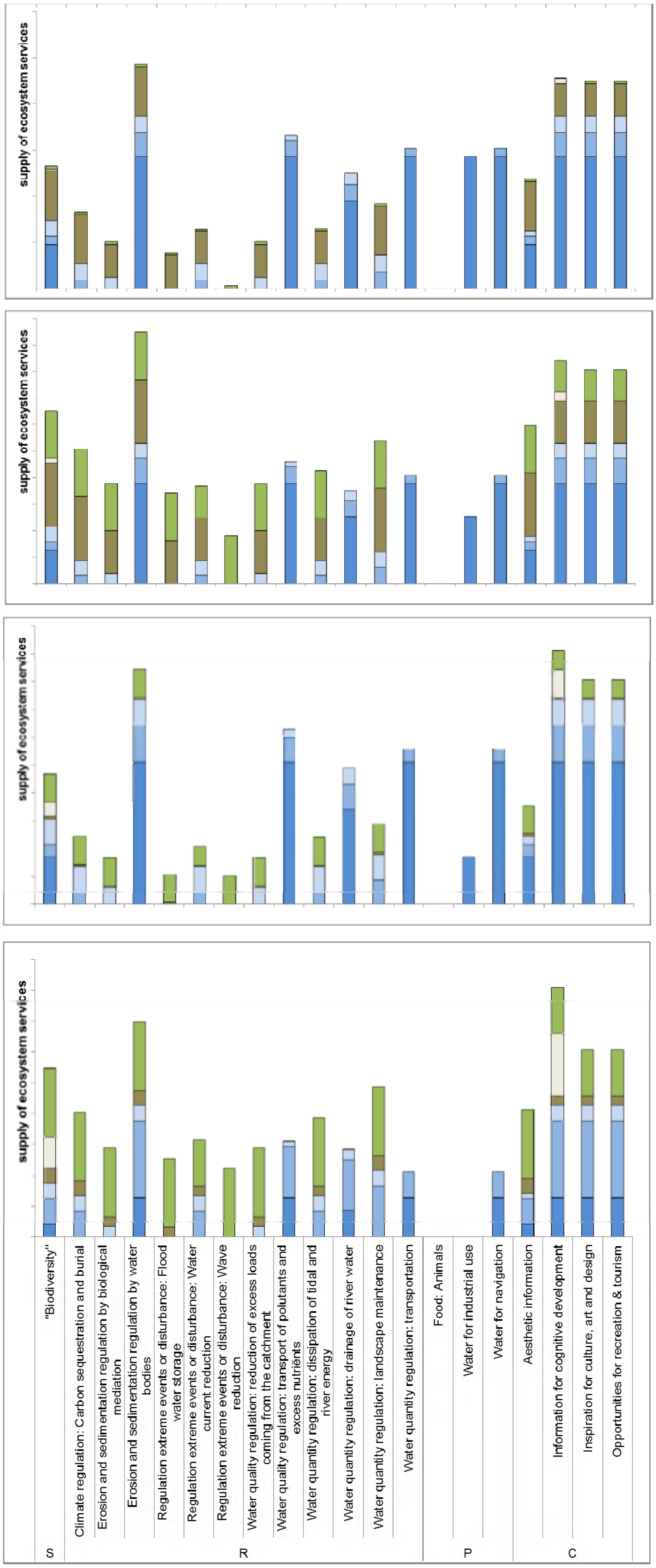
The local supply of Ecosystem services of the four estuaries can be compared per zone. Surfaces of habitats as well as their importance/contribution to supply are different among estuaries and zones by multiplying the supply score and relative surface of a habitat yields a (non-dimensional) measure of ES supply for the zone. These measures can be compared between zones and estuaries. Relative surfaces were used since absolute surfaces reflect purely the divide in zones. Relative surfaces however reflect the existing equilibrium and habitat gradient.

The supply of a certain service by a habitat can be multiplied by its surface to get a qualitative assessment of differences in ES supply. However, the surface-supply relationship is not the same for all habitats and services. Differences exist in the quantity of this relationship: e.g. one hectare of tidal flat will not supply the same 'amount of benefit' for nutrient capture as of sedimentation regulation. Also, surface-supply curves might be linear, exponential, or saturated: e.g. more deep water will increase navigation service, but after a certain amount is reached and demand is met, the service will not further increase. Therefore ES calculations based on surfaces should be interpreted as an indication and interpreted with caution.

The supply was calculated as *relative surface proportion of each habitat (% to total zone surface, see section 5.1) times their service supply score (see section 5.1)*. A high service supply in a certain zone can thus be caused by a high surface proportion of a habitat and/or by a high supply score of this habitat.

The purpose of this section is to present the data in a way which enables direct comparison of supply over zones and estuaries per ES, as well as the relative contribution of each habitat. As stated in section 275.2 the surface relationship does not allow comparison of ES among each other, but informs us about the origin of differences in supply *per ES* among salinity zones.

Scheldt



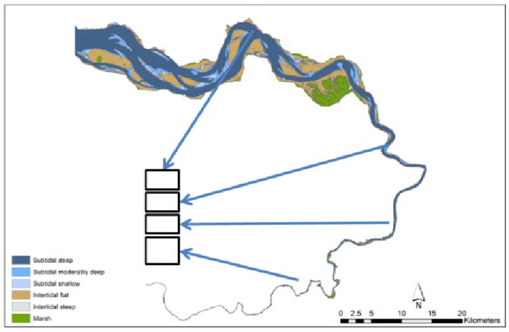
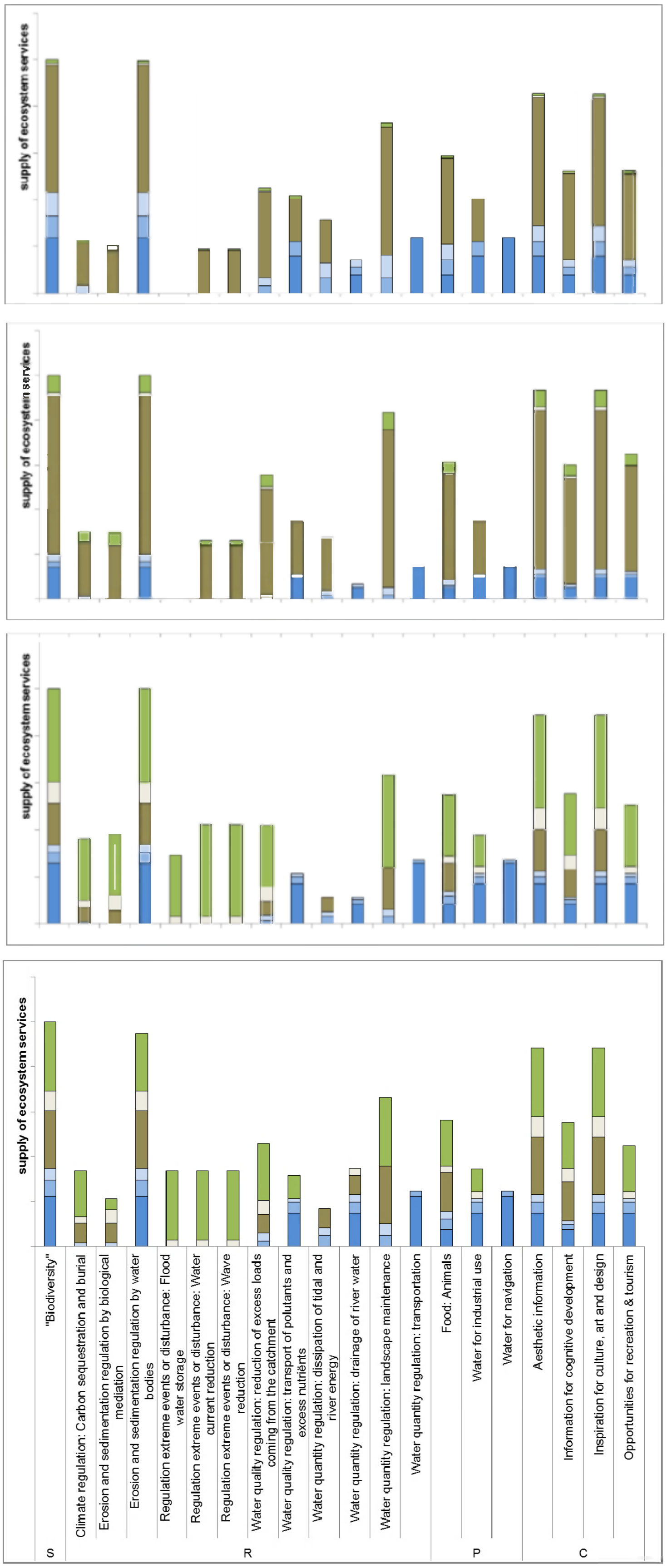


Figure 30 : Ecosystem service supply in each salinity zone of the Scheldt estuary.

