A participative ecosystem service mapping of four industrialized estuaries

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ABSTRACT

The TIDE project (Tidal River Development, EU - INTERREG IVB North Sea Region Programme) aimed at developing an integrated management vision and scientific inter-estuarine comparison, based on data and expertise from four intensively used NW European estuaries: the Scheldt (Belgium), the Elbe (Germany), the Weser (Germany) and the Humber (UK). As a first step, a screening of ecosystem services was performed, using expert surveys. The surveys provide an inventory of local demand and supply maps of ecosystem services in each estuary, distinguishing salinity zones and main habitats.

The assessment allowed to determine trade-off risks and synergy opportunities between ecosystem services. Internal consistency and accordance tests suggest that the supply data as well as the general assessment methodology are applicable in similar estuaries.

Performing an ecosystem service assessment with scientists and participation of a broad stakeholder group yielded a complete overview of ecosystem services, rose awareness on the importance of regulating and supporting services among estuarine managers, and was effective in setting the starting point for integrated assessment and management of estuaries.

KEY WORDS: *Ecosystem services, estuarine management, participative survey, mapping.*

INTRODUCTION

Ecosystem services (ES) are defined as 'the benefits which people derive from nature' (Costanza, 1997; MA, 2005), or more precisely '*the aspects of ecosystems, utilized actively or passively, to produce human well-being*' (Fisher *et al.*, 2009). The field of ES aims to classify, describe and assess these natural assets, their demand and supply functions, quantification, valuation and management. ES are currently categorized in provisioning, regulating, and cultural services. All of those are eventually generated, supported and ensured by ecosystems in all their diversity (supporting services or broadly defined biodiversity) (MA, 2005; TEEB, 2010).

Estuaries and coastal marine ecosystems are among the most productive biomes of the world, and serve important life-support systems for human beings (Day *et al.,* 1989). Estuaries support many important ecosystem functions: biogeochemical cycling and movement of nutrients, purification of water, mitigation of floods, maintenance of biodiversity, biological production, etc. (Daily *et al.,* 1997).

Many estuaries are of tremendous economic and social importance. Consequently, they are some of the most heavily used and threatened natural systems globally (Lotze *et al.,* 2006; Worm *et al.*, 2006; Halpern *et al.*, 2008), and deterioration due to human activities is intense and increasing. This has a direct impact on the services delivered by estuaries.

Assessing and valuing ES is critically important for improving estuarine management and designing better integrated policies (Barbier *et al.*, 2011). Particularly in estuaries, where ecosystem functioning is inherently complex, many data gaps exist and management decisions affect a multitude of societal groups (Granek *et al*., 2010), many benefits have not been estimated reliably, and even for those services that have been valued, only a few dependable studies have been conducted (Barbier *et al*., 2011).

Within the TIDE project, a participative ecosystem service screening was performed to obtain a spatial inventory of demand, supply and interdependences of ES, and to raise awareness on ecological and socio-economic complexity among estuarine decision makers and managers.

METHODS

All four TIDE estuaries - the Scheldt (Belgium), the Elbe (Germany), the Weser (Germany) and the Humber (UK) – are situated in densely populated areas, and consist of major transport and industry hubs, while in the same time a full salinity gradient and tidal dynamics in the main channel were preserved. Similar uses and systemic features provoke typical conflicts between nature conservation, recreation, port accessibility, dredging activities, protection from flooding, etc.

In order to select key ES from a drafted longlist (48 ES) and obtain an estimate of service demand, the value (sensu Costanza, 2000: appraised value or "importance for society") of services was scored by a broad selection of 27 professional respondents. This corresponds to the concept of assigned values (Brown, 1984; Lockwood, 1999) as applied by Bryan *et al.* (2010). As the confidence and legitimacy of survey results depends on the representativeness of the respondents, this demand survey was conducted in the TIDE regional working groups of each separate estuary, which consisted of experts from different institutions being familiar with the characteristics of the estuary, and expertise fields in ecology, hydrology, sediment management, engineering, European directives, etc. The number of respondents per estuarine group and their expertise level ranged widely. Groups were asked to provide a consensus demand score for 48 ES, in order to select key services for further consideration and to explore patterns in ES demand. (1-don't know; 2-unimportant; 3-less important; 4-important; 5-very important). This was scored per estuary for every salinity zone (fresh-oligohaline-mesohaline-polyhaline), and for historical (<1930), present and future (1950) timeframes.

For the supply of services, an adapted approach from Burkhard *et al.* (2010, 2012) was used, where supply values were scored by 12 specialized respondents. A habitat x ecosystem service matrix was created, distinguishing six habitat types as service providing units (Luck *et al*. 2003, 2009) based on elevation and slope (Table 1).

