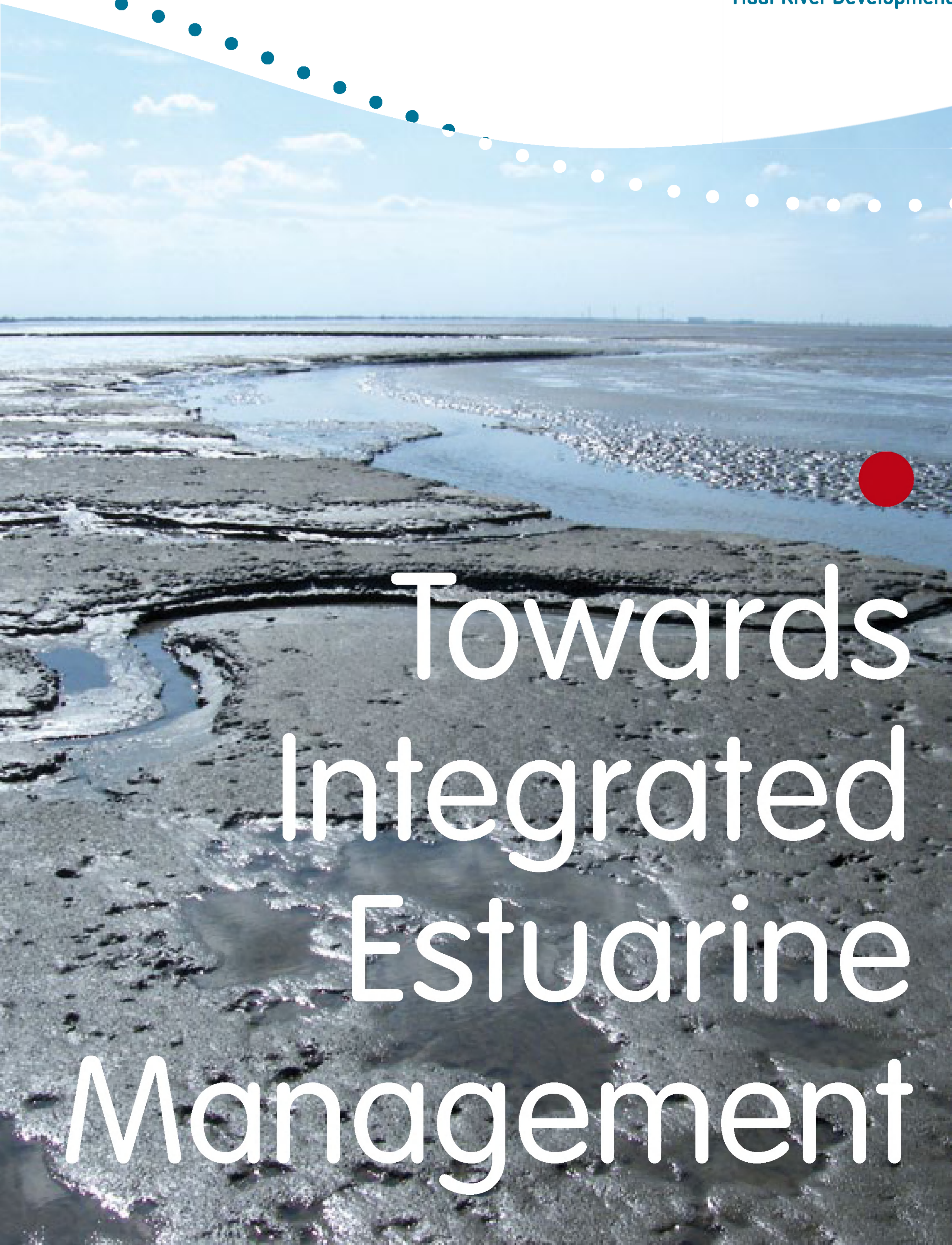
TIDE

Tidal River Development



Towards Integrated Estuarine Management

The North Sea Region Programme 2007–2013

European Union The European Regional Development Fund

TIDE
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March 2013

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Introduction

Different uses: Port of Hamburg, Elbe

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Why TIDE?

Estuaries are amongst the **most socio-economically and ecologically important environments** which support large urban, agricultural and industrial areas both surrounding the estuaries and in their catchments. They are the sites of many major cities and ports worldwide and have a high economic value for food production and recreation as well as nutrient and contaminant recycling. They are also important as nursery areas for many marine fishes and overwintering areas for waterbirds.

However, because of these often competing and conflicting uses and users, estuaries and their management face many challenges. Hence, the management of estuaries and their catchments has to ensure that their natural characteristics are protected and maintained, whilst at the same time ensuring the present and future delivery of ecosystem services and benefits required by society. In particular, valuable, productive and safe living and recreational space has to be safeguarded. **This 'big idea' is termed the Ecosystem Approach as defined by the global Convention on Biological Diversity.** The Ecosystem Approach is 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 levels of biological organisation which encompass the essential processes, functions and interactions among organisms and their environment. It recognises that humans, with their cultural diversity, are an integral component of ecosystems.

The four estuaries Elbe, Humber, Scheldt and Weser in the North Sea Region face similar challenges:

- They all support major cities and ports, are important shipping channels, have large catchments containing industry and agriculture, and have similar physical characteristics in being coastal plain estuaries with high tidal influence and high sediment transport.
- At the same time, they are conservation-designated Natura 2000 sites protected by EU legislation because of their habitats, large fish nursery areas and large populations of overwintering waterbirds.

As a result, the management of these systems is extremely challenging as it has to consider the different estuary functions, stakeholder and resident interests, and the implementation of the national and European legislative framework. As such, there are many types of existing (often sectoral) estuarine management plans. In order to be sustainable, the management of these dynamic and complex environments should lead to 'triple wins' – for ecology, economy and society.

Protected birds and fishes:

Common snipe, Freshwater lamprey.

© IBP Elbe Estuary

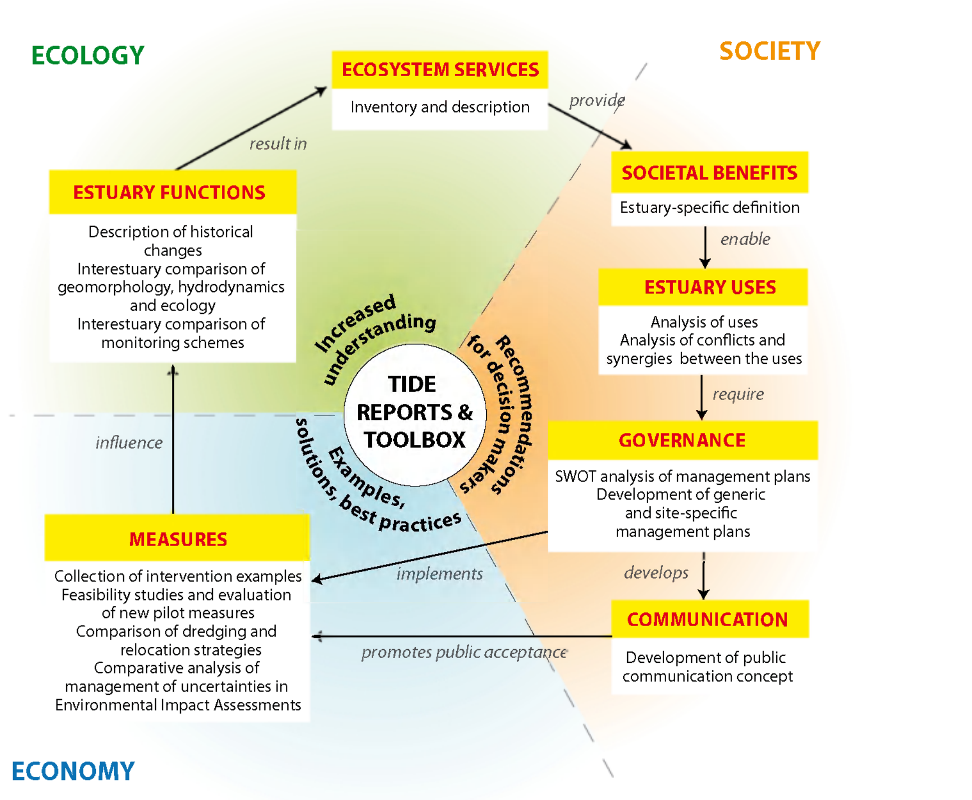
These common challenges led to the **EU INTERREG IV B project TIDE (Tidal River Development)**. TIDE addresses the necessary ingredients for a sustainable estuarine management strategy. The complexity of estuaries requires **integrated management** which is fundamental to achieving the Ecosystem Approach. This project has applied the concept of **Ecosystem Services** as a central element of an integrated management. This approach aims to preserve the natural functioning of the system whilst recognising humans as an integral component of the ecosystem.

Different uses: recreation & shipping (Weser).

© Nowara

TIDE has brought together relevant interdisciplinary scientific expertise and partners of various institutions related to estuarine science and management. TIDE has provided knowledge on estuarine functioning and the delivery of ecosystem services which in turn can provide societal benefits. Governance structures and related aspects of communication and public participation have been evaluated and restoration and management measures indicated as necessary. TIDE has also carried out an inter-estuarine comparison of most of these aspects showing how the different aspects of integrated management relate to each other. TIDE partners established and involved Regional Working Groups (RWGs) in particular activities such as determining the demand for ecosystem services, or using 'expert judgement' to determine estuarine-specific conflict matrices.

TIDE Approach



Yellow boxes refer to general processes taking place in the ecological, economical and societal realms of an estuary and the arrows point to the inter-relations between them.
White boxes refer to the activities to be conducted by the TIDE project in the framework of these various processes.

Tegeler Plate | Unterweser
© NLWKN

TIDE Messages

In recorded history, estuaries have had to accommodate both natural events and human demands such as space for settlement, agricultural and industrial land use, and supporting ports and navigation. This, together with a complicated governance framework, has resulted in a system of multiple uses which have often led to multiple conflicts. Here we provide the main results of TIDE addressing those challenges and giving our conclusions and recommendations.

Successful management and governance requires us to:

- **understand the dynamics and functioning of estuaries** in relation to both natural and anthropogenic features, and
- **to pass on this knowledge to estuarine managers.**

The TIDE project has shown that whilst the four estuaries differ from each other, they also have in common certain basic processes, structures and demands.

The TIDE studies have shown that different estuarine zones may have different functions, ecology and human uses. However, estuarine managers must consider the system as a whole when decisions have to be taken or management measures implemented; this will then achieve the most sustainable outcome and avoid conflicts between different uses. For example, adopting a Natura 2000 management plan which recognises the demands of society is already approaching a **holistic approach**.

As estuaries are dynamic systems, they need an **adaptive management** approach which accommodates natural development and anthropogenic demands and changes. TIDE emphasises that any management which cannot accommodate such changes will eventually either be costly or may not succeed.

1

The success of any management strategy and measure depends on whether its outcome is monitored appropriately, i.e. the right amount of the right parameters at the right location. The monitoring may be for operational reasons, e.g. to ensure a navigational route remains open or that industries comply with licences to operate in an environmentally safe manner, or merely to determine the overall health of the system, e.g. whether or not the ecology is in Favourable Conservation Status or Good Ecological Status according to respective European Directives. It is important that **monitoring programmes are cost-effective and fit-for-purpose** and should be integrated so that they not only allow evaluation of a management strategy or operational objective, but also allow a true understanding of the functioning and development of the whole estuarine system. All data should also be maintained in a common and widely-available database.

TIDE has shown that the successful implementation of management plans and measures requires an **appropriate communication strategy**, or at least providing substantial knowledge, in order to be accepted by the public and stakeholders.

An appropriate communication strategy should include:

- indicating the technical basis for any decisions;
- involving the concerned parties as early as possible;
- considering regional differences;
- increasing awareness of existing conflicts between various uses
- finding synergies, and
- adapting the communication and its language to the targeted audience and the media used.

However, we not only have to reach out to those with an interest but they should participate in the process to achieve the maximum possible acceptance of management plans and anticipated projects.