Weser



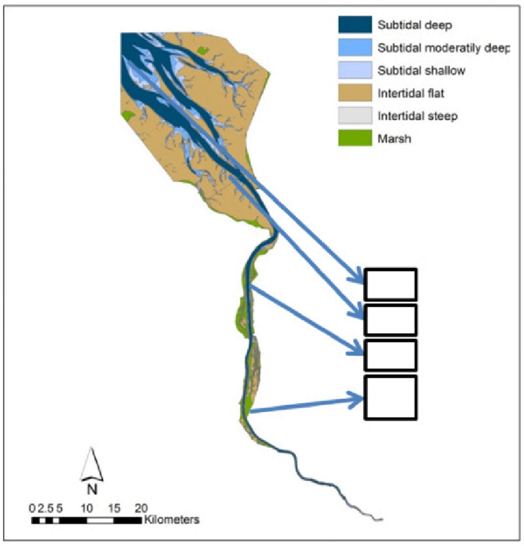
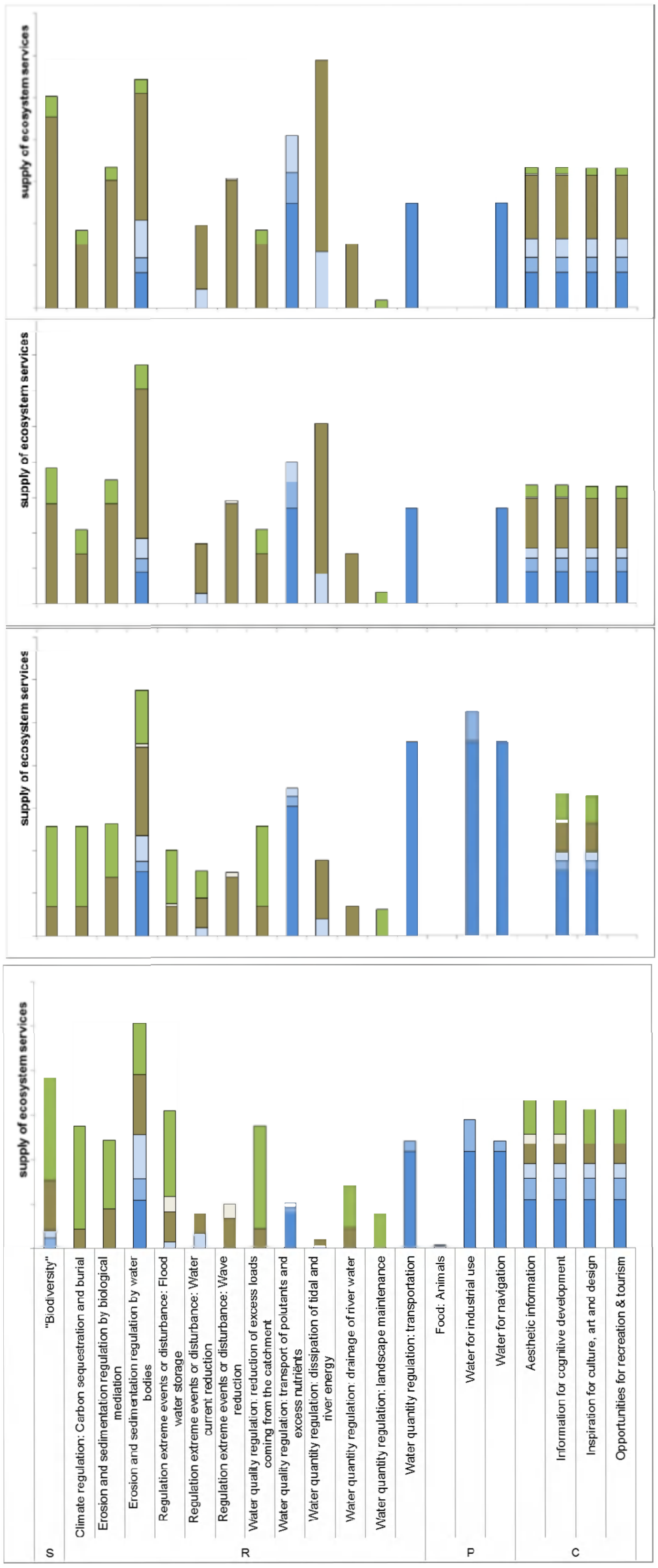


Figure 31: Ecosystem service supply in each salinity zone of the Weser estuary.

Elbe



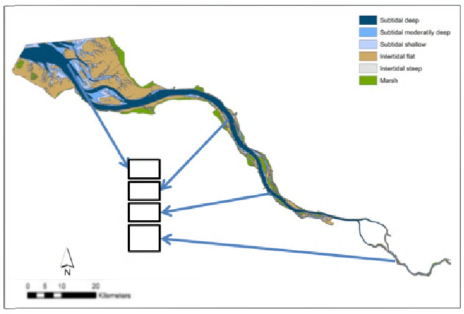
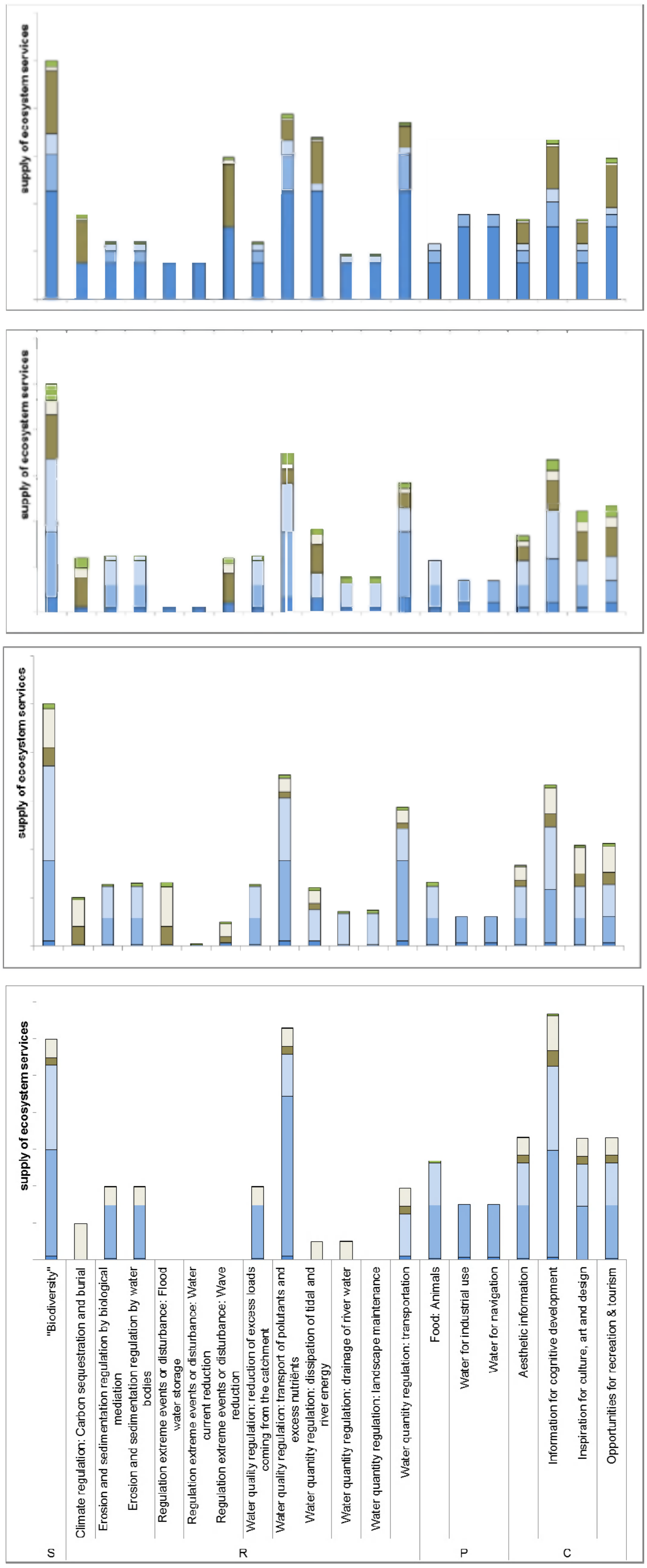


Figure 32: Ecosystem service supply in each salinity zone of the Elbe estuary.

Humber



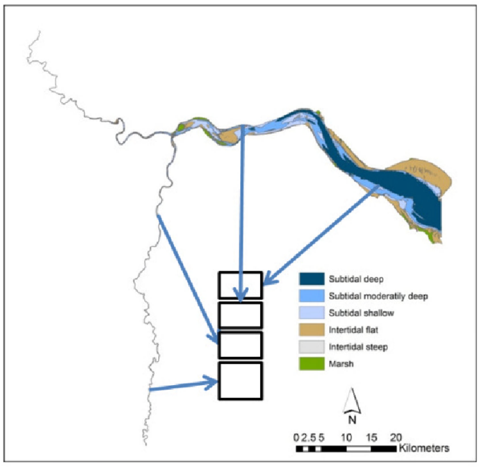


Figure 33: Ecosystem service supply in each salinity zone of the Humber estuary.

In the **Scheldt** (Figure 30), provisioning services show a low supply in freshwater and oligohaline zones. However, food provision supply is very low (less than 1% of scale). Low scores for *food provision*, were attributed since high levels of pollution prevent consumption of fish and filter feeders from the estuary. However, historically as well as potentially, this supply could thus be higher than shown here.
The increase in supply scores of *provision of water* and regulating functions for *water quantity*, as well as the higher proportions of deep and moderately deep subtidal habitats towards the mouth provoke an increase in supply of these services, while decreases in most other regulation services (*regulation of extreme events* and *water quality*) and habitat services are observed.
Supply by marsh habitat is very low in the polyhaline zone. This is caused by the low surface of this habitat, as the supply does not vary much (see section 5.1).
The same holds for tidal flat habitat in the oligohaline and freshwater zone, and shallow subtidal habitat in all zones. Supply scores are high (see section 5.1), but due to low relative surfaces, the contribution to overall ecosystem service delivery is relatively low.

In the **Weser** (Figure 31), the overall contribution of tidal flat habitat to ecosystem service supply is remarkably high in the mesohaline and polyhaline zone. This is caused by the high proportional surface and the relatively high potential supply scores of this habitat.
The same holds for marsh habitat in the freshwater and oligohaline zone. Provisioning services are quite equally supplied along the estuarine gradient. The supply of supporting services is high and also quite stable along the estuarine gradient.
Water quality regulation and regulation of disturbance services are doing less in the meso- and polyhaline zone, since the proportion of marsh habitat is very low.

In the **Elbe** (Figure 32), the contribution of marsh habitat to ES supply decreases towards the mouth in favor of tidal flat habitat, as can be seen from for instance climate regulation and flood water storage services. This decrease is mainly driven by the difference in relative surface.
Provisioning services, such as water for industrial use and water for navigation, are mainly supplied in fresh and oligohaline zone, as the port activities are located in the more upstream area. Supporting services are mainly provided by intertidal flats and marshes, while subtidal habitats are more important for provisioning and water quantity regulating services.