Table 1: Common habitat definition based on physical parameters

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

The habitat x ES matrix consisted of 6 habitat types and 20 ES (120 intersections) and was scored for each salinity zonation in each estuary yielding in total 16 matrices of 120 scorings each (1920 combinations). Scorings were defined as "*importance of the habitat in supply of ES*" (1-not important; 2-very low importance; 3-moderate importance; 4-important; 5-essential).

An often overlooked aspect in using expert data are the statistical checks of consistency and agreement among respondents (or 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 backgrounds. This is crucial before interpreting results of the survey, but also to verify whether data can be extrapolated to other systems.

Three different tests were applied here. First, the Cronbach's alpha (Cronbach, 1951; George *et al.,* 2003; Kline, 1999) coefficient of reliability, which is commonly used as a measure of the internal consistency or reliability in the social sciences, business, nursing, and other disciplines, was applied. Secondly, the intraclass correlation coefficient (abbreviated ICC, Koch, 1982) was applied to assess agreement and consistency of scores made over different classes. Finally, as alpha (or ICC) can return high values even when several unrelated latent constructs are measured (e.g., Cortina, 1993; Green *et al.,* 1977; Revelle, 1979; Schmitt, 1996), it is only appropriately used when the items measure different areas within a single construct. Therefore, the coefficient omega_hierarchical (omegaH) is more appropriate (McDonald, 1999; Zinbarg *et al.*, 2005). If our estuaries are similar entities of "the industrialized estuary", the omegaH should yield about the same result as alpha and ICC. All tests were performed in R package multilevel version 2.3.

Patterns emerging from the surveys were visually analyzed and detailed expertise of respondents was registered to ensure traceability of the results.

ES which were averagely scored 'important for society' were further considered and spatiotemporal patterns in their demand and supply analyzed. Supply scores were applied to visualize ES supply for each estuary (cfr. Burkhard, 2012), and to explore potential trade-offs.

Potential trade-offs were then calculated by comparing the an optimized habitat configuration for supply of single services. The differences between ES-supply habitat distribution visualizes potential trade-offs. For instance complete optimization to navigation service would imply creating deep subtidal habitats at the cost of shallow, intertidal and marsh habitats (and delivery of their services). The indicator used is thus the sum of the habitat's differences in supply between services or:

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

With:

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

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.

RESULTS

Ecosystem service demand

The demand survey has an acceptable reliability (alpha: 0.798), inter-estuarine consistence (ICC-c: 0.798) and agreement (ICC-A: 0.792). Estuaries have also a high similarity concerning ES-demand (Omega-H: 0.77).

20 ES (average score > 'less important') were selected as "focal" (sensu Granek *et al.,* 2010) ES 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.

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 (Figure 1).

ES demand in the four estuaries is very similar, due to the fact that these estuaries are both ecologically as socio-economically alike. 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.

Demand 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. These higher demands can mostly 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.

Temporal variance is generally very low. The highest variance is observed in the flood control service. This demand is considered to increase following climate change and sea level rise.

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

Important Ecosystem Services in TIDE estuaries	Category
Food: Animals	Provisioning
Water for industrial use	Provisioning
Water for navigation	Provisioning
Climate regulation: Carbon sequestration	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 from catchment	Regulating
Erosion and sedimentation regulation by water bodies	Regulating
Erosion and sedimentation regulation by biological mediation	Regulating
"Biodiversity"	Supporting
Aesthetic information	Cultural
Opportunities for recreation & tourism	Cultural
Inspiration for culture, art and design	Cultural
Information for cognitive development	Cultural

Ecosystem service supply

The supply survey has an acceptable reliability (alpha: 0.7479), inter-estuarine consistency (ICC-C: 0.748) and accordance (ICC-a: 0.71). The high Omega-H (0.73) 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.

From the supply survey results, 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 (mostly) delivered by a broad range of habitats can be distinguished. Separate maps of every ES were produced (Figure 2).

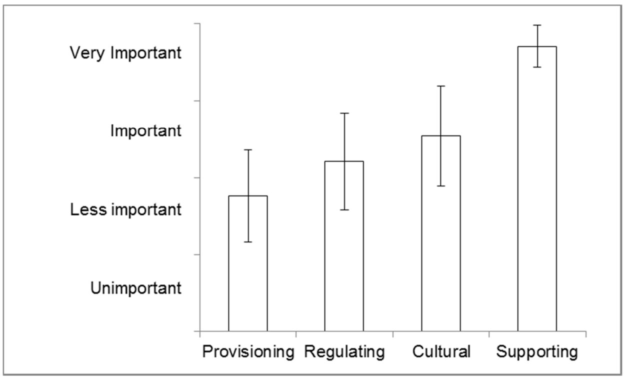

Figure 1: Importance scoring of ecosystem services from all four estuaries and zones per service category, with standard deviations of scorings.