An integrated management approach should:

Summary

- **apply the Ecosystem Approach;**
- **use the ecosystem services approach to measure and communicate changes which can deliver societal benefits;**
- **accumulate and share knowledge of estuary structure and functioning;**
- **use best practice from similar cases;**
- **follow a holistic approach – consider the system as a whole;**
- **practice adaptive management;**
- **employ an appropriate and adaptive monitoring strategy, and**
- **apply an appropriate communication strategy.**

2

The four TIDE Estuaries

Zonation

Historical Evolution

The four TIDE Estuaries

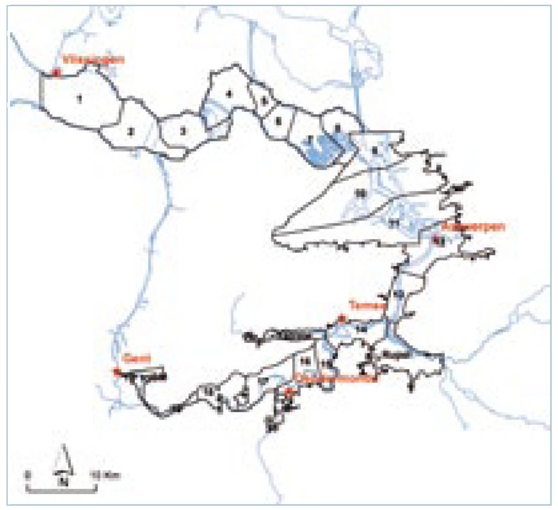
Zonation

The TIDE estuaries (**Scheldt**, **Elbe**, **Weser** and **Humber**) were directly compared to learn more about their functioning, governance and management measures. To ensure this was a valid exercise, comparable zones within the estuaries were considered. However, although management related for example to the Water Framework Directive, Natura 2000 Directives, macrocells concept (OMES) or spatial planning, already uses different zones, TIDE used its own modified zonation approach.

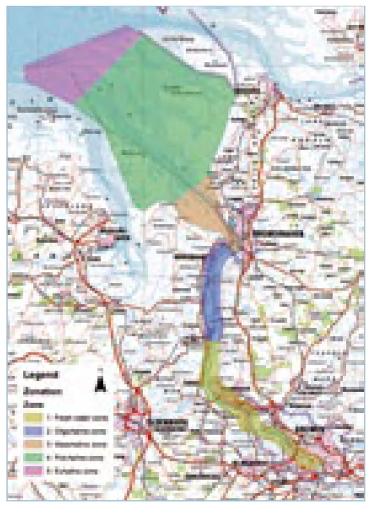
Selected examples of existing zonation

Humber estuary

Elbe estuary



Scheldt estuary



Weser estuary

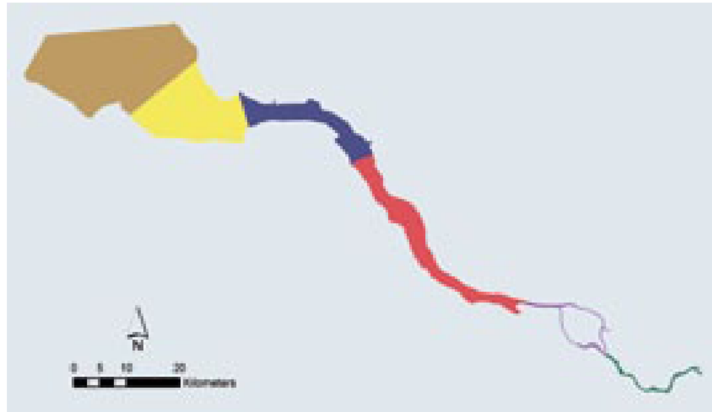
The TIDE zonation is based on the 'Venice system' which is related to different salinity levels extending from the freshwater (limnetic) zone to the polyhaline (euhaline) zone at the mouth of the estuary. Therefore salinity calculations were based on the median values of chlorinity for a 6 year period (2004-2009). The innermost limit of each TIDE estuary was the place of furthest tidal penetration. This allowed a better comparison between the four estuaries.

2

TIDE zonation

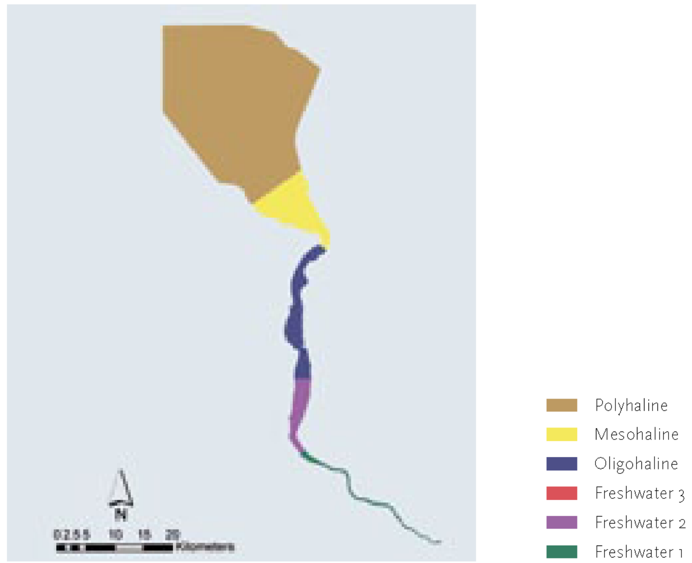
Humber estuary

Elbe estuary



Scheldt estuary

Weser estuary



Historical Evolution

Estuaries are very dynamic systems and have changed greatly during geological time, particularly over the last 3 centuries through both natural events as well as anthropogenic activities. Estuarine environments have been modified and managed by Man throughout human history – particularly in relation to protecting the landscape from flooding and erosion, to claim wetlands for agriculture and habitation (previously called 'reclamation'), and to allow and maintain navigation. In addition, North Sea estuaries have changed as the result of isostatic rebound, the adjustment of the Earth's surface in recovering from the last Ice Age, such that sea-level may apparently be rising because parts of eastern England, the Netherlands and the German Wadden Coast are sinking.

Each natural and human action has therefore changed the 'hydrogeomorphology' of the estuaries – the water movements, the underlying geology and sedimentology, and the shape of the estuaries. In particular, navigation became more important because the settlements developed into prosperous trading places reliant on these shipping routes.

We have modified the hydrogeomorphology of estuaries by:

- straightening and deepening;
- building dykes;
- claiming land for agriculture and habitation;
- protecting shorelines, and
- isolating/cutting-off tributaries and side channels.

Meanders Scheldt
© Dauchy

The loss of estuarine areas, as well as different types of habitats can be related to several anthropogenic impacts. In some estuaries, the isolation of tributaries from the main estuary can be considered as the primary cause of loss. Similarly, dyke construction (either for land-claim or for flood protection), reduces marsh area under tidal action.

The increased tidal penetration into the freshwater zones may have both increased tidal flats and the amount of subtidal habitats in both deep as well as shallow water areas. However, these effects may have been confounded by the straightening of watercourses and by 'coastal squeeze' where rising water levels are prevented from naturally creating new intertidal areas due to coastal defences.

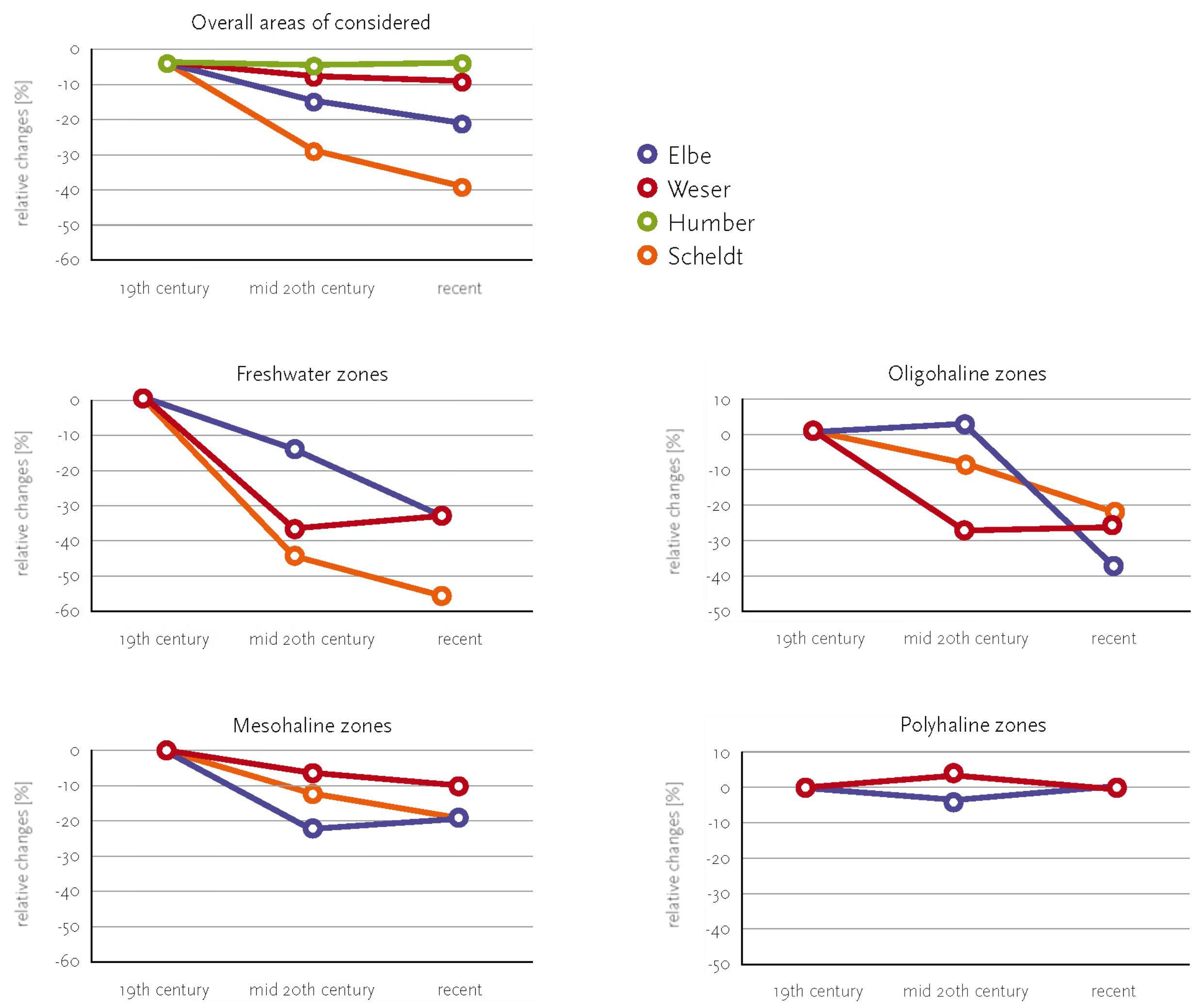
In hydrogeomorphological terms, such a change has reduced the resilience of estuaries to cope with further change in turn requiring further management measures. These changes have partly led to higher current velocities and further upstream penetration of the tides. To protect the catchment from those changes, higher dykes and weirs to cut off the tidal influence have been constructed. These management measures further altered the hydrological characteristics, leading to higher current velocities and in changes to sedimentation and erosion patterns. Subsequently, new measures were required such as stabilising the new estuary beds with shoreline structures, groynes and training walls and, where ports had been built in accreting and turbid areas, intensified maintenance dredging.

Mudflat
© Silinski

Analysis of change in TIDE estuaries

TIDE analysed the evolution of the four estuaries in three time steps: (1) to the end of 19th century, (2) to the mid of 20th century, and (3) in recent times. This allowed a comparison of the overall sizes of the estuaries, the areas relating to a particular salinity zone (see TIDE zonation), and different habitats within these zones.

Spatial changes within the TIDE estuaries (%)



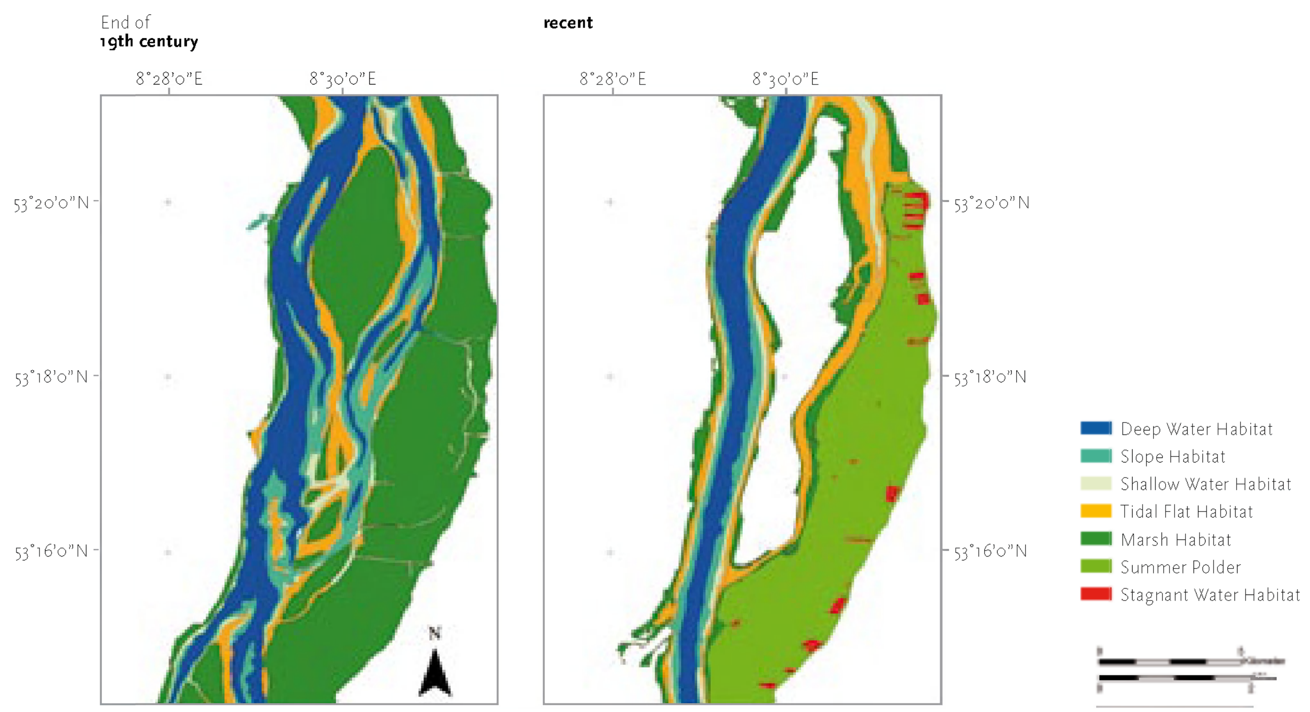
It is notable that the estuaries generally show the highest losses of area in the inner freshwater and oligohaline zones. In the meso- and polyhaline zones (the more seaward parts of the estuaries) less area has been lost with approximately similar losses and gains. In total, across all salinity zones, the **Elbe**, **Weser** and **Scheldt** show decreases of between 5–>30% of their area.

- Whilst the overall size of the **Humber** was greatly reduced during the 18th and 19th Century through land-claim for agriculture and port developments, more recently it has remained relatively stable. Highest losses had occurred in the oligohaline zone.
- In the **Scheldt**, over half of the freshwater area has disappeared, whilst in the mesohaline zone the loss is less than 20%.
- In the **Elbe**, 16% of the area has been lost in the last century, most of it in the freshwater zone. In contrast, the polyhaline zone has remained stable.

- The **Weser** shows a total loss of 4% in overall area, with one third of this in the freshwater zone. No substantial change was observed in the polyhaline zone.

The anthropogenic influence on the hydromorphological characteristics has changed habitat distributions in the estuaries. For example, at the end of the 19th century the **Weser** was a braided stream whereas it is now characterised by a deep fairway and increased intertidal areas.

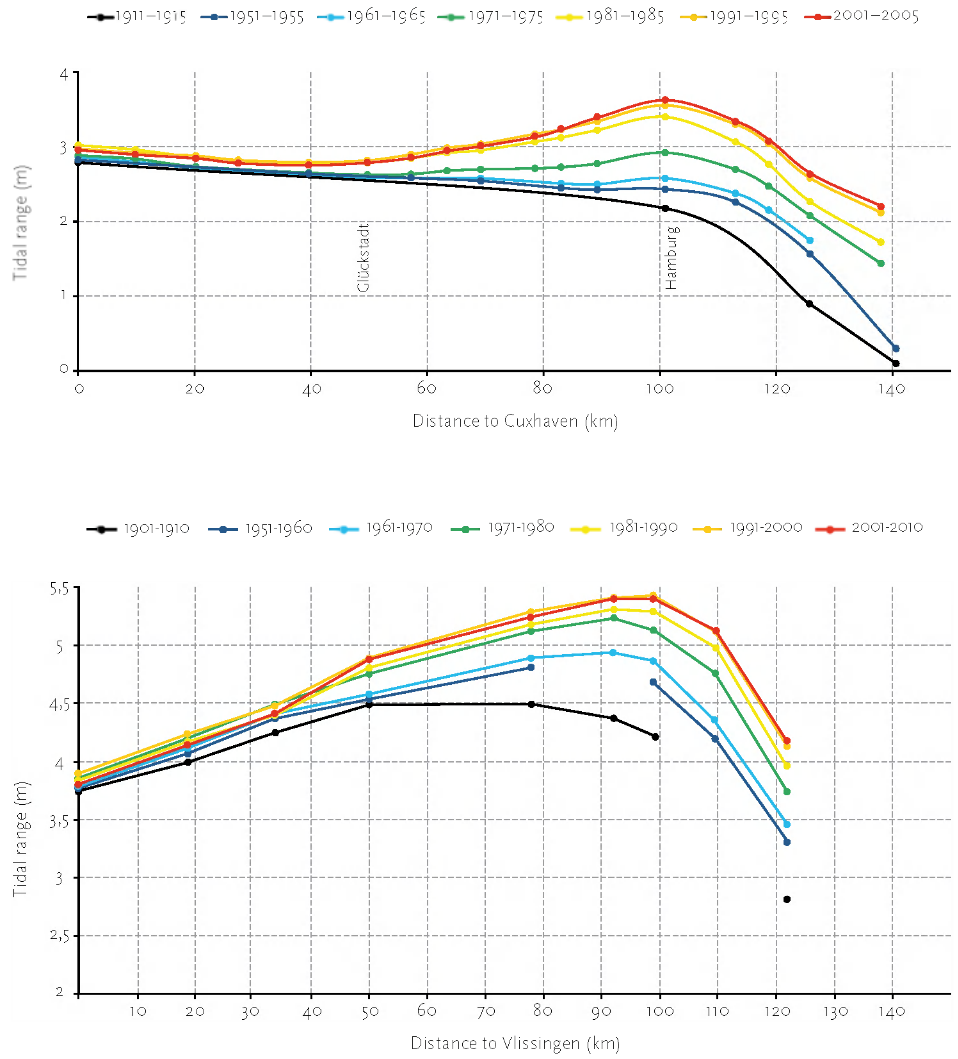
Changing habitat distribution in the Weser estuary at Harrier Sand



One of the many influences on the characteristics of the estuary bed habitat is the tidal range (the difference between mean high- and mean low water) which has increased at particular locations for example 'Harrier Sand' from 2m in the 19th century to the present 4m.

The **Elbe** and **Scheldt** estuaries showed a similar development to that of the **Weser**, with the greatest change in tidal range in the inner estuary during the last century, e.g. in the harbour area of the city of Hamburg. The tidal range in this area can be explained by the anthropogenic changes discussed above, the lack of a buffer area such as intertidal flats, and the sudden decrease of water depth upstream of the harbour.

Development of the **tidal range** in the Elbe and the Scheldt during the last century



These changes in hydromorphological features and in the abundance, quality and distribution of certain habitats in turn affect the estuarine ecological functioning. The flora and fauna depend on the presence and extent of different habitats and related environmental conditions which are the result of the hydrology, especially currents, tides and water residence times as well as the sedimentology, the erosion and deposition cycles and the position and extent of the turbidity maximum zone.

The four TIDE Estuaries

Summary

- **TIDE created its own consistent zonation approach for comparing the estuaries.**
- **All estuaries show highest losses of area in the inner estuary.**
- **The loss of estuarine area can be related to several anthropogenic impacts, e.g. isolation of tributaries, dyke construction, straightening and deepening.**
- **Changes in hydromorphological features have changed the abundance and distribution of certain habitats which area important for ecological functioning of the system.**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3

Estuary Functioning

Hydro-geomorphology

Filtering Functions

Primary Production

Dissolved Oxygen Levels

Habitats & Bird Distribution

Estuary Functioning

A fundamental knowledge of the physics, chemistry and biology of the system is required to effect successful and sustainable estuarine management. Comparisons in the fundamental scientific understanding between different estuaries can deliver new insights for estuarine management. TIDE has compared the system functioning of the four estuaries to show their similarities and differences. For example, this includes ecological processes such as primary production or the distribution of habitats which influence the occurrence of overwintering birds or nursery stages of fishes.

Hydro-geomorphology

Brackish Creek
© Herman

As ecological processes and habitat distribution are controlled by hydro-geomorphological variables, we need to extensively study the hydrology, morphology and ecology and their interactions.

An understanding of hydrogeomorphology has required data on widely-used parameters such as:

- riverine discharge,
- topography/bathymetry (drying areas, depth and other shape aspects of the system),
- tidal amplitude,
- current velocities,
- residence times,
- suspended matter, and
- habitat distribution.

In addition, some specific techniques (e.g. the **cubage technique** – calculating flow velocities based on topo-bathymetric data and water levels, and the **Dalrymple energy concept** – calculating energy terms based on water levels and flow velocities), were used to compare the driving forces behind the tidal amplitude (amplification or damping) and the energy distribution. This new knowledge allowed the basic description of the TIDE estuaries to be updated.

The hydrogeomorphological characteristics showed a **high variability between and within systems**. All estuaries showed tidal amplification (i.e. the tidal range increased together with its consequences) with a progression upstream in relation to morphological changes. This was more pronounced in the **Scheldt**, resulting in a maximal tidal range (TR, the difference between high and low tide) approximately halfway along the estuarine longitudinal distance. An important outcome of TIDE is that by analysing both the convergence (the degree of narrowing of the river bed), and the friction (the intrinsic resistance of the system against water movements), new basic insights were obtained to diagnose the causes of tidal amplification and damping. The **Elbe** combined low **convergence** with low **friction**, whilst the **Humber** was characterised by a large degree of **convergence** but also a large degree of **friction**. This created new insights such as tidal damping in an estuary became important once the estuary depth (as the cross-section averaged depth at low water) became lower than 4.2–7.7m.

Of the four estuaries, the **Elbe** is the only one in which tidal damping occurs within the estuarine mouth. Together with the relative low degree of estuarine convergence between the mouth and the city of Hamburg (meaning that the estuary is not as narrow in this section), this partly explains why the **Elbe** tidal range (below 4m) is the smallest of all TIDE estuaries.

The **Humber** is unusual in that the city of Kingston-Upon-Hull is situated at the transition between tidal amplification and (extreme) damping, resulting in a tidal range maximum.

The **Weser** shows moderate hydrological gradients, whilst the **Scheldt** shows maximum tidal amplification (explaining the large tidal range of more than 5m), thus indicating the greatest need for ecosystem regulating services to help reduce the strength of the estuarine hydraulic dynamics.

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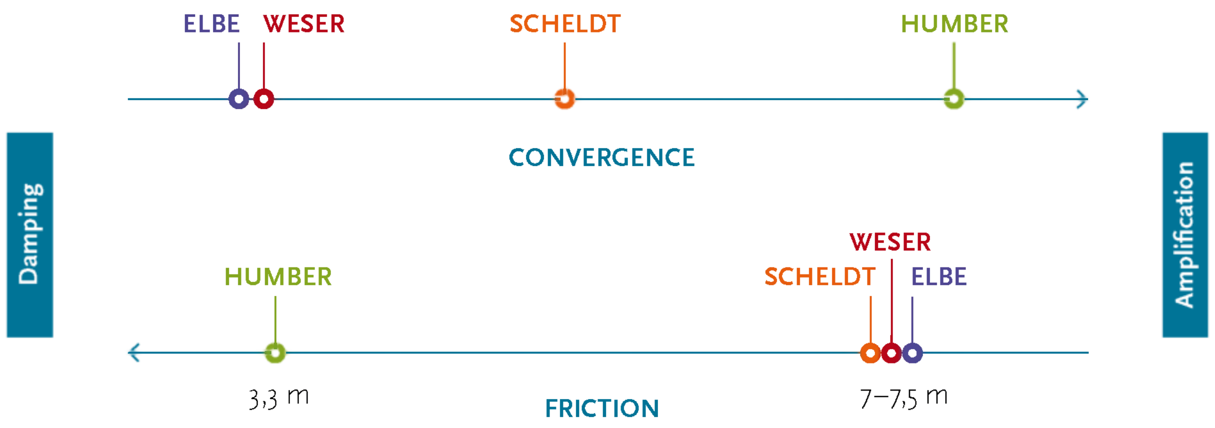
The relative amount of convergence and friction for the TIDE estuaries



The relative amount of convergence (or narrowing) and friction (or resistance against water movement) for the TIDE estuaries, two main factors determining if an estuary is damping or amplifying the tide. The numbers indicate the water depth at low tide on the location where friction occurred most.

Values and ranking of the 4 TIDE estuaries for a selection of hydro-geomorphological parameters

	Elbe	Weser	Humber	Scheldt
Maximum tidal range (mean tide) [m]	3,6	4,1	5	5,5
Tidal amplification				
Maximum TRx/TRo (o = mouth, x distance x until the mouth)	1,3	1,1	1,15	1,4
Maximum tidal range gradient [cm/km]	2,2	2	3,2	3
Tidal damping				
Minimum tidal range gradient [cm/km]	-5,5	-0,8	-7,5	-7,5
Maximum flood current [m/s]	1,3	1,3	1,9	1,5
Tidal asymmetry at the upstream border	1,6	1,4	-	1,7
Total freshwater discharge (mean) [m³/s]	722	331	209	107
Residence time of the water [days]				
High discharge	16	7	13	50
Mean discharge	29	11	27	92
Low discharge	63	27	69	247
Maximum difference in salinity between winter and summer	16	16	16	13
Estuary volume [billion m³]	1,45	0,4	0,94	2,85
Estuary surface [ha]	24010	9977	15757	35424
Relative subtidal deep area [%]	37	25	23	49
Relative intertidal flat area [%]	20	31	23	26
Relative marsh area [%]	22	34	4	8

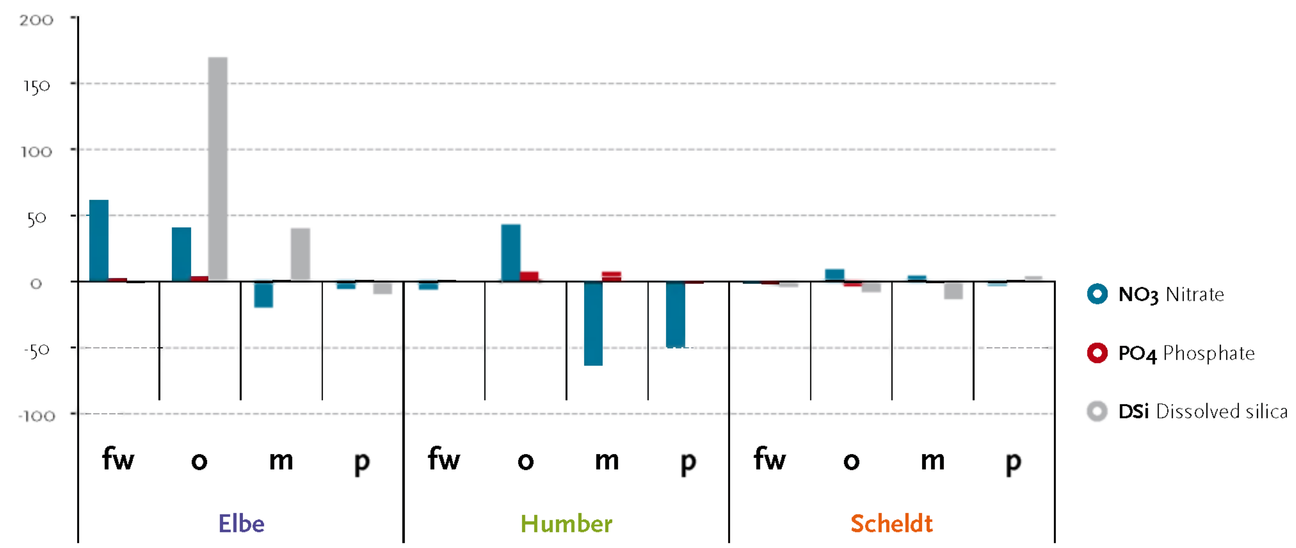
Filtering Functions

The oxygen concentrations in all estuaries were sufficiently high to support a normal estuarine food web, consisting of primary producers such as micro- and macro-algae, which are grazed by secondary producers, e.g. zooplankton and macrozoobenthos, serving as food for the higher trophic levels (fish, birds).

As oxygen conditions have improved in all estuaries in recent decades, the dominant form of nitrogen has changed from ammonia towards nitrate. In general, a decrease in concentrations of both nitrogen and phosphorus has occurred. The biogeochemical removal of nutrients within the estuary, the so called filter function of estuaries, was studied by comparing measured concentrations of nutrients with the theoretical expected concentrations along the salinity gradient. In this way, gains (production in the estuary) or losses along the longitudinal gradient were calculated.

The **Scheldt** was characterised by the conservative behaviour of nitrate and removal of ammonium in the oligohaline zone, whilst the **Elbe** showed a notable gain in nitrate in the oligohaline and freshwater zone and losses downstream; this indicates that the **Elbe** had a relative lower capacity to improve water quality (in this case nitrogen), compared to the other estuaries. It is of note that despite the high oxygen content, the **Humber** showed a high removal of nitrate in the mesohaline zone, preceded by large increases in the upper parts. As the **Humber** was naturally the most turbid of all the estuaries (with suspended sediment concentrations normally c. 5g/l, this indicated the role of suspended matter in the filter function. The **Humber** also showed the highest phosphate release.

Yearly gain or loss of nutrients for each estuary



Yearly gain (+) or loss (-) of nutrients (in tons per year and per km estuarine length) for each estuary;
fw = freshwater zone, o = oligohaline zone, m = mesohaline or brackish zone, p = polyhaline or saline zone;
NO_3 = nitrate, PO_4 = phosphate, DSi = dissolved silica

Primary Production

Estuaries are characterised by a high production of organic matter within the system (autochthonous production), although there is also a large import from outside the estuary both upstream from the catchment and downstream from the sea (allochthonous production). In some areas, the in-situ primary production determines the carrying capacity of the food web, hence of the food provisioning ecosystem services.

Aquatic primary production was highest in the **Scheldt**, a recent consequence of restoration efforts, with the treatment of the wastewater of Brussels a major element.

In contrast, the **Humber** is naturally so turbid that the food chain depends mostly upon detritus from the catchment, the adjacent wetlands and human-derived inputs, resuspended microphytobenthos (the sediment microalgae), and local benthic production on tidal flats, the light-exposed sites, thus emphasising the importance of intertidal habitats in this estuary. Despite this, the **Humber** has the lowest relative area of intertidal habitats – mudflats and marshes together cover approximately a quarter of the total system surface; an example where the interestuarine comparison revealed a case of high demand versus low offer of an estuarine function.

Compared to the **Scheldt**, the **Elbe** estuary is in general deeper, more turbid and has a shorter residence time, which together explain its relatively low primary production. Consequently, the filter function of the **Elbe** estuary is reduced, thus explaining the important release of dissolved silica, a crucial element in the food web.

The **Weser** potentially has a high primary production capacity.

Dissolved Oxygen Levels

Many estuaries naturally have low dissolved oxygen levels (termed a DO sag) especially in the turbidity maximum zone, because of the high oxygen demand by the detritus and suspended sediment there, and during the summer months because of intense microbial activity. Part of that DO sag is attributable to freshwater microalgae dying once they reach brackish conditions. Historically in many estuaries, that natural DO sag has been exacerbated by human organic inputs either from the catchment or surrounding cities and industries.

In the **Elbe** the occurrence of a large local summer oxygen sag in the freshwater zone, just downstream from Hamburg remains a major management issue as it is a barrier to fish migration. This oxygen sag appears in a transition zone of changing hydromorphological characteristics and gives a pronounced transition between river dominance and tidal dominance. The **Elbe** estuary thus acts as many estuaries in receiving organic matter and nutrients from the catchment and other sources, having high free-living and attached microbial populations which create an oxygen demand by using the carbon and nutrient load, while the microalgae are limited by the turbid, light-limited conditions in the water column. The addition of less turbid shallow water areas, containing oxygenated water may locally import oxygen into the turbidity maximum/DO sag zone and provide a better environment for algal primary production.

Habitats & Bird Distribution

Greylag Goose
© APA

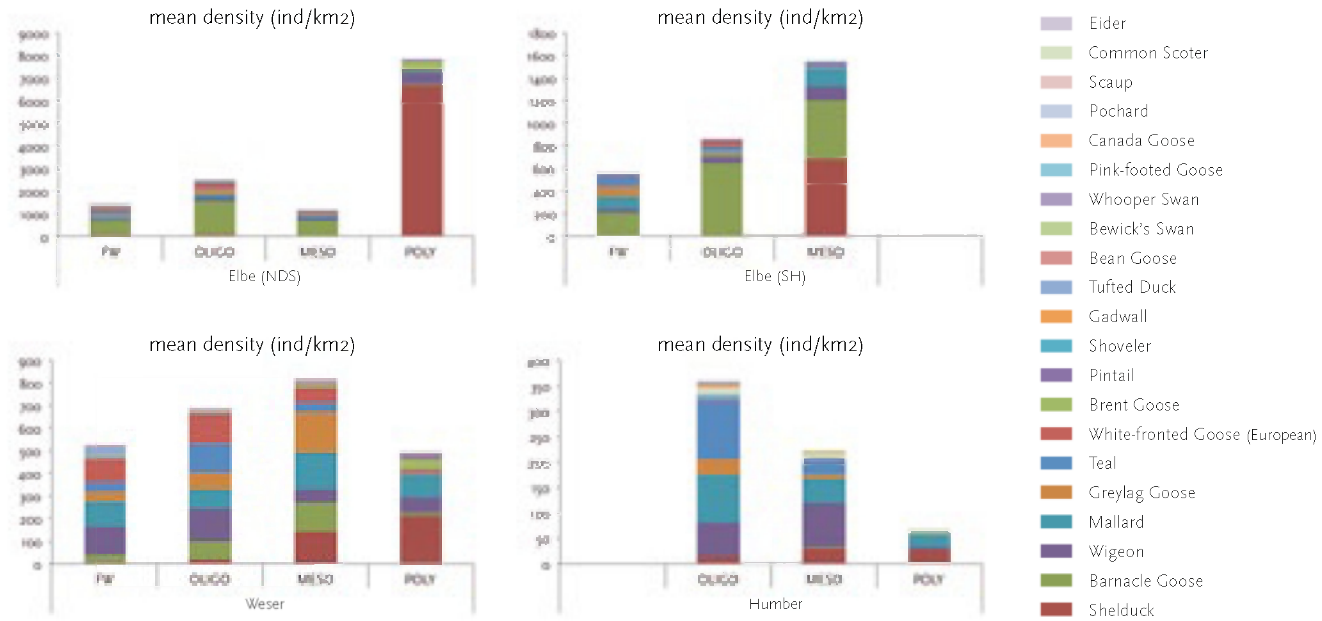
The estuarine hydrogeomorphological characteristics indirectly affect the distributions of higher predators as they determine the extent of intertidal mudflats and marsh habitats. In particular, intertidal mudflats are important feeding areas for waders and juvenile fishes as is marsh for wildfowl and as refuge areas for fishes.

The distribution of waterbirds in estuarine habitats and the identification of the main factors affecting bird habitat use have been investigated using a statistical approach combining high tide bird count data with a series of environmental characterising variables (including natural habitat area, water quality parameters and indicators of anthropogenic disturbance). This has given the habitat requirements for different bird species although it is based on waterbird usage data from around high tide, a period when birds may be predominantly roosting and almost certainly not using optimal foraging areas, although the environmental variables include habitat provision at low water. Whilst the results are therefore effectively for high tide roosting/loafing activity, assuming most species will not move a great distance from preferred feeding areas, there are similar conclusions for foraging activity.

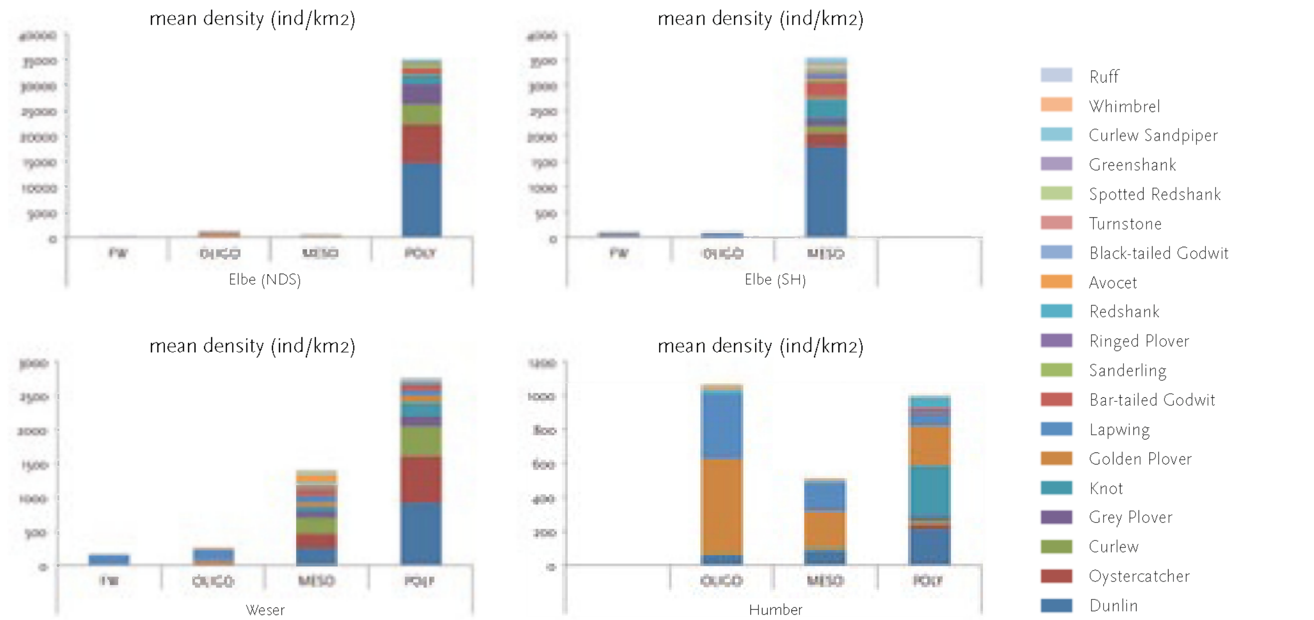
Although TIDE only quantified the value of habitats available within the estuary at a small spatial scale (i.e., within an average area of 6km² around roosting sites), the analysis suggested that habitat availability on a wider spatial scale (i.e. areas adjacent to the estuary) can also increase roosting potential in certain estuarine areas by providing additional bird feeding grounds. This has been observed, for example, with waders in the polyhaline zones of the **Elbe**, due to the presence of extensive mudflats in adjacent marine areas (presumably with a diurnal migration of waders to and from preferred roost and foraging areas), or with wildfowl in the oligohaline zone of the **Humber**, due to the presence of adjacent inland habitats.

Mean density of waders and wildfowl in the salinity zones within the Elbe

Wildfowl



Waders



Mean density (ind.km-2) of waders and wildfowl in the salinity zones within the Elbe (E; NDS=southern bank, SH=northern bank), Weser (W) and Humber (H, northern bank) estuaries.

Importantly, the analysis also indicated that larger estuarine habitats appear to support greater waterbird densities compared to smaller habitat areas, especially for generalist feeders (i.e., species such as Dunlin and Redshank that are able to take advantage of a wider range of food prey). This may be due to the higher diversity of resources associated with greater mudflat extent benefiting the aggregation of these generalist feeders. In turn, this is less evident for specialist feeders, such as Bar-tailed Godwit, which are more likely to depend on the distribution of specific prey species, a factor that might be more relevant at a smaller spatial scale (i.e., within a mudflat) hence resulting in a negative relationship between Bar-tailed Godwit density and total intertidal habitat area.

Black-tailed godwit
© APA

Our analysis also suggests that lower waterbird densities generally occur in locations where natural estuarine habitat area is smaller. This reduced habitat availability is often the result of the natural variability in the estuarine morphology (e.g. narrower mudflats present in the freshwater zone compared to the estuarine meso- and polyhaline zones) or the presence of anthropogenic developments and land-claim (e.g. smaller mudflat areas in the mesohaline zone of the **Humber** or in the freshwater and oligohaline zone of the **Elbe**). As such, the availability of natural estuarine habitats mainly determines the density of waders and wildfowl within the estuarine system, especially in the **Weser** and **Humber**.

Water quality characteristics such as the salinity gradient, nutrient levels and organic enrichment are also important in affecting species distribution, especially in the **Elbe**. The salinity gradient was the most important factor affecting bird density as a whole in the **Elbe**, particularly for Dunlin, although this effect is more likely to be related to other factors that are correlated with the salinity gradient in the estuary rather than to an effect of salinity itself. These factors include the distribution and availability of feeding habitats and food resources (as indicated by longitudinal changes in benthic invertebrate communities) along the estuarine gradient. The lesser anthropogenic disturbance in outer estuary sands/remote islands may also contribute to the higher bird density observed in the polyhaline zone of the **Elbe**.

The positive relationship between intertidal habitat area and waterbird density is potentially important for estuarine management, as it suggests that the fragmentation of intertidal habitat from a range of anthropogenic activities, as well as the effective reduction in the width of mudflat from coastal squeeze, may result in reduced waterbird usage density, Furthermore, compensatory measures such as managed realignment resulting from intertidal development offsetting may need to consider the delivery of sufficient area to accommodate fragmentation effects of the land-claim e.g. an increase in the offset area compensation ratio.

Estuary Functioning

Summary

In general the four estuaries show usual hydro-geomorphological and ecological estuarine characteristics, but there is a high variability between and within systems. The intercomparison indicated:

- **the cubage technique and the Dalrymple energy concept were applied to compare the driving forces behind the tidal amplitude;**
- **all estuaries showed tidal amplification with a progression upstream in relation with morphological changes although the Scheldt has the highest tidal amplification and tidal range;**
- **the Weser has the the shortest residence time and most intertidal flat and marsh area;**
- **the Elbe combines low convergence with low friction, while the Humber has a large degree of convergence but also a large degree of friction;**
- **the Elbe has a relative lower capacity to improve water quality (in this case nitrogen), compared to the other estuaries;**
- **the Humber had the highest phosphate release, was the most turbid of all the estuaries (with suspended sediment concentrations normally ca. 5 g/l), and consequently a higher filter function;**
- **aquatic primary production is highest in the Scheldt;**
- **a major issue on the Elbe is a local oxygen sag in the freshwater zone;**
- **the Humber is so turbid that the food chain depends mostly upon detritus from the catchment, the adjacent wetlands and human-derived inputs;**
- **bird abundances are determined by habitat availability (Weser, Humber), water quality (Elbe) or by the presence of anthropogenic developments and land-claim (Humber, Elbe);**
- **waterbird density increased together with intertidal area, this has implications for estuarine management and habitat loss/compensation ratios.**

These findings are reflected in the diversity of management practices which in turn are often related to protecting and enhancing the range of habitats. This is especially important as the abundance and distribution of habitats is closely related to the delivery of ecosystem services.

4 Ecosystem Services

Ecosystem Services

Ecosystem Services in relation to Structure and Functioning

Human health and well-being depends entirely, albeit often indirectly, upon the provision of natural resources (MA, 2005: Millennium Ecosystem Assessment – Ecosystems and Human Well-being: Synthesis.) and society can take benefits from many resources and processes, termed ecosystem services, that are supplied by natural ecosystems.

Ecosystem services (ES) result from:

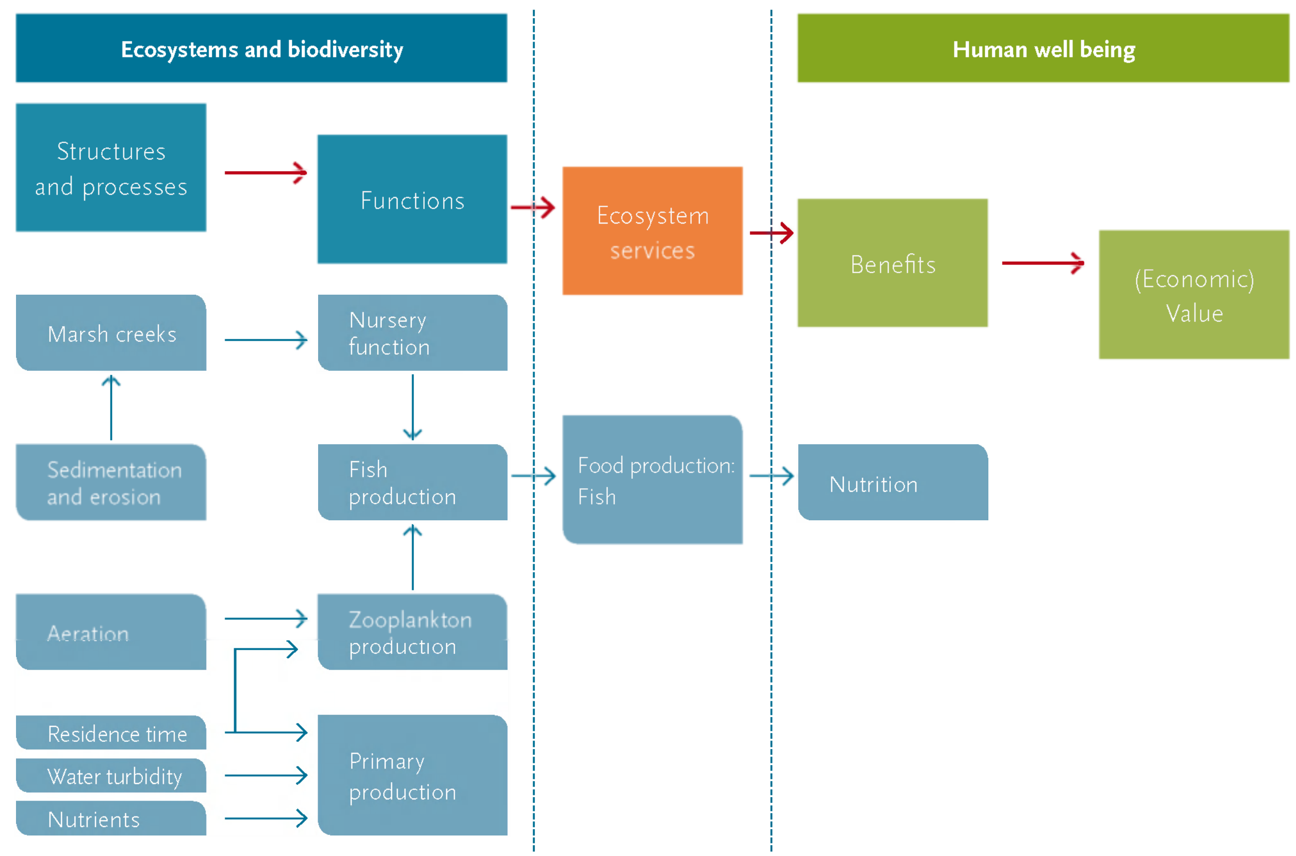
- ecosystem functions (for example, primary production, nutrient cycling, hydrodynamic conditions);
- biophysical processes (such as plant nutrient uptake, photosynthesis, mineral weathering, sedimentation, tidal pumping);
- structure such as the collection of habitats and species.

In essence, the ecosystem contains the physico-chemical and ecological processes which in turn allow ecosystem services to be produced and which again in turn are used by society after the addition of complementary assets and human capital.

For example, the appropriate water conditions and sediment will support invertebrates which in turn provide fish food. Society can then exploit those fishes but only if it provides the means (using skills, energy, money) of catching them. The benefit 'Nutrition' depends on the service 'Food provision, fisheries' which in turn depends on the function of a viable fish population production; in turn the latter depends on other functions such as primary production, nutrient cycling, oxygen production and the presence of suitable habitats.

Resting geese and ducks

The pathway from ecosystem structures and processes to human well being



The pathway from ecosystem structures and processes to human well being (after TEEB), with an example of the service "Food production": fish, showing some ecosystem factors that eventually determine the human benefit "Nutrition"

To deliver these services in a certain quantity requires an adequate ecological structure (amount, diversity) and functioning (rate processes such a primary production) of the respective habitats as well as suitable hydrodynamics such as the flooding frequency. Each of these factors is governed by hydromorphological features which in most estuaries are influenced by natural or anthropogenic factors. In addition to describing and understanding the underlying ecosystem processes, ecosystem services are increasingly being valued allowing us to integrate the economic value of our ecosystems in management choices, which are mainly based on economic aspects.

TIDE has quantified the services in order to relate the complexity of estuarine functioning to society's use and the management of the estuaries. Hence, ecosystem services bridge ecology, economy and social sciences.

The ecosystem services are separated into:

- **Provisioning** services, as the products we derive from ecosystems i.e. food, building material, fibre, water, etc.;

- **Regulating services**, as the benefits obtained from the regulation of ecosystem processes, such as air quality and climate regulation, natural hazard regulation;
- **Habitat services**, e.g. formation and maintaining of habitats and gene pool;
- **Cultural services** are the nonmaterial benefits people obtain from nature (aesthetic, spiritual, educational and recreational).

Provisioning ecosystem service 'Provision of food'
© HPA

Cultural ecosystem service 'Opportunities for recreation & tourism'
© Kieler Institut für Landschaftsökologie

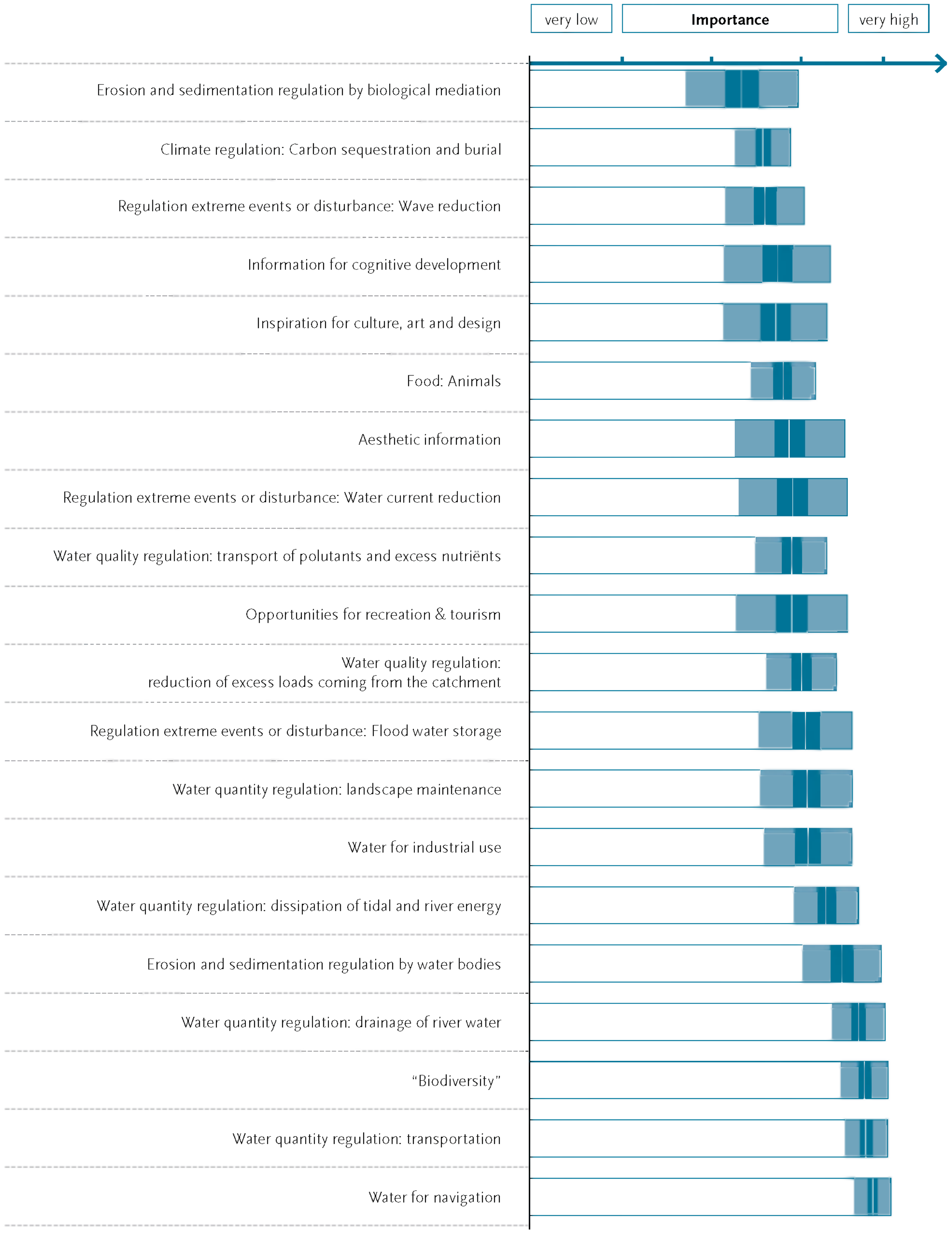
The TIDE Importance Score of Ecosystem Services

Ecosystem services are valued by the balance between:

- a societal **demand**, i.e. the benefits which are obtained,
- a **supply**, i.e. the functioning of the system structures and processes.

A list created by the project TEEB (The Economics of Ecosystems and Biodiversity) was used by the 4 Regional Working Groups to determine the ES demand in the TIDE estuaries. This survey led to a list of 20 ES which were considered to be the most important in the four estuaries.

Importance of Ecosystem services in the TIDE estuaries with margins of variance



Importance of Ecosystem services in the TIDE estuaries with margins of variance; standard errors (light blue) and standard deviation (white)

Service Demands

Of the 10 services with the highest demand, 7 were regulating for hydro-geomorphologic aspects and two were directly linked with navigational or industrial use of water. Except for water, there was a relatively lower demand for provisioning services (e.g. food, building materials) even though estuaries are amongst the most productive ecosystems worldwide. The low ranking of local production may be due to the fact that society is now more globally-oriented and provisioning goods and services such as food and building materials can be imported from elsewhere. As a consequence, services such as transportation are more important whereas provisioning services have declined over time due to habitat loss and pollution. With increasing urbanisation and industrialisation, regulating services have become more important especially because of increased flooding and pollution.

Service Supply

The service supplies, as derived from the underlying estuarine functioning, have been ranked for all estuaries.

Table Ecosystem service supply

	Elbe	Weser	Humber	Scheldt	
Mean high water level	3	4	2	1	Safety, drainage
Tidal range	4	3	2	1	Safety, drainage
Tidal energy flux	4	3	2	1	Energy dissipation
Tidal amplification	3	4	1	2	
Tidal damping	2	4	1	3	
Maximum flood current	3	4	1	2	Erosion, sediment transport
Tidal asymmetry at the upstream border	2	3	?	1	Sediment transport
Freshwater discharge	1	2	3	4	Drainage, transport
River energy flux	1	2	4	3	Drainage, transport
Residence time of the water	2	4	3	1	Water quality, primary production
Difference in salinity between winter and summer	3	2	1	4	
Estuary volume	1	4	3	2	
Estuary surface	2	4	3	1	
Relative subtidal deep area	2	3	4	1	Navigation
Relative intertidal flat area	4	1	3	1	Food production, friction
Relative marsh area	2	1	4	3	Diversity, dike protection, sedimentation

Ecosystem service supply (related benefits, description, ranking of supply amount for the four TIDE estuaries; from 1 = estuary providing the highest supply to 4 = lowest supply, and locations or factors determining the occurrence of the service

The Ecosystem Services in Detail

Biodiversity

In contrast with services related to water and air quality regulation, the demand for biodiversity was ranked very high, although estuaries host few endemic species. They act as a nursery for several species of fish and crustaceans, as migration routes for fish, overwintering and staging areas for migratory birds, and provide shelter against predators; hence we take the view that biodiversity is both the amount and types of organisms. All of these functions depend strongly upon water and habitat quality and quantity/availability. The perceived importance of biodiversity centres on the crucial role of estuaries in the life cycle of key species which is reflected in the fact that European national and environmental protection laws require a certain ecological status.

Water and Air Quality Regulation Services

Due to urbanisation and industrialisation, water quality has been a concern for many decades and hence water regulation services are very important. Tidal marshes act as aeration sources for estuaries and, for example, the anabranches near the oxygen depletion zone of the **Elbe** are important to provide sufficient oxygen to restore fish migration routes. However, as the oxygen concentrations of all TIDE estuaries have either recovered or are relatively high, the demand and supply of the aerating service are sufficient within these estuaries.

Nitrogen retention has been influenced by a decreased supply and the supply of dissolved silica by tidal marshes is an underestimated service as it was only documented for the **Scheldt**. Dissolved silica is pivotal between eutrophication and animal food production. It is released by marshes during the summer, when the uptake by primary producers in the water column is highest. In general, the importance of water quality regulation services and also air regulating services (gas emissions) depend on concentrations and loads, especially those from the catchment. Hence the sustainable functioning of the estuaries cannot be separated from the sustainable functioning of the freshwater catchments.

The air regulating service related with global warming may be less important as the effect of enhanced methane emissions – a more severe greenhouse gas that CO2 – counters the carbon burial through sedimentation.

Water and Sediment Quantity Regulating Services

Whereas water and air quality regulating services of estuaries are also related to services in the catchment or elsewhere, water quantity regulating services are more strictly related to intrinsic estuarine features. The estuarine hydro-geomorphology determines the potential for navigation, the flooding risk and the habitat quality, hence biodiversity.

The TIDE project indicated that different water or sediment regulating services had high rankings because of their demand:

Water quantity regulation: dissipation of tidal and river energy:
As the morphology of estuaries has increasingly been altered together with the relative influence of river and tidal features, there are repercussions for e.g. flood protection, dyke abrasion, and habitat deterioration. Therefore it is important for managers to know where are the opportunities to restore these dynamics, for example by dissipation of

energy and reducing water level and velocity. As shown in TIDE using the Dalrymple approach, river energy was dissipated most in the **Elbe**, and tidal energy dissipation was maximal in the **Humber** and the **Scheldt** due to specific morphological characteristics.

Water quantity regulation: transportation
Water quantity for shipping is a result not only of the depth of the fairway, docks etc. but also of river discharge and tidal characteristics. Higher values of this service mean that less dredging is necessary. However, that under a given type of hydrogeomorphology the estuary will be in an equilibrium and anthropogenic actions, such as building ports, will disturb it from that equilibrium thus requiring management actions to maintain human uses.

Water quantity regulation: drainage of river water
High tides will restrict catchment drainage and increase upstream water retention. The Dalrymple approach showed, for example, that the **Weser** was the only system where river dominance could extend as far as downstream as Bremerhaven, near the estuarine mouth,, illustrating the importance here for the drainage service.

Erosion and sedimentation: regulation by water bodies
Estuaries have strong and weak water movements which respectively cause erosion and deposition of bed sediments, thus termed 'erosion-deposition cycles'. These respectively occur on a daily basis (with flood/ebb tides and slack water), a weekly basis (with spring and neap tides), on a lunar basis, and seasonally (with equinoctial and inter-equinoctial periods and with wet and dry periods). Human activities disturb this equilibrium potentially affecting navigation, safety and habitats. Loss of tidal marshes in front of a dyke due to erosion may exacerbate the erosion and increase maintenance costs.

Cultural Services

The supply of cultural services (tourism, aesthetic and cultural inspiration, and spiritual and cognitive experience) is very difficult to estimate but TIDE has shown that these aspects are valued. This increases the recognition of estuaries as essential for the quality of (human) life and wealth creation.

The Tidal Elbe – a people's perspective – results of 812 street interviews along the Elbe estuary:

- 52% of interviewed residents use the Elbe for recreational activities at the shore
- 25% of interviewed residents use the Elbe for water sports and swimming

Important Habitats and Zones for the Delivery of Ecosystem Services

The delivery of ecosystem services is spatially variable – among habitats and between different systems, and in time showing large seasonal variability. The service supplied by habitats is comparable among the TIDE estuaries as a whole, and most service supplies are also similar along the salinity gradient.

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.

Valuation and Application

The complexity of estuaries requires that an integrated management approach will have the best chance of success when based on the **Ecosystem Service Approach and aimed at preserving the natural functioning of the system and recognising humans as an integral component of the ecosystem**. The TIDE project importantly used the ecosystem service approach as a common denominator between the economic, ecological and social system. As such it has increased our understanding on how we depend on the delivery of these services on the one hand and on the functioning of the system delivering the services on the other hand. It was not the aim of TIDE to value the services for the different estuaries but a guideline was developed to allow the economic valuation of the ecosystem services. For this purpose we compiled a database of values of the different processes and functions.

Ecosystem Services

Summary

- **The ecosystem contains the physico-chemical and ecological processes which in turn allow ecosystem services to be produced and which again in turn are used by society after the addition of complementary assets and human capital.**
- **The ES water for navigation, water quantity regulation (transportation) and biodiversity were considered to be the most important ES in the TIDE estuaries.**
- **The delivery of ecosystem services is spatially variable among habitats and between different systems, and in time showing large seasonal variability.**
- **Of the 10 services with the highest demand, 7 were regulating for hydro-geomorphologic aspects and two were directly linked with nautical or industrial use of water.**
- **The complexity of estuaries requires that an integrated management approach based on the Ecosystem Service Approach will provide the best chances for successfully managing estuaries.**
- **That management must be aimed at preserving the natural functioning of the system whilst recognising humans as integral component of the ecosystem.**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5

Uses and Conflicts

Uses and Conflicts

The Conflict Matrix Approach

North-west European estuaries are multi-user environments requiring appropriate management to ensure the best use of resources amongst the various legitimate stakeholders. As this varies along an estuary, severe and less-severe conflicts between users will occur at particular areas and so management actions need to reflect this variability. Estuarine managers and planners therefore need information on the main areas of spatial and sectoral uses and conflicts within their estuary for the targeting of resources, as well as information on appropriate tools needed to address these problems.

The TIDE project has demonstrated the value of conflict matrices for the initial determination of such issues for each of the management zones of each estuary including information on:

- the 'amount' of each use or user activity within each estuarine zone;
- the likely considered level of conflict between two users/use, and
- the severity of the actual conflict between two users/uses.

The conflict matrices employ a simple approach based around a series of standard human uses/users that are considered to be generic across north-west European estuaries. The matrices are designed for completion at an estuary level and to include the anticipated level of **generic conflict** between two users/uses and the **actual level** of each use in each estuarine zone, these being combined to produce an **actual conflict score** for each zone of an estuary.

We consider this to be a valuable tool for the initial assessment of potential user conflict, spatial extent, severity and management focus. The tool is also a useful, transparent medium to inform stakeholders of the basis for management options and decisions.

The conflict analysis was undertaken for the four TIDE estuaries through estuary-specific **Regional Working Groups** (RWGs). These groups included 'experts' representing the main areas of estuarine 'use', e.g. nature conservation management, flood risk protection, the ports industry, navigation, and other important user groups including the diverse recreational user community, fisheries and the scientific community. We therefore recommend the formation of a RWG to aid this process, as not only is sectoral bias reduced, but such a group may also be of value as a forum for wider issue raising and alliance building between disparate and sometimes conflicting groups.

However, we emphasise that this procedure uses expert opinion and as such can still be subject to bias or perception and it also relies heavily on the composition of the RWG – the conflict matrix will reflect any RWG more heavily dominated by one sector or another. We therefore emphasise that this is aimed at providing a high level management tool, rather than a detailed empirical output hence we note the limitations in using this for the four TIDE estuaries.

Human Uses

Initial RWG management focus was established for each of the TIDE estuaries through the ranking of human uses (high, moderate or low). Whilst the RWGs for most estuaries identified the provision of Transport & Accessibility, Ecological Function & Diversity and Flood Protection & Assimilative Capacity as being of high importance, for the **Humber**, Transport & Accessibility was ranked as being of moderate importance. Across all of the estuaries, however, Recreation & Social Use were ranked as being of moderate importance. This ranking process also indicated systemic variations in the way in which individual estuary RWGs would 'score' user conflicts within the main matrices, and any associated inter-estuarine or inter-user bias.

The completed conflict matrices identify the **Scheldt** as having the greatest level of human use, and the **Elbe** the lowest (c. 25% lower than that of the **Scheldt**). Across the TIDE estuaries, the mesohaline zone supported the greatest level of uses, with the polyhaline zone featuring the lowest level. The **Elbe** and the **Weser** recorded their highest individual use levels in the freshwater zone, the **Scheldt** in the oligohaline and the **Humber** in the mesohaline zone. This variation in human use concentration between the salinity zones of the TIDE estuaries shows the need for estuary specific management, targeted at specific spatial and sectoral areas.

Summary of usage scores for each estuary zone and for TIDE estuaries

		Limnetic		
Humber	**Elbe**	**Scheldt**	**Weser**	**Total Zone**
40	40	41	51	172
		Oligohaline		
Humber	**Elbe**	**Scheldt**	**Weser**	**Total Zone**
40	38	55	45	178
		Mesohaline		
Humber	**Elbe**	**Scheldt**	**Weser**	**Total Zone**
52	37	52	51	192
		Polyhaline		
Humber	**Elbe**	**Scheldt**	**Weser**	**Total Zone**
46	31	43	35	155
	Total Estuary			
Humber	**Elbe**	**Scheldt**	**Weser**	
178	146	191	182	

In assessing the similarities and differences in uses and issues between salinity zones across all TIDE estuaries, the most important uses/issues identified from the freshwater zone were flood protection, recreation, channel stabilisation and residential housing, with the oligohaline zones featuring similar key uses (flood protection, recreation and channel stabilisation) as well as conservation protection. The mesohaline zone was also identified as important for conservation protection and flood protection, but with increased importance for vessel movement and capital dredging, this zone supported the highest level of overall use across the TIDE estuaries. Although the polyhaline zone had a lower level of human use across the estuaries, it was identified as being important for a range of uses including conservation protection, flood protection, vessel movement, capital dredging and maintenance dredging; the **Humber** identified this zone as having the highest level of use.

Summary of usage for the TIDE estuaries per zone

Human Use	Freshwater					Mesohaline				
	Humber	Elbe	Scheldt	Weser	Total	Humber	Elbe	Scheldt	Weser	Total
Landscape – High value landscape feature	0	2	2	1	5	1	2	1	2	6
Conservation – Protected area adjacent to system	1	2	2	1	6	1	2	1	1	5
Conservation – Protected subtidal area	1	2	1	2	6	3	3	3	3	12
Conservation – Protected intertidal area	1	2	2	2	7	3	3	3	3	12
Archaeology – Archaeology/History protected site	1	1	0	1	3	2	1	0	1	4
Access (e.g. Disturbance) – Recreational access on water	2	2	3	2	9	3	2	2	2	9
Access (e.g. Disturbance) – Recreational access on the banks & intertidal	3	2	3	3	11	3	2	3	1	9
Access (e.g. Disturbance) – Commercial	0	0	3	1	4	1	0	3	1	5
Flood/coast protection – Defence set-back	0	1	2	1	4	3	0	1	0	4
Flood/coast protection – Flood bank (dyke/gabbion/wall)	3	3	3	3	12	3	3	3	3	12
Navigation – Channel stabilisation	2	2	3	3	10	1	2	3	3	9
Navigation – Capital dredging	0	2	0	2	4	2	2	3	3	10
Navigation – Maintenance dredging	2	2	2	2	8	1	2	3	3	9
Navigation – Vessel movement	2	3	2	1	8	3	3	3	3	12
Ports & Harbours – Port land claim (intertidal/subtidal)	1	1	0	1	3	2	0	1	3	6
Ports & Harbours – Port related activity adjacent to system	2	1	1	2	6	2	1	2	3	8
Ports & Harbours – Port activity on the intertidal/subtidal area	2	1	0	2	5	2	0	1	3	6
Infrastructure – Infrastructure on bed or in water column	1	1	2	2	6	2	1	2	1	6
Industry – Tidal/current energy device	0	0	0	1	1	1	0	0	0	1
Industry – Water abstraction	2	1	0	2	5	1	1	2	1	5
Industry – Aggregate extraction	0	1	1	1	3	0	0	3	1	4
Industry – Industrial discharge	2	1	1	2	6	1	1	2	1	5
Industry – Industrial activity adjacent to system	1	1	1	1	4	2	1	2	1	6
Agriculture – Water abstraction	1	1	0	1	3	0	0	0	0	0
Agriculture – Agricultural run-off	3	1	2	2	8	3	1	3	2	9
Biological Extraction – Commercial (e.g. fish & shellfish)	1	0	0	1	2	0	1	0	1	2
Biological Extraction – Recreational	1	1	1	2	5	1	1	1	1	4
Biological Extraction – Wildfowling	1	0	1	1	3	1	0	0	0	1
Residential – Waste water discharge	1	1	1	2	5	2	1	0	2	5
Residential – Housing adjacent to system	2	2	2	3	9	2	1	1	2	6
Residential – Drinking water abstraction	1	0	0	0	1	0	0	0	0	0
Total Usage / Estuary	40	40	41	51		52	37	52	51	

Highest number of uses is marked in orange

Conflicting Uses and Users in the TIDE Estuaries

Whilst many north-west European estuarine management user issues are to some extent generic, there are estuary specific variations, both in the user interactions, but also the severity. It is also evident that synergisms exist between several uses as shown by the conflict matrices applied to the TIDE estuaries.

- **Elbe Estuary:** For instance, the main use/issue of importance identified by the **Elbe** RWG was in relation to Transport and Accessibility. The associated conflict matrices indicate that the main management problems are associated with the provision of safe navigation requirements from the estuary mouth to the port of Hamburg, with the most highly-scored conflicts from this use occurring with Natura 2000 requirements. Similarly, the need to meet the requirements of the Natura 2000 Directives is potentially in high conflict with the need to maintain safe navigation along this part of the estuary.

- **Weser Estuary:** Flood protection was identified as a key requirement by the **Weser** RWG, but transport and biodiversity (conservation protection) rated almost as highly. This reflects both the need to maintain deep navigable access to the port of Bremen, but with substantial issues relating to Natura 2000 requirements and tidal range along the estuary. The highest conflict interactions related to the impacts of conservation protection in the subtidal zone on navigation requirements as well as the converse channel stabilisation and navigation needs affecting Natura 2000 protection in the intertidal and subtidal zones. The need to provide flood protection was also recorded as conflicting with Natura 2000 protection in the intertidal zone.

- **Scheldt Estuary:** The broad provision of ecological function and diversity was identified as being of greatest importance by the **Scheldt** RWG but closely followed by Flood Protection & Assimilative Capacity and Transport & Accessibility. However, whilst fewer severe conflict issues were identified for the **Scheldt** as a whole than for the other TIDE estuaries, specific conflicts were recorded in the outer estuary between dredging needs and protection of the subtidal habitat. Similarly, high level conflicts increase around the port of Antwerp to include Natura 2000 site protection on specific flood protection measures (managed realignment), port activity, industry, recreation and housing provision, as well as conflicts resulting from managed realignment on conservation protection in sites adjacent to the estuary and housing provision. However, notably, a number of positive synergisms between users were also identified, more than for the other TIDE estuaries.

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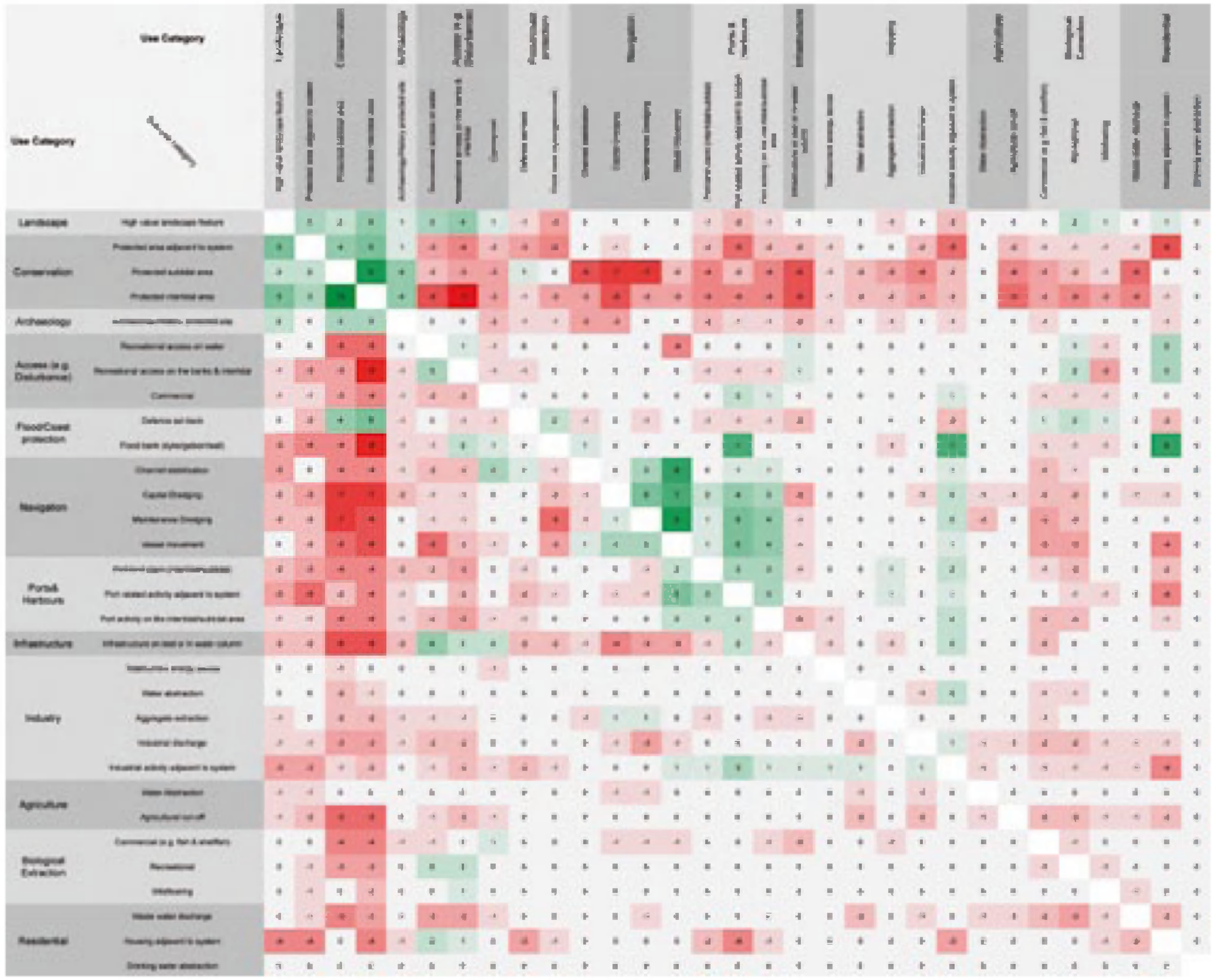
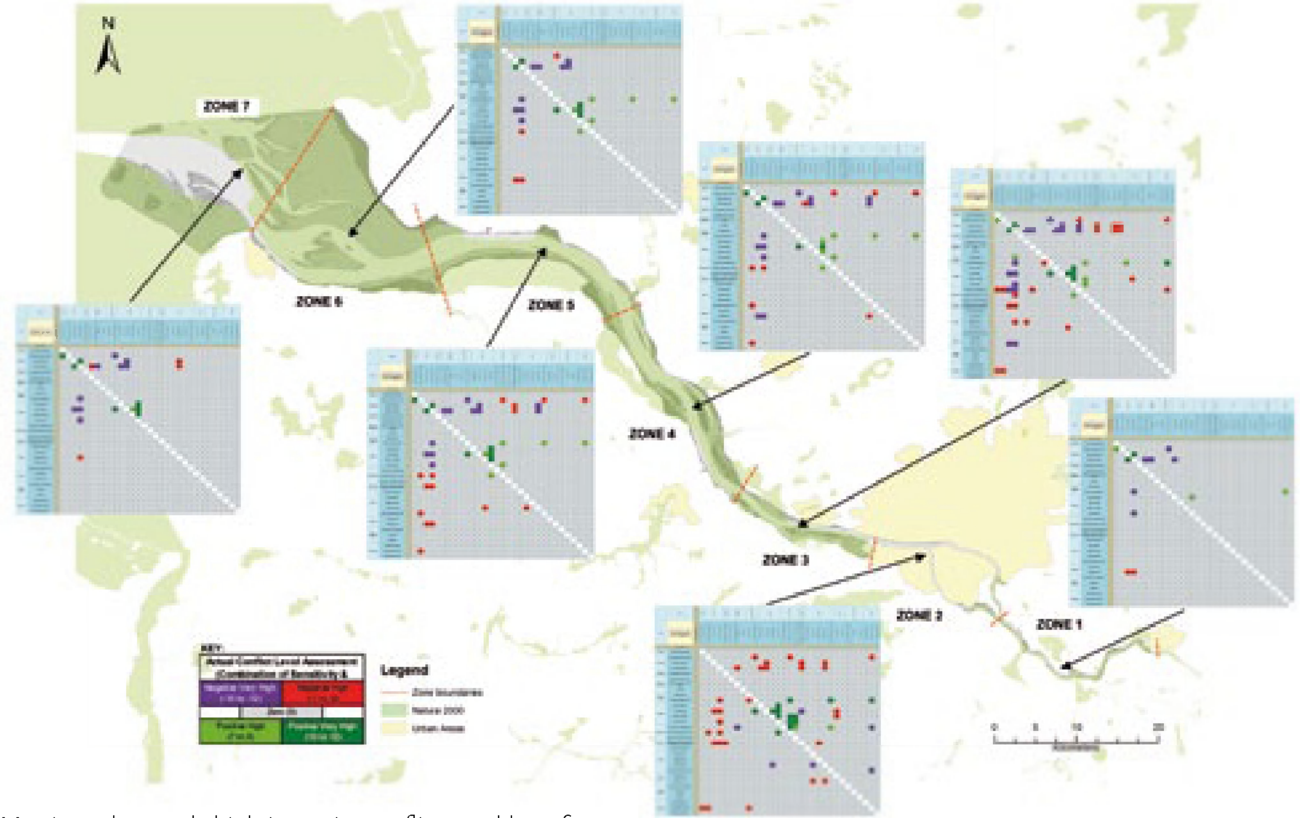
Summary of use conflicts for all TIDE estuaries



- red shading: conflicts
- green shading: benefits
(color intensity reflects the level of antagonism or synergism)

Humber Estuary: The provision of Flood Protection & Assimilative Capacity and Ecological Function & Diversity were ranked as the most important uses for the **Humber**, with the provision of transport and accessibility scoring far lower than for the other TIDE estuaries. This reflects the somewhat different management priorities in the **Humber**, with the region low lying and subject to relative sea-level rise and, whilst featuring the UK's largest port complex, there is almost no need to artificially maintain navigable channels through dredging and channel stabilisation. However, the matrix analysis identified many notable conflicts, with Natura 2000 conservation protection, primarily in the intertidal zone, impacting on port infrastructure activity, recreational access and flood protection provision, as well as recreational access impacts on intertidal conservation protection, the requirements of flood protection provision and port activity on Natura 2000 protection.

Conflict matrices for each salinity zone of the Elbe.



Matrices show only high intensity conflicts and benefits

The average conflict scores across all zones and all TIDE estuaries illustrates the main sectors of potential estuarine user conflict which may require management (shaded red in the figure), together with areas of synergistic potential (shaded green in the figure).

Whilst the conflict matrix process has highlighted a number of already established antagonisms between key sectoral uses in estuaries, the spatial distribution of these was variable across some of the estuaries. The **Humber** in particular showed considerable dissimilarity with reduced conflict levels arising from navigation-related issues on Natura 2000 protection requirements and vice versa. This is mainly due to the position of the main ports industry on the **Humber**, compared to the other estuaries, with the **Humber's** main port industry proportionally closer to the mouth of the estuary and with non-accreting shipping channels than the other TIDE estuaries.

Furthermore, the conflict matrix analysis identified some notable sectoral variations between estuaries. For instance, on the **Humber**, the provision of Natura 2000 protection in the intertidal zone was frequently identified as having a high level of impact on the provision of managed realignment, whilst the presence of flood protection dykes was similarly identified as having a high impact on intertidal Natura 2000 provision. On the **Scheldt**, managed realignment was further identified as impacting on conservation protection requirements on adjacent terrestrial areas. As managed realignment is often used as a measure to mitigate for the impacts of coastal squeeze arising from the presence of fixed flood protection dykes, then this would seem to be a considerable management pinch-point requiring addressing. In addition, managed realignment provision was also identified as having the potential for high level conflicts with industrial activity and residential housing in the immediate flood plain. Again, given the potential for the tool to be used as a measure to increase flood assimilation capacity, then the success of the technique requires both management focus and possibly additional stakeholder involvement.

Mechanisms for Resolving Conflicts

As shown above, estuaries are subject to many often similar competing and conflicting uses and users. While high level management needs are the same across most north-west European estuaries, to protect and enhance nature conservation while ensuring public safety and the delivery of ecosystem services and societal benefits, there are clear differences in priorities for specific management actions. We have shown that these vary between estuaries but also within an estuary and so management needs to reflect this and be targeted.

In particular, the need for conservation protection raises several management conflicts with other uses, including the ports industry, flood protection requirements and recreational access to the estuary and vice versa. In particular, we highlight that measures employed to mitigate one management problem may affect others. For instance, managed realignment can be used to offset losses in both intertidal habitats from direct land claim and/or coastal squeeze in order to satisfy Natura 2000 as well as flood assimilation capacity. However, applying managed realignment can in itself impact on Natura 2000 provision as well as on flood protection requirements not to mention potential provision for housing and industry.

As such, mechanisms are necessary to assist in stakeholder inclusion and conflict resolution as part of a wider integrative management strategy.

Public awareness study 'The Tidal Elbe – a people's perspective':

In terms of land use conflicts, interviewed residents along the **Elbe** estuary considered nature conservation to offer the most serious potential for conflict since people perceived nature conservation to be incompatible with other land uses. In the rural parts of the **Elbe** region, nature conservation and agriculture are perceived to be the main conflict, whereas elsewhere it is nature conservation and industry. However, these responses mostly reflect general opinions about the interaction of different land uses and do not refer to existing regional conflicts.

It is assumed that these **Elbe**-specific findings are broadly transferable to other similar estuaries. Nevertheless it is suggested that estuary-specific surveys might be required to confirm this, and perhaps incorporate local variations.

Several high level conflicts were identified from the assessment process within the **Elbe**, **Weser** and **Humber** systems, but this was less the case for the **Scheldt**. Whilst having some very high level conflicts, primarily between navigation requirements and Natura 2000 protection needs, the **Scheldt** in general featured a reduced number of conflicts and an increased number of synergistic activities.

Whilst this may be to some extent an artefact of the RWG assessment process, and has not been identified directly as a result of a specific management action, it is possible to conclude that management of the **Scheldt** appears to be effective in several areas. This may be a result of its relatively long period of integrated management arising from the 'Long-term vision Westerscheldt' plan (2000), integrating 'safety accessibility and environment' aspects, including requirements for trans-national action and data sharing between Belgium and The Netherlands.

Based on the results of the conflict matrix approach, together with those from other TIDE aspects, we have derived a typology of key conflict areas for most estuaries and, based on these, produced guidance principles for integrated management. We have also determined a series of measures to assist in both in determining conflict areas and addressing some of the impact factors.

5

Uses and Conflicts

Summary

TIDE concludes that whilst north-west European estuaries present many generic management challenges, management initiatives need to be site-specific in order to accommodate both the natural and human systems. Furthermore, the Ecosystem Services and Conflict Matrix approaches employed in TIDE have the potential to be combined to assist in effective management.

However, it is important to understand that measures employed to provide a management solution for a specific problem can also generate their own management issues. This is particularly the case for measures used to address flood protection, land claim offset and Natura 2000 requirements.

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Management initiatives and governance

The Legal Framework

Implementation of EU Directives

SWOT Analysis

Environmental Assessment

Management initiatives and governance

The Legal Framework

The many uses and users of estuaries have led to extensive current management measures driven by international obligations and European Directives as well as the Member State or federal province policies. In order to share best practice between the estuaries, and to understand their planning and governance, it is necessary to understand the Member State legislative management frameworks and their differences. This encompasses national and local political demands and management organisations and their responsibilities.

The TIDE estuaries provide a range of managerial differences from the international catchment areas of the **Elbe** and **Scheldt**, to the regionally managed estuaries of the **Weser** and the **Humber**. As such, **holistic management** planning frameworks for estuaries must build on existing structures, use a multi-manager sectoral framework and have an understanding of:

- the management issues in estuaries;
- the governance framework (i.e. policies, politics, administrative bodies and legislation);
- the methods used to deliver the management;
- the basis on which that management is delivered;
- the efficacy of the management tools;
- the best tools/plans available to meet these needs, and
- the gaps in management (knowledge).

All European estuaries