In the **Humber** (Figure 33), the very low proportion of tidal flats and even lower for marshes in fresh and oligohaline zones yields a clearly different picture for the Humber. In the fresh water zone, shallow subtidal habitats are very important, while the deeper habitats increase importance towards the mouth.

5.6 Habitat contributions to ES supply

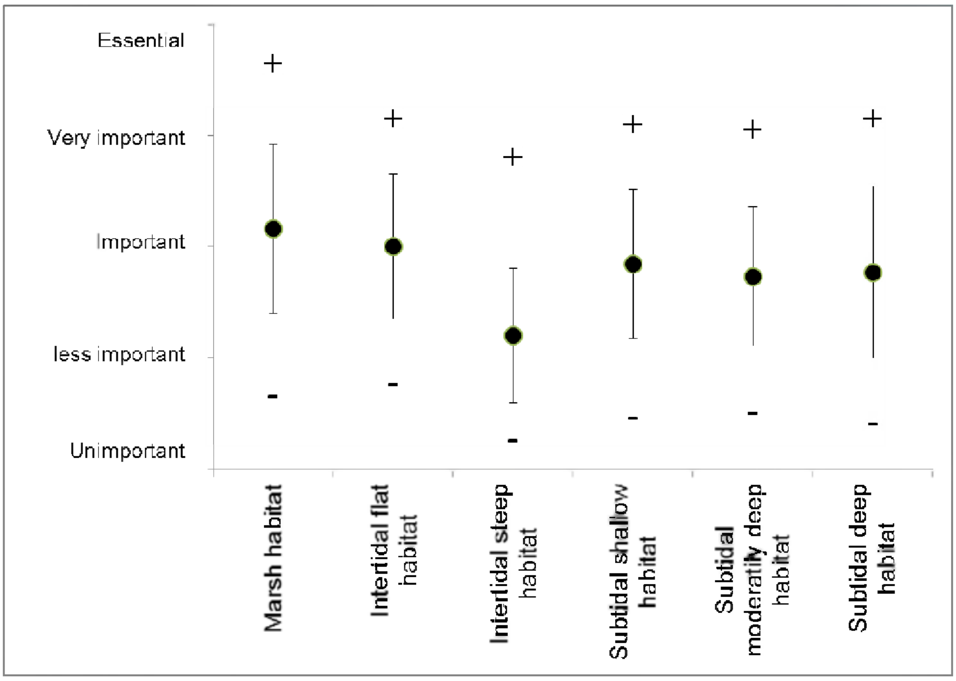


Figure 34: Average importance score of habitats for the supply of the entire bundle of ecosystem services and throughout the TIDE zones and estuaries. Error bars are standard deviations, - and + show maximum and minimum scores averaged over all ecosystem services.

As current ecological management and legislation is mostly using species- and habitat approaches, the contribution of habitats to the supply of the total bundle of ecosystem services is an important aspect to consider. Figure 34 gives an indication of the contribution of each habitat to the delivery of ecosystem services, which can complement information on ecological status, quality and trend in these habitats. This sum is composed of all information on supply for estuaries, zones and ecosystem services (section 5.1 and 5.5).

Generally all habitats are important to very important, especially the marsh and intertidal mudflat habitats. Steep intertidal habitats have the lowest importance. This re-affirms that to deliver a full bundle of ecosystem services and benefits to society, all of these habitats are required. As can be observed in figure 25- 28, ecosystem services (and by extension the entire bundle) can be delivered by several habitats. However, total supply will be highest if all habitats are present and the proportion of habitats with high delivery scores in the considered zone are larger.

Some essential aspects also involved in ES supply are the functional quality of these habitats, and their connectivity. In TIDE, habitats are defined on the basis of elevation in the tidal frame. As is clear from section 5.4, the functioning of these habitats is much more complex. Each service is delivered based on certain abiotic and biotic conditions, while feedbacks and interactions also play a role. This implies that one habitat cannot always be replaced by the other, as the functionality might differ for several services. Also, in a dynamic environment like an estuary, habitats will naturally evolve and shift into other habitats. Naturally, deeper areas become shallow, shallow areas become intertidal and finally marsh habitat due to sedimentation on the one hand, while erosion can shift habitats down in the tidal gradient or maintain habitats at their present state. The need for presence of the entire gradient, combined with the inherent shifts between them due to morphological processes (which are in an important way influenced by estuarine management) is the challenge of a sustainable estuarine management. Shifts in habitat abundance will cause shifts in ES supply, and less habitat or incomplete gradients will result in less supply and consequently, less overall benefits. Translation of directives in rigid surface claims (e.g. EU habitat directive) provide a legislative backup but do not fit a system where the location of these surfaces shifts over time. Optimization of habitat conservation and restoration measures towards ecosystem service supply should therefore target a dynamic mixture of habitat types instead of spatially explicit surface goals for very precise habitats or species assemblages.

To complement the explicitly designated and claimed areas by the habitat and bird directives, sustainable estuarine management would benefit from estuary-wide, non-spatially explicit surface claims and (process-based) goals on e.g. rates of (maximal) habitat erosion and (minimal) sedimentation zones, based on specific ecosystem service supply studies as explained in section 5.1 and 5.4.

As the ecosystem service approach has demonstrated the importance of all habitats and their dynamic interplay for society, a more equilibrated management can be developed, where habitats delivering more direct economic interests (e.g. deep water habitat) are no longer solely promoted at the cost of habitats which deliver services which benefit long term system functioning (e.g. mudflats, shallow areas,…).

6 Historical image of ES value

6.1 Goal

In historical times, the TIDE estuaries have played a different but not necessarily less important role. Major shifts in physical aspects (tidal amplitude, saline penetration, marsh formation, embankments,…) have occurred during the last centuries, and the demand for ecosystem services in historical times (food provision, recreation, navigation) is entirely different from todays'.
The goal of this "hindcasting" exercise is thus to project the historic habitat configuration (and estimation of historical ES demand) on todays' estuaries and get a tentative idea of the gained and lost values of ecosystem services. As data availability on habitats (compatible with supply survey categories) was limited, this exercise was only performed for the Weser and the Scheldt.

6.2 Method

The supply of a certain service by a habitat can be multiplied by its surface to get a qualitative assessment of changes in ES supply caused by shifts in habitat surfaces. However, the surface-supply relationship is not the same for all habitats and services. Differences exist in the quantity of this relationship: e.g. one hectare of tidal flat will not supply the same 'amount of benefit' for nutrient capture as of sedimentation regulation. Also, surface-supply curves might be linear, exponential, or saturated: e.g. more deep water will increase navigation service, but after a certain amount is reached and demand is met, the service will not further increase. Therefore ES calculations based on surfaces should be interpreted as an indication and interpreted with caution. This is mainly the case for services like water for navigation, wave reduction and water current reduction, which strongly depend on the form of the habitat (length-width, orientation along river, presence of bottlenecks,…).

Using the habitat surface areas and the ES supply scores per habitat, ES supplies were was calculated. This supply was weighed with the demand scores of the appropriate time period and zone. This yields a "total value indicator" per ES, which contains supply, surface area and demand aspects.

$$TV_{ESx} = \sum\nolimits_{1-y} [A_{Hy} * (S_{Hy} + D_{ESx})]$$

With

- TV_{ESx} total value indicator of ES_x
- A_{Hy} the surface area of habitat y in hectares
- S_{Hy} the average supply score of habitat y over the salinity zones.
- D_{ESx} the average demand score of ES_x over the salinity zones. For 1930 or earlier, historical demand scores were applied.

This indicator can be compared between historical time steps. A higher value can thus be generated by a higher surface, a higher supply score or a higher demand for the ES.

Habitat categories could be reconstructed based on historical physiotope maps, but not all habitats were available. For the merged "intertidal' category, intertidal flat supply scores were used (assuming minor relative surface importance of intertidal steep habitat), for the merged subtidal moderately deep and deep habitat, the supply scores were averaged. The *TV* change over time gives an *indication* of the shift in total ES value.

6.3 Weser Estuary 1950-2005

Habitat shifts In the Weser were derived from the report "Shallow water areas in North Sea estuaries" and summed according to the habitats used in the ES supply survey.

(in hectares)	**marsh**	**Intertidal flat + steep**	**subtidal shallow**	**Subtidal deep + moderately deep**
1950	5062	49387	12097	71797
2005	5147	46840	14892	70046

Table 4: Habitat surface evolution in the Weser estuary in ha (see report "Shallow water areas in North Sea estuaries"). For 1950, only data for four categories are available. 2005 habitats were merged accordingly.

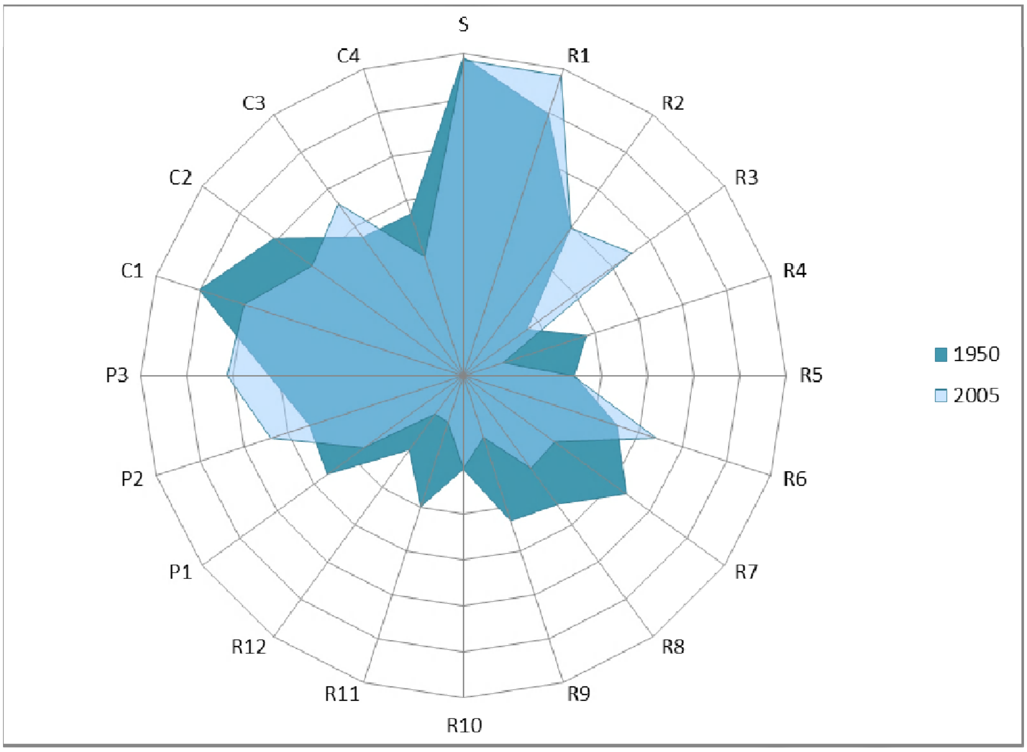


Figure 35: shift in Total Value indicator in the Weser between 1950 (dark blue) and 2005 (transparent blue). Calculation see section 6.2 (legend see Figure 365)

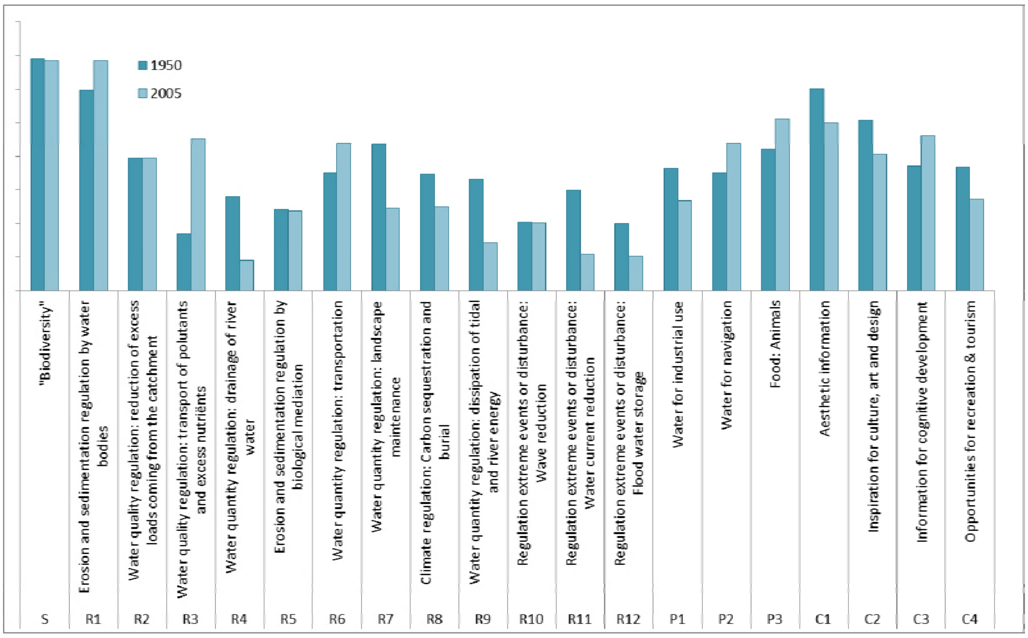


Figure 36: Shift in configuration of Total Value indicators in the Weser between 1950 and 2005.

In the Weser, the total value is lower for most services today than in the scenario with habitat surfaces of 1950. Only six services (water quality regulation, water for navigation, …) seem to have higher Total Value in the current habitat configuration. A remarkable higher value of the water quality regulation, is caused by increase in surface of marsh and subtidal shallow habitat. However, the total bundle supply does not seem so different in 2005 compared to the 1950 hindcasting scenario. As can be observed from the Scheldt hindcasting exercise, it could be that main shifts in habitat surfaces (and ES supply) occurred at earlier stages.

6.3.1 Scheldt Estuary 1880-1930-1960-2001-2010

Habitat shifts

(in hectares)	**intertidal flat + steep**	**Marsh**	**subtidal deep**	**subtidal moderately deep**	**subtidal shallow**
1880	1106	1016	*1639*	*928*	*631*
1930	882	1338	1656	994	621
1960	829	933	1635	964	605
2001	801	595	2074	823	423
2010	612	560	1742	653	328

Table 5: Habitat surface evolution in the Scheldt estuary from 1880 till 2010. For subtidal categories in 1880, only the total surface is known (see report "Shallow water areas in North Sea estuaries"), separate surfaces were estimated (italics) based on ratios of 1930. Historical data are only available for freshwater, oligo- and mesohaline zones.

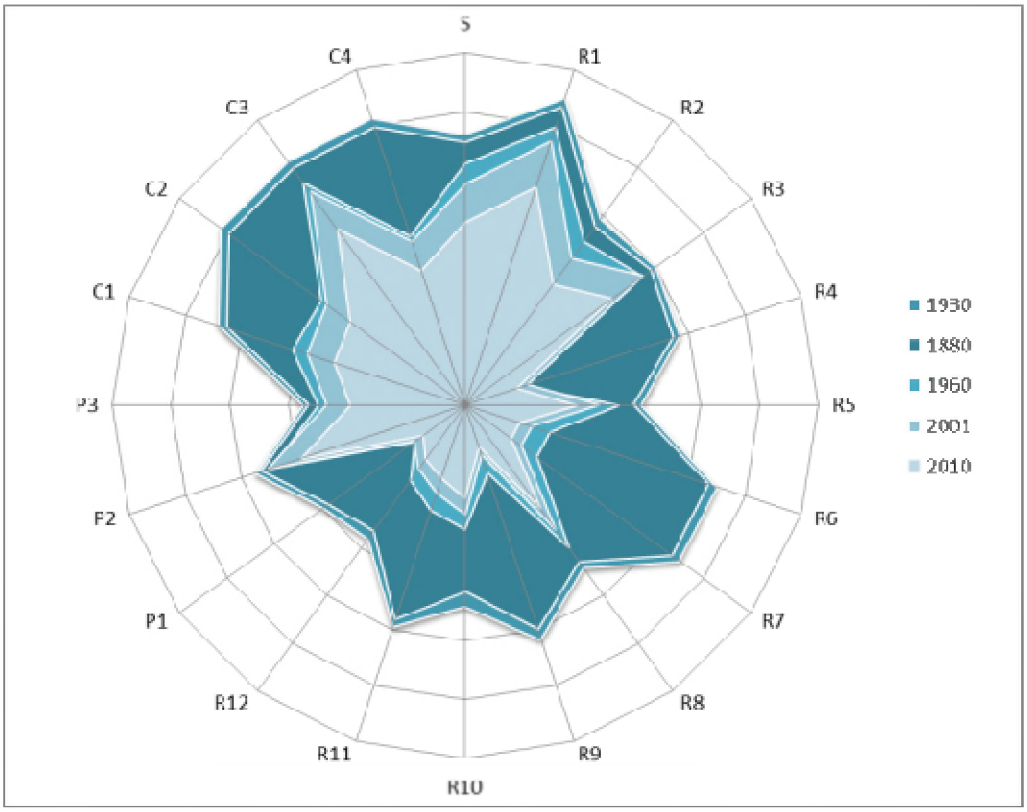


Figure 37: Shift in ES total value (TV) indicator in the Scheldt between 1880 and 2010. (legend see Figure 38: Shift in configuration of supply of ES in the Scheldt between 1880 and 2010.)

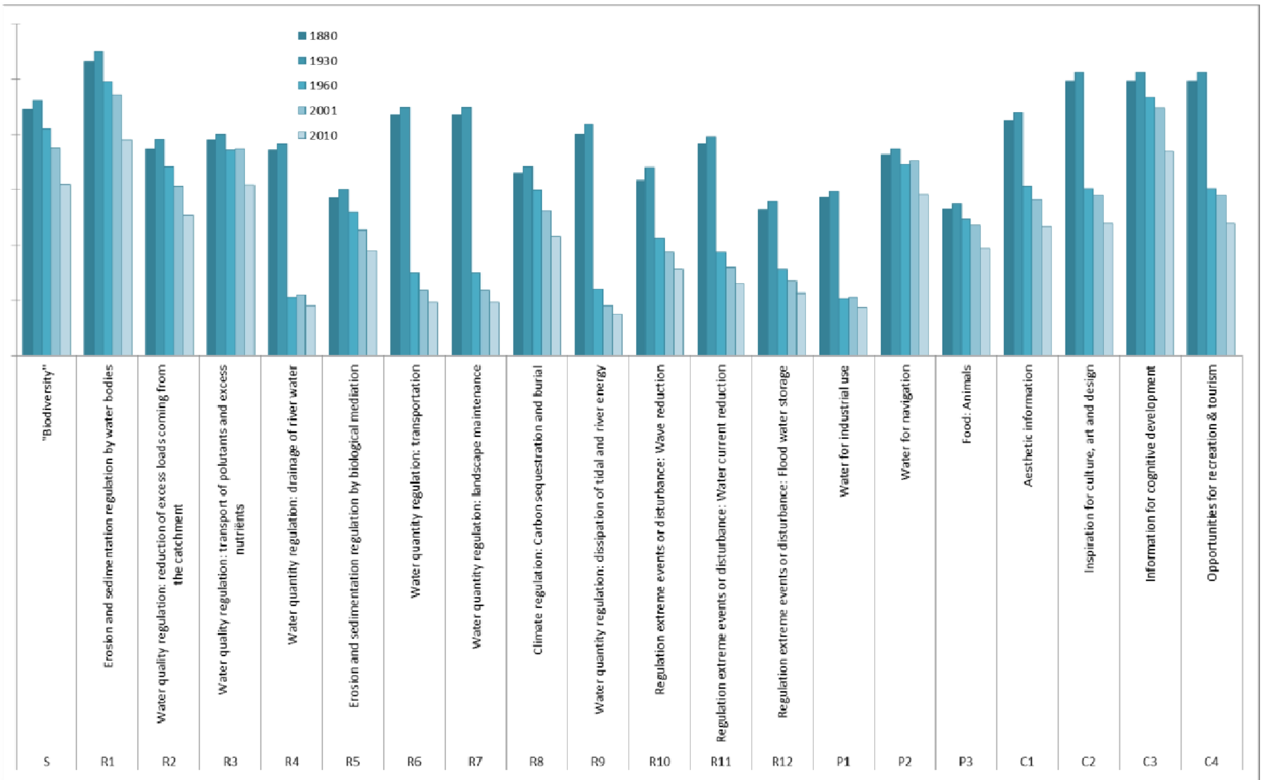


Figure 38: Shift in configuration of supply of ES in the Scheldt between 1880 and 2010.

For the Scheldt estuary, a general decrease in all ecosystem service values can be observed along the different hindcasting scenarios from 1880 till 2010. Most remarkable is the general negative for all services. This decrease is mainly driven by a decrease in habitat surfaces, but the major shift observed from 1930-1960 is also influenced by the demand values used in the formula (see section 6.2). For 1880 and 1930, historical demand values were used in the calculation, yielding a higher total value for some ecosystem services in before 1930.
Because of this higher demand, some services' value indicators have increased from 1960 to 2001 (water for navigation, water for industrial use, transport of excess nutrients and drainage of river water), but even these values apparently declined during the last decennium.
Compared to the Weser, the total bundle of values decreases from the mid-nineties up till today. As can be observed in the habitat surface areas, a continuous decrease of all habitat types is observed in favor of deep water habitat. However, the ongoing and planned restoration of about 1500 ha of tidal habitats (mainly marshes and intertidal flats) could probably reverse this trend.

7 Trade-off risk assessment

Recent advances in ecosystem service modeling focus on linking ecosystem service delivery, their associated values and trade-offs across services (e.g. Integrated Valuation of Ecosystem Services and Trade-offs InVEST, and Artifical Intelligence for Ecosystem Services ARIES). Bastian et al (2011) made a clear distinction between potential supply of ecosystem services (based on the natural capacity of an ecosystem), and the actual delivery.

Van der Biest et al (2013) discern three different levels of trade-offs between ecosystem services:

- *first level trade-offs* are generated by the biophysical potential of the ecosystem to deliver the different services (e.g. marshes have a higher capacity to provide biodiversity than deep water habitats); *second-level trade-offs* refer to the actual delivery within the study area, capturing biophysical potential trade-offs as well as land use and management based trade-offs (e.g. choosing to graze marshes determines which potential services are more and less delivered: food provision, biodiversity, carbon storage, etc.) and *third-level trade-offs* concern the final provision to society, depending on demand, accessibility, ecosystem service flow and generation of benefits (e.g. is the food actually sold, is the marsh accessed for recreation).

Knowledge about first-level trade-offs is essential to avoid unrealistic optimization scenarios. As the TIDE approach remains restricted to habitat surface measurement, the entire functional process and structural background of these trade-offs cannot yet be captured. However, conflicts between different uses (and services) da actually follow from the high demand for different services on a limited surface (see report "Conflict Matrices: Comparisons For TIDE Estuaries"). A *trade-off risk* indicator derived from the habitat supply data is therefore a useful tool to explore potential trade-offs and synergies between services.

Using the supply scores of habitats, a trade-off *risk* indicator can be derived. In the case that (a portion of) an estuary is optimized entirely for supply of a single service, the differences between ES-supply distribution over habitats (Figure 11) will provoke trade-offs. For instance, "water for navigation" exhibits a high trade-off risk with biodiversity, cultural services and regulation of extreme events, since complete optimization to navigation would imply creating deep subtidal habitats at cost of shallow, intertidal and marsh habitats (and delivery of their services). The calculation is the sum of the habitat's differences in supply between services or:

$$T_{ESa-ESb} = \sum_{1-i} (SHi_{ESa} - SHi_{ESb})$$

With:

- $T_{ESa\text{-}ESb}$= Trade-off between ES_a and ES_b
- SHi_{ESx} = Supply score of Habitat i for ES_x

The higher this number, the bigger the total difference in habitat supply distribution, and thus the higher the trade-off risk when management measures affect habitat surfaces.

	"Biodiversity"	Aesthetic information	Climate regulation: Carbon sequestration and burial	Erosion and sedimentation regulation by biological mediation	Erosion and sedimentation regulation by water bodies	Food: Animals	Information for cognitive development	Inspiration for culture, art and design	Opportunities for recreation & tourism	Regulation extreme events or disturbance: Flood water storage	Regulation extreme events or disturbance: Water current reduction	Regulation extreme events or disturbance: Wave reduction	Water for industrial use	Water for navigation	Water quality regulation: reduction of excess loads coming from the catchment	Water quality regulation: transport of polutants and excess nutrients	Water quantity regulation: dissipation of tidal and river energy	Water quantity regulation: drainage of river water	Water quantity regulation: landscape maintenance	Water quantity regulation: transportation
"Biodiversity"	0.00																			
Aesthetic information	0.54	0.00																		
Climate regulation: Carbon sequestration and burial	1.21	0.87	0.00																	
Erosion and sedimentation regulation by biological mediation	1.43	0.95	0.22	0.00																
Erosion and sedimentation regulation by water bodies	0.54	0.73	1.24	1.38	0.00															
Food: Animals	1.83	1.32	0.87	0.83	1.78	0.00														
Information for cognitive development	0.60	0.39	1.18	1.26	0.64	1.56	0.00													
Inspiration for culture, art and design	0.48	0.32	1.10	1.17	0.48	1.51	0.17	0.00												
Opportunities for recreation & tourism	0.77	0.52	0.98	0.98	0.56	1.21	0.38	0.33	0.00											
Regulation extreme events or disturbance: Flood water storage	1.58	1.07	0.52	0.34	1.56	0.83	1.35	1.26	1.11	0.00										
Regulation extreme events or disturbance: Water current reduction	1.58	1.07	0.45	0.37	1.53	0.56	1.32	1.26	0.97	0.49	0.00									
Regulation extreme events or disturbance: Wave reduction	1.71	1.20	0.82	0.66	1.87	0.93	1.44	1.39	1.35	0.35	0.59	0.00								
Water for industrial use	1.88	1.44	1.56	1.52	1.79	0.69	1.57	1.52	1.22	1.35	1.25	1.35	0.00							
Water for navigation	2.28	1.83	1.88	1.83	2.04	1.01	1.92	1.87	1.54	1.67	1.57	1.67	0.40	0.00						
Water quality regulation: reduction of excess loads coming from the catchment	1.17	0.84	0.19	0.33	1.21	0.75	1.15	1.06	0.83	0.50	0.47	0.80	1.44	1.75	0.00					
Water quality regulation: transport of polutants and excess nutriënts	1.48	1.15	1.48	1.45	1.15	0.79	1.08	1.01	0.71	1.54	1.11	1.63	0.75	0.89	1.34	0.00				
Water quantity regulation: dissipation of tidal and river energy	1.26	0.94	0.74	0.71	1.21	0.56	1.03	0.96	0.79	0.97	0.56	1.03	1.16	1.52	0.67	1.00	0.00			
Water quantity regulation: drainage of river water	1.71	1.20	1.02	0.98	1.66	0.34	1.44	1.39	1.10	1.03	0.71	1.13	0.57	0.86	0.90	0.75	0.70	0.00		
Water quantity regulation: landscape maintenance	1.25	0.79	0.39	0.34	1.20	0.80	1.08	0.99	0.81	0.68	0.43	1.00	1.40	1.71	0.44	1.33	0.54	0.89	0.00	
Water quantity regulation: transportation	2.14	1.70	1.83	1.78	1.90	0.95	1.79	1.73	1.40	1.61	1.52	1.61	0.26	0.20	1.70	0.75	1.42	0.82	1.64	0.00

Table 6: Potential trade-offs and synergies between ES (0: synergy / 3: very high trade-off risk). This analysis is based on the supply functions of the habitats. Each score presents the average of differences in supply score (1-5) per habitat.

The trade-off risk analysis (Table 6) situates the highest risks with supporting services ("biodiversity"), exhibiting high trade-off risks with provisioning services and water quantity regulating services. These same provisioning and water quantity regulating services exhibit trade-off risks with regulation of sedimentation-erosion and extreme events or disturbance.

Synergies are mostly found among services within the same group (eg cultural services, regulation of extreme events or disturbance,…).

In practice these trade-offs might not be apparent (as second level trade-offs) for instance where an adequate amount of provisioning deep water habitat is present without impacting supply by other habitats.

Comparison with the inventory of conflicts between direct uses (see report "Conflict Matrices: Comparisons For TIDE Estuaries") reveals large similarities with this trade-off risk indicator. For instance, potential trade-offs occur between supporting and habitat services ("biodiversity") , sedimentation-erosion regulation, prevention of extreme events and disturbance on the one hand and provisioning and regulating services related to industrial use on the other hand. This is also reflected in the conflict matrix. However, many potential synergies occur between (sets of) regulating services, cultural services and biodiversity.

Assessment of the trade-off risk is an important tool to capture potential conflicts of ‘direct uses’ (e.g. shipping, recreation, see report “Conflict Matrices: Comparisons For TIDE Estuaries”) with the many non-use services (regulating services, supporting and habitat services). These essential services are rarely represented by stakeholders but can severely affect long-term use of the estuary, and therefore should be taken into account in management decisions. This trade-off risk assessment provides a useful screening to guide a localized trade-off analysis, aiming at conserving/restoring/compensating supply of all services and securing long-term multi-functional use of the estuary.

8 Assessment of estuarine management measures

An assessment of ecosystem services in function of (estuarine) management can assist in the comparison of several development scenarios regarding efficiency, sustainability and equity. For a broad set of 38 selected TIDE measures, an explorative ES analysis was therefore performed to assess potential impact of the measures on ecosystem service supply. The separate results of this screening can be found in (see report “Management measure analysis and comparison”). It provides an immediate snapshot of expected increase or decrease in ES supplies by the different measures.

Additionally, knowing that potential interactions (see section 7) between ecosystem services take place (see sections 5.1, 5.4, 7) and measures differ in their expected impact on several ES (for detailed examples, see report “Management measure analysis and comparison”), it is important to verify which ecosystem services supplies actually increase together and how this relates to the total supply. Therefore, we took the results from the measure-ES assessments and verified correlations between separate ES supply shifts and the total summed supply shift per measure (Figure 39, n=38).

This correlation demonstrates that supporting / habitat service (“biodiversity”) increases have the highest significant correlations with the increase of total bundle supply, followed by aesthetic information and a selection of regulating and cultural services. This suggest that estuarine measures aimed at restoring or developing habitat / supporting services effectively yield high ecosystem service benefits and are highly synergetic. From all other correlations, none were significant within these selection of measures, which indicates effective trade-offs persist. The absence of significant negative correlations between increased service supply within the measures reflects the selection of the 38 measures, which mostly consisted in biodiversity and regulating service targeted measures and less in direct provisioning service increasing measures.

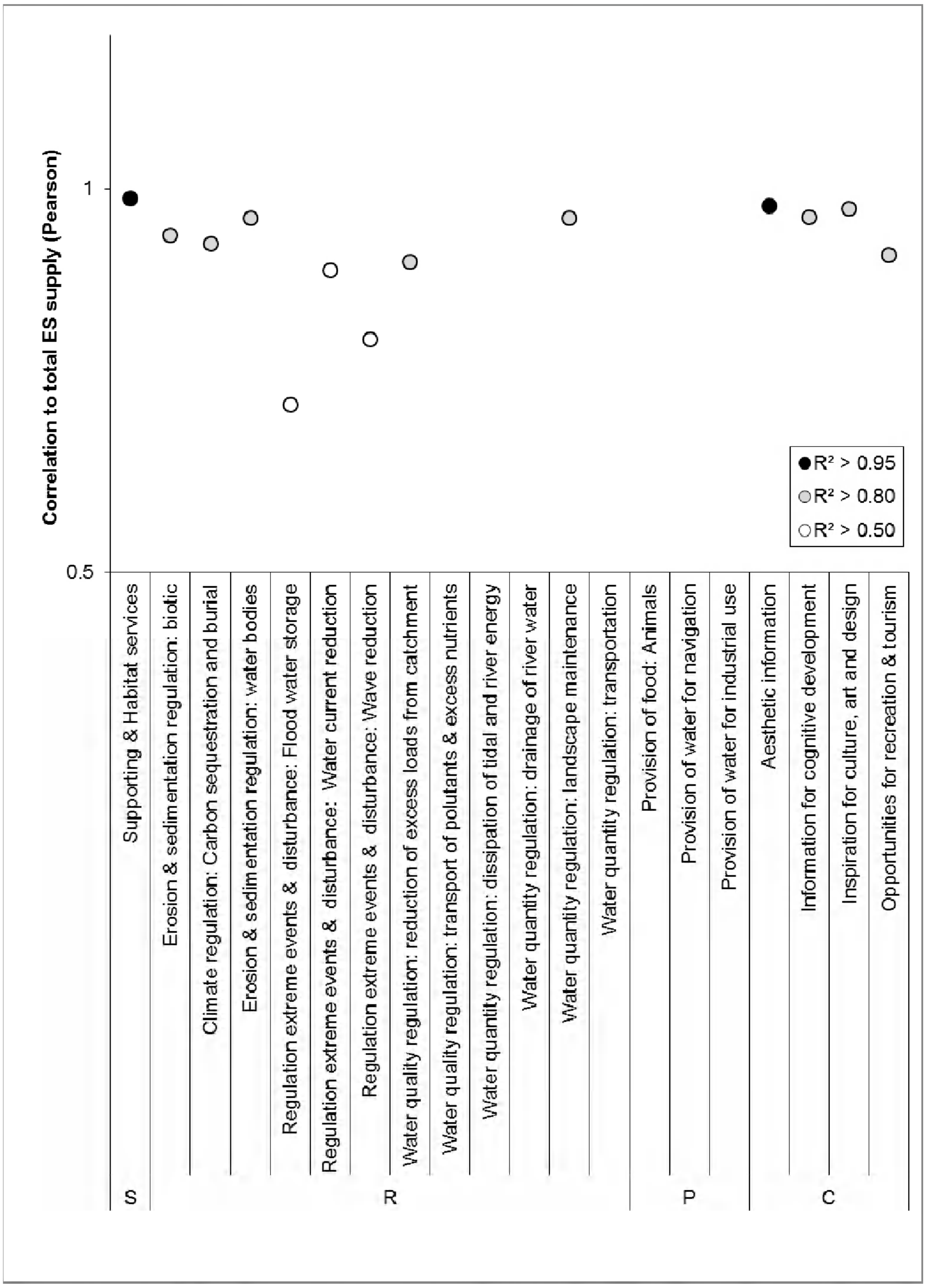


Figure 39: correlation between separate service supply shift with total summed supply shift. Based on 38 estuarine management measures (see report “Management measure analysis and comparison”).

9 Ecosystem Services in TIDE: Conclusions

9.1 Key question answers

The ecosystems service work carried out in the TIDE project has answered a number of key questions which were put forward at the start of the project (see 2.3).

- **What are the key ES for the TIDE estuaries and what is the demand for these services in the estuary?**

20 key ecosystem services were determined based on a broad demand survey among regional working group experts of the TIDE estuaries. These were the subject of further investigation.

ES demand in the four estuaries is very similar, due to the fact that these estuaries are both ecological as socio-economic very similar. A remarkable difference is the lower demand for sedimentation-erosion regulation by biological mediation, extreme water current reduction and landscape maintenance services in the Humber estuary, due to its naturally extreme turbidities and fluid mud conditions, combined with lower dredging requirements compared to the other estuaries.

Assessing the importance of a long list of ES by performing a survey is an efficient method to determine focal ES and involve a broad range of stakeholders in applying the ES concept. However, local particularities should be addressed when implementing estuarine management projects, and surveys should be thoroughly checked for reliability.

- **How does ES demand vary in time and along the salinity gradient?**

The demand survey included a spatio-temporal component that covered this aspect. Demand was only slightly variable since only ES linked to specific features of freshwater zones have a higher demand there (e.g. flood control, wave reduction), while future demand was higher for services mainly related to climate change (e.g. protection from flooding, carbon sequestration). Again, local particularities should be addressed when implementing projects, and surveys should be thoroughly checked for reliability.

- **How do habitats differ in ES supply?**

An expert survey resulted in a semi-quantitative estuarine zone specific ES-supply score for estuarine habitats. Generally all habitats are important to very important, especially the marsh and intertidal mudflat habitats. Steep intertidal habitats have the lowest importance.

The statistical reliability of the survey method is acceptable, and the matrix can be applied for the mapping of ES in similar estuaries. However, it is advisable to perform the survey method in the local context to increase validity of the data and participation of local experts. Differential supply of ES by habitats means that trade-offs between ES supplies occur when habitat surfaces change. Mechanistic and empirical research is needed to quantify these trade-offs.

- **What is the spatial variation and historical changes in ES supply?**

The scores for supply of ES differ only slightly among the zones. However, habitat ratios can differ through time or among zones and this influences the estimated total supply. A rough historical image can be derived by hind-casting supply and demand functions and using historical habitat surfaces. This analysis reveals a clear decrease in service supply over time for the Scheldt, even affecting provision services related to direct use of the estuary. In the Weser, the decrease was less clear as the habitat shifts over the available time period were less pronounced.

- **What are potential trade-offs or synergies in supply of ES?**

As ecosystem services are delivered by different (combinations of) habitats, trade-offs and synergies are exhibited. Provisioning services and supporting services exhibit most potential trade-offs, but many potential synergies among regulating services and with supporting services are present. On the other hand, some habitats (and combinations) deliver bundles of related services. The risk of exhibiting trade-offs or synergies can be directly derived from the supply scores. As expected, these risks coincided well with the inventory of direct use conflicts occurring in the TIDE estuaries (see report "Conflict Matrices: Comparisons For TIDE Estuaries").

- **How can the ES approach be used in conservation / restoration / development?**

On the short term, the demonstration (by mapping, valuation etc.) of socio-economic importance of regulating and supporting services can raise awareness, increase legitimacy and improve existing conservation and development of natural habitats.
On the long run, ES can provide more integrated visions and policies on natural resource use and protection, as described in detail in section 9.2.

- **How can ES be used to assess estuarine management measures?**

In the measures work package (see report "Management measure analysis and comparison") and the valuation study (Liekens et al 2013), first steps to include an ecosystem service assessment are taken based on the ES analysis within TIDE. These assessments aim to widen the scope of measure assessments, from strictly technical or strictly red list species approaches to a more integrative assessment directed towards socio-economic effects. It is essential to focus on tangible, concrete projects and increase data availability to perform any quantitative ES approach.
Not only could cost-effectiveness of measures be determined, but also the ecological sustainability and social fairness could be evaluated (see 9.2.2).

9.2 Future challenges

9.2.1 Ecosystem research

As pointed out in section 5.4, ecosystem services are produced by a complex and intertwined, difficult to delineate and open system which we call the ecosystem. Although large amounts of empirical data on parts of this system are available, and many of these data have been synthesized in models with varying degrees of applicability and confidence, these results are scattered and integration is essential. This is also the case for estuaries. TIDE has brought together experts, datasets and know-how on four estuaries.

The first task at hand is centralization and linking of this knowledge. Automatically, data gaps will be determined and scientific debates will emerge. These should be used as a guideline to generate hypotheses and perform research to tackle these uncertainties.
Second, functional production models have to be constructed per ecosystem service. This requires integration of coupled existing models and empirical relationships per ES, complemented with scientific expertise to obtain a functional production model per ES. When constructing these production models, the focus will be on intermediate services.
Third, probabilities for all model relationships have to be determined: for empirical data confidence intervals can be used, while for expert data accordance and amount of expert evidence can be assessed. This process is necessary to determine final probabilities of estimates for each service production.
Fourth, ES production models have to be merged. This allows capturing first level trade-offs, determination of tipping points for delivery of (parts of) the ES bundle, and determine the impact of pressures exerted by use/harvest of services.
Last, but by far not least, these results have to be translated in clear estimate of ES production *differences* (including the ranges) *between given situations or scenarios*. This is essential input for valuation and fully informed decision making.

There is a fundamental difference when a service is expressed in different units. For instance, flood water storage as a storage volume will be very similar throughout the estuary, but the *effect* (or the benefit) on flood protection depends on other factors like the local (storm flood) volume of water in the estuary: a same area can have a large benefit upstream, but a very small one at the mouth where the estuarine volume is larger. The same holds for nutrient removal, as a marsh could remove the same amount of nitrogen per hectare upstream or downstream, but the local concentration and load of nitrogen in the estuary will differ, hence the final amount removed. A 'distance to target' indicator would be needed for all ES. Moreover, the demand (e.g. number of properties where a flood risk is present) also varies spatially. These spatial relationships are essential to take into account, and the choice of parameters is important in determining the outcomes.
The central idea is that the risk of exceeding local thresholds (water quality, water levels,…) can be reduced as well as realization benefits (reduction of loads, flood protection,…) further down- or upstream or for the estuary in general.

9.2.2 Valuation research

Ecosystem services have to be valued in order to make choices. This value or importance is not easy to determine. As Maris and Bechet (2010) point out, values are contextual, relative to a certain place, a certain time, and a certain group of people is facing a problem and is engaged in collective action. As Costanza (2000) puts it: 'we humans have to make choices and trade-offs concerning ES and this implies and requires valuation, because any choice between competing alternatives implies that the one chosen was more highly valued.

The use of the economic valuation of ES is well recognized but many ecosystem services are absent from a real market and thus require a non-market valuation: assessing values in the absence of an *actual* market. One approach is demand-oriented, by measuring the level of willingness-to-pay (e.g., contingent valuation). The other approach is supply/cost-oriented. Third, the embodied energy approach measures energy used directly and indirectly to value ecosystem services. According to Costanza and Folke (1997), the valuation of ecosystem services occurs in three ways: ecological sustainability (S-value), economic efficiency (E-value) and social fairness (F-value). Dendoncker et al (2013) therefore propose a three pillar valuation framework. Valuation can be seen has the final step before decision making: It translates the consequences of maintaining the status quo and opting for each alternative into comparable units of impact on human well-being, now and in the future. it consists of efficiency, sustainability and equity.

Economic valuation uses a broad range of techniques to evaluate efficiency of scenarios. Valuation thus targets *changes* in supply of ES, which can be compared between scenarios in order to choose the more efficient one. This comparison occurs on two levels: costs and benefits. Both can be compared "as is" (e.g. number of people protected from flooding, area of marshes with high biodiversity) or translated in monetary terms. This monetary approach is often very eye-opening, but it has to be applied with care and involves many uncertainties.

Adopting a strictly benefit-oriented approach risks an over-concentration on changes in benefits which places underlying ecological assets at risk (Turner, 1999), thereby risking over-exploitation and system change or collapse (e.g. focusing on the fish only and neglect functions as water quality, breeding areas etc. leads to the overexploitation as we know today, Liekens et al 2013). This has to be guarded against by imposing the constraint that ecosystem assets are not run down to unsustainable levels and by valuing bundles of ecosystem services rather than a single service (TEEB, 2010).

Also, the quantification of the risk to reach tipping points is an essential challenge. As *Risk = Chance * Damage*, this involves both probabilities derived from research described in section 9.2.1 as valuation of the eventually occurring losses. This gives a pragmatic and measurable interpretation to the intuitive and theoretical concept of carrying capacity and resilience which are key in reaching a sustainable management.

9.3 Conclusion

The Ecosystem services approach offers a pragmatic, rational approach to biodiversity management and an opportunity to sustainably manage natural capital for human benefits. The societal demand for regulating services to cope with growing risks of lowered ecosystem functioning is growing, especially in coastal zones and estuaries which are/will be subjected to effects of climate change. Such a rational approach is therefore needed.

This report presents an overview of demand and supply of ES in four estuaries. It allows for their comparison and linkage to their specific functional characteristics. Trade-offs and synergies, historical value estimates, and ES impacts of estuarine measures are provided.

These results can be used in different fields of estuarine management.

- Improvement of knowledge on ES in general, addressing of knowledge gaps and further pooling of expertise.
- For the implementation of measures: which habitats should be maintained/ restored in order to stimulate certain ES, or how to obtain the maximum supply of the entire bundle of ES.
- For decision making processes: which ES are important or less important for the vision on a certain estuary or for the respective society/residents.
- For estuarine governance: synergies and conflicting aims (with other processes) can be deduced.

There are however important challenges in ecological research, valuation as well as governance to obtain an ecosystem based planning and management. However, the current knowledge and this ES assessment provides ample reasons to avoid negative effects from single-benefit directed estuarine measures.

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11 References

Barbier, Edward B., Sally D. Hacker, Chris Kennedy, Evamaria W. Koch, Adrian C. Stier, and Brian R. Silliman. “The Value of Estuarine and Coastal Ecosystem Services.” Ecological Monographs 81, no. 2 (May 2011): 169–193.

Bianchi, T. 2007. Biogeochemistry of Estuaries. Oxford University Press, Oxford.

Brown, Thomas C. “The Concept of Value in Resource Allocation.” Land Economics Vol. 60, no. No. 3 (August 1984): 231–246.

Bryan, Brett A., Agnès Grandgirard, and John R. Ward. “Quantifying and Exploring Strategic Regional Priorities for Managing Natural Capital and Ecosystem Services Given Multiple Stakeholder Perspectives.” Ecosystems 13, no. 4 (May 25, 2010): 539–555.

Burkhard, B., Kroll, F., Nedkov, S., Müller, F., 2012. Mapping ecosystem service supply, demand and budgets. Ecological Indicators 21, 17–29.

Burkhard, Benjamin, Irene Petrosillo, and Robert Costanza. “Ecosystem Services – Bridging Ecology, Economy and Social Sciences.” Ecological Complexity 7, no. 3 (September 2010): 257–259.

Chmura, G. L., Anisfeld, S. C., Cahoon, D. R., and Lynch, J. C.: Global carbon sequestration in tidal, saline wetland soils, Global Biogeochem. Cycles, 17(4). doi:10.1029/2002GB001917.

Cortina. J. M. (1993). What is coefficient alpha? An examination of theory and applications. Journal of Applied Psychology, 78, 98–104.

Costanza, R. 2000. Visions of alternative (unpredictable) futures and their use in policy analysis. Conservation Ecology 4(1): 5.

Costanza, R., Folke, C., 1997. Valuing ecosystem services with efficiency, fairness and sustainability goals. In: Daily,G. (Ed.),Nature's Services: Societal Dependence on Natural Ecosystems. Island Press, Washington, D.C., pp. 49 – 68

Cronbach, L. J. (1951). Coefficient alpha and the internal structure of tests. Psychometrika, 16(3), 297–334.

Crooks, S., Emmett-Mattox, S., Findsen, J., 2010. Findings of the National Blue Ribbon Panel on the Development of a Greenhouse Gas Offset Protocol for Tidal Wetlands Restoration and Management: Action Plan to Guide Protocol Development. Restore America’s Estuaries, Philip Williams & Associates, Ltd., and Science Applications International Corporation.

Daily, G. C. “ECOLOGY: The Value of Nature and the Nature of Value.” Science 289, no. 5478 (July 21, 2000): 395–396.

Daily, G. C., S. Alexander, P. R. Ehrlich, L. Goulder, J. Lubchenco, P. A. Matson, H. A. Mooney, et al. Ecosystem Services: Benefits Supplied to Human Societies by Natural Ecosystems. 2. Ecological Society of America Washington (DC), 1997. http://www.wms.org/biod/value/EcosystemServices.html.

Day, J. W., Hall, C. A. S., Kemp, W. M. & Ya´n˜ ez-Arancibia, A.1989 Estuarine Ecology. John Wiley & Sons, Inc., (eds). New York, Chichester, Brisbane, Toronto, Singapore, 558 pp.

de Groot, R., et al., Global estimates of the value of ecosystems and their services in monetary units. Ecosystem Services, 2012. 1(1): p. 50-61.

Dendoncker,N.; Keune, H. & Jacobs, S. (2013) Integrated Ecosystem Services Valuation in: Jacobs, S.; Dendoncker N. & Keune, H. (Ed.), Ecosystem service debates – reflections from the community of science and practice in Belgium. (in preparation)

Fisher, Brendan, R. Kerry Turner, and Paul Morling. “Defining and Classifying Ecosystem Services for Decision Making.” Ecological Economics 68, no. 3 (January 2009): 643–653.

Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz and R. Van Dorland, 2007: Changes in Atmospheric Constituents and in Radiative Forcing.In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change[Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

George, D., & Mallery, P. (2003). SPSS for Windows step by step: A simple guide and reference. 11.0 update (4th ed.). Boston: Allyn & Bacon.

Granek, Elise F., Stephen Polasky, Carrie V. Kappel, Denise J. Reed, David M. Stoms, Evamaria W. Koch, Chris J. Kennedy, et al. “Ecosystem Services as a Common Language for Coastal Ecosystem-Based Management.” Conservation Biology 24, no. 1 (February 2010): 207–216.

Green, S. B., Lissitz, R.W., & Mulaik, S. A. (1977). Limitations of coefficient alpha as an index of test unidimensionality. Educational and Psychological Measurement, 37, 827–838.

Halpern, B. S., S. Walbridge, K. A. Selkoe, C. V. Kappel, F. Micheli, C. D’Agrosa, J. F. Bruno, et al. “A Global Map of Human Impact on Marine Ecosystems.” Science 319, no. 5865 (February 15, 2008): 948–952.

Kline, P. (1999). The handbook of psychological testing (2nd ed.). London: Routledge

Koch, Gary G. (1982). "Intraclass correlation coefficient". In Samuel Kotz and Norman L. Johnson. Encyclopedia of Statistical Sciences. 4. New York: John Wiley & Sons. pp. 213–217.

Liekens Inge, De Nocker Leo, Broekx Steven, Aertsens Joris (2013)

Liekens Inge, De Nocker Leo, Broekx Steven, Aertsens Joris (2013) Ecosystem services and their monetary value in: Jacobs, S.; Dendoncker N. & Keune, H. (Ed.), Ecosystem service debates – reflections from the community of science and practice in Belgium. (in preparation)

Liekens, I. & S. Broekx, 2013B. Guidance for valuation of ecosystem services in estuaries. VITO, commissioned by Antwerp Port Authority (APA)

Lockwood, M. (1999). Humans valuing nature: synthesising insights from philosophy, psychology and economics. Environmental Values, 8, 381-401

Lotze, H. K. “Depletion, Degradation, and Recovery Potential of Estuaries and Coastal Seas.” Science 312, no. 5781 (June 23, 2006): 1806–1809.

Luck, G. W., G. C. Daily, and P. R. Ehrlich. 2003. Population diversity and ecosystem services. Trends in Ecology & Evolution 18 (7):331-336.

Luck, G. W., R. Harrington, P. A. Harrison, C. Kremen, P. M. Berry, R. Butger, T. P. Dawson, F. De Bello, S. Diaz, C. K. Feld, J. R. Haslett, D. Hering, A. Kontogianni, S. Lavorel, M. Rounsevell, M. J. Samways, L. Sandin, J. Settele, M. T. Sykes, S. Van Den Hove, M. Vandewalle, and M. Zobel. 2009. Quantifying the contribution of organisms to the provision of ecosystem services. BioScience 59 (3):223-235.

MA. 2005. Millenium Ecosystem Assessment. Ecosystems and Human Well-being: Synthesis.

Maris, Virginie, and Arnaud BéChet. “From Adaptive Management to Adjustive Management: A Pragmatic Account of Biodiversity Values.” Conservation Biology 24, no. 4 (February 11, 2010): 966–973.

McDonald, R. P. (1999). Test Theory: A Unified Treatment, Erlbaum, pp. 90–103.ISBN 0805830758

Miedema, S. Kwalitatieve en kwantitatieve methoden van pedagogisch onderzoek: Enkele invalshoeken. Nederlands Tijdschrift voor Opvoeding, Vorming en Onderwijs 4, 263-272. 1988.

Norton, Bryan G., and Bruce Hannon. “Environmental Values: A Place-based Approach.” Environmental Ethics 19, no. 3 (1997): 227–245.

Nunnally, J. C. (1978). Psychometric theory (2nd ed.). New York: McGraw–Hill.

Revelle, W. (1979). Hierarchical cluster analysis and the internal structure of tests. Multivariate Behavioral Research, 14, 57-74.

Schmitt, N. (1996). Uses and abuses of coefficient alpha. Psychological Assessment, 8, 350–353.

Shrout, P.E., & Fleiss, J.L. (1979), Intraclass correlation: uses in assessing rater reliability. Psychological Bulletin, 86, 420-428.

Smaling,A. (2004) Methodologische objectiviteit en kwalitatief onderzoek. Swets & Zeitlinger.

TEEB, 2010. The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A Synthesis of the Approach, Conclusions and Recommendations of TEEB.

Turner, R.K. (1999) The place of economic values in environmental valuation. In I.J. Bateman and K.G. Willis (eds.) Valuing Environmental Preferences, Oxford University Press, Oxford.

Van Crombrugge, H. 2002. Fundamentele Pedagogiek II; 2.8.: Wetenschappelijke Kwaliteit van de Methode. Studentennota's. Faculteit Psychologie en pedagogische wetenschappen UGent.

Van IJzendoorn, M. H. 1988. De navolgbaarheid van kwalitatief onderzoek: Methodologische uitgangspunten. Nederlands Tijdschrift voor Opvoeding, Vorming en Onderwijs 4[280], 288.

Van IJzendoorn, M. H. en Miedema, S. 1986. De kwaliteit van kwalitatief onderzoek. Pedagogische Studien 63, 498-505.

Worm, B., E. B. Barbier, N. Beaumont, J. E. Duffy, C. Folke, B. S. Halpern, J. B. C. Jackson, et al. "Impacts of Biodiversity Loss on Ocean Ecosystem Services." Science 314, no. 5800 (November 3, 2006): 787–790.

Zinbarg, R., Revelle, W., Yovel, I. & Li, W. (2005). Cronbach's , Revelle's , and McDonald's : Their relations with each other and two alternative conceptualizations of reliability. Psychometrika, 70, 123–133.

Zinbarg, R., Yovel, I., Revelle, W. & McDonald, R. (2006). Estimating generalizability to a universe of indicators that all have an attribute in common: A comparison of estimators for . Applied Psychological Measurement, 30, 121–144.

APPENDIX I

Respondents survey I

Scheldt Estuary

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Elbe Estuary

- Bernd Netz/ Schleswig Holstein, Integrated station lower Elbe/ Expertise:, biology, N2000 management plan for the Elbe estuary
- Dr. Elisabeth Klocke/Hamburg, Ministry of Urban Development and Environment (BSU)/ Expertise: chemistry, N2000 management plan for the Elbe estuary
- Sabine Burckhardt/ Lower Saxony, Lower Saxony Water Management, Coastal Defence and Nature Conservation Agency (NLWKN)/Expertise: landscape planning, N2000 management plan for the Elbe estuary
- Dr. Boris Hochfeld/ Hamburg Port Authority/Expertise: soil science, geography, N2000 management plan for the Elbe estuary
- Mrs. Dr. A. Seifert/ Hamburg Port Authority/Expertise: soil science, civil engineering
- Dr. Henrich Röper/ Hamburg Port Authority/Expertise: environmental engineering, sediment management
- Sonja Wild-Metzko/ Hamburg Port Authority/Expertise: agricultural engineering, WFD, MSFD
- Manfred Meine/ Hamburg Port Authority/Expertise: civil engineering
- Maja Schmidt/ Hamburg Port Authority/Expertise: hydrology, hydraulic engineering
- Dr. Kirsten Wolfstein/ Hamburg Port Authority/Expertise: hydrobiology, estuarine ecology

Weser Estuary

- Dirk Hürter / position: Civil Servant, Bremen Ministry for Environmental Affairs, Construction and Transport / expertise: nature conservation/ landscape development, integrated management planning
- Kay Hamer / position: Senior Researcher, Project Manager, Lecturer, University Bremen / expertise: Assessment of sediments, products and groundwater considering the fate of pollutants and nutrients; ground water management; treatment technologies for polluted sediments; national implementation of groundwater directive

(2006/118/EG); consulting considering surveillance and operational monitoring in groundwater

- Jochen Kreß / position: Environmental Policy Officer, Bremen Ministry of Economic Affairs, Labor and Ports / expertise: ports, shipping, nature conservation, ecology
- Dr. Wilfried Heiber / position: Scientific Assistant Lower Saxony Water Management, Coastal Defense and Nature Conservation Agency (NLWKN) / expertise: ecology-hydro morphology interactions, water quality, implementation of WFD, ICZM
- Dr. Jürgen Schröter / position: Senior scientist University Kiel and Bremen / expertise: Geology, Hydrogeology, Environmental sciences, hydro/geochemistry, hydraulic modeling, transport behavior of pesticides and other substances including inorganic and organic contaminants
- Sonja Saathoff / position: Scientific Assistant Lower Saxony Water Management, Coastal Defense and Nature Conservation Agency (NLWKN) / expertise: ecology, measure planning and implementation, WFD, especially regarding Weser estuary

Humber estuary

- Nick Cutts (IECS) Estuarine Scientist
- Krystal Hemingway (IECS) Estuarine Scientist
- Philip Winn (Environment Agency) Estuarine Manager (Flood Risk and Protection Management)
- Sue Manson (Environment Agency) Estuarine Manager (Flood Risk and Protection Management)
- Phil Proctor (Environment Agency) Estuarine Management (Ecosystem Services & WFD Delivery)
- Tom Jeynes (Associated British Ports) Port Operator and Statutory Body (Environmental Compliance of the Humber Ports)
- Tania Davey (Humber Management Scheme) Integrated Estuary Manager (User Community Manager – e.g. environment, industry, recreation etc)
- Tim Page (Natural England) Natura Site Manager (Favourable Condition Assessment)

Appendix II

Respondents survey II

Scheldt Estuary

- Dr. Sander Jacobs, post doc researcher, University of Antwerp, research group ecosystem management.
- Annlies Boerema, PhD researcher, University of Antwerp, research group ecosystem management and researcher at Antwerp Port Authority.

Elbe Estuary

- Dr. Kirsten Wolfstein/ Hamburg Port Authority/Expertise: hydrobiology, estuarine ecology
- Ulrich Ferk / Hamburg Port Authority/Expertise: geography, hydrology
- Johanna Knüppel/ Hamburg Port Authority/Expertise: biology, environmental engineering
- Dr. Henrich Röper/ Hamburg Port Authority/Expertise: environmental engineering, sediment management
- Wiebke Schönberg/ University Hamburg, Inst. of Botany/Expertise: geography, vegetation of the Elbe estuary

Weser Estuary

- Dr. Wilfried Heiber / Scientific Assistant Lower Saxony Water Management, Coastal Defence and Nature Conservation Agency (NLWKN) / ecology-hydromorphology interactions, water quality, implementation of WFD, ICZM
- Sonja Saathoff / Scientific Assistant Lower Saxony Water Management, Coastal Defence and Nature Conservation Agency (NLWKN) / ecology, measure planning and implementation, WFD, especially regarding Weser estuary

Humber estuary

- Sue Manson / FCRM Advisor (Humber) Yorkshire and North East Region Environment Agency / Hydrology and geomorphology
- Nick Cutts / Deputy Director Institute of Estuarine & Coastal Studies / estuarine ecology
- Krystal Hemingway / researcher Institute of Estuarine & Coastal Studies / estuarine ecology