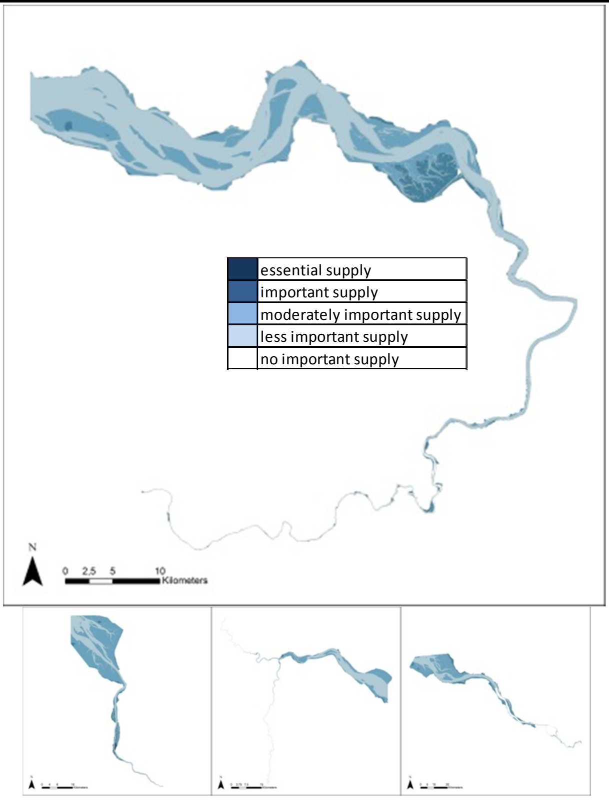

Figure 2: example map of ecosystem service supply: Reduction of excess nutrient loads in (upper left to lower right) the Scheldt, Weser, Humber and Elbe estuary, based on average habitat-specific supply scores per zone.

Scheldt

Provisioning services show a low supply in freshwater and oligohaline zones. High levels of pollution prevent consumption of fish and filter feeders from the estuary. Supply scores of provision of water and regulating functions for water quantity increase towards the mouth, while decreases in most other regulation services (regulation of extreme events and water quality) and supporting services were observed.

Weser

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 of the Weser. 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.

Humber

The very low proportion of tidal flats and even lower amounts of 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.

Elbe

The contribution of marsh habitat to ES supply decreases towards the mouth in favor of tidal flat habitat, impacting climate regulation and flood water storage services. 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.

Trade-offs and synergies

The trade-off risk analysis (Figure 3) situates the highest risks with supporting services "biodiversity"), exhibiting high trade-off risks with provisioning services and water quantity

	"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 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
"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

Figure 3: 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.

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 (e.g. cultural services, regulation of extreme events or disturbance,) and many potential synergies occur between (sets of) regulating services, cultural services and biodiversity.

CONCLUSIONS

The TIDE projects presents an screening of demand and supply of 20 ES in four North Sea estuaries (Elbe, Weser, Humber, Scheldt), including maps and analysis of trade-off risks and synergy opportunities between services. The scores per ES, habitat and salinity zone can be applied to map ES supply in similar estuaries, but local application of the survey method is advised.

The survey method was efficient in obtaining a broad and comparable overview of ES. It provided an inventory of available knowledge, gaps and scientific debates as a first step for detailed research. Performing the survey in debated consensus created awareness and dialogue on different socio-economic stakes among experts from research institutions, professionals from different administrations and decision makers.

The method can be improved by adding qualitative arguments to the scores given, herewith determining the amount and accordance of empirical evidence behind the scores and providing causal explanations which give input to functional quantification of ES. Average scores and maps from the first survey round can also be evaluated by the same experts in a second round to verify consensus. A first round using individual surveys would also be useful to get an idea of the agreement between individual respondents.

The ES approach offers a rational approach to nature management and an opportunity to sustainably manage natural capital. In complex socio-ecological systems as estuaries this approach is particularly useful. However, ecological functioning of supply functions, ecological sustainability and fair distribution of benefits are prerequisites to live up to these expectations. Apart from broad surveys and knowledge inventories, in depth research is required on several services, while implementation of the concept in existing decision structures and planning phases is needed.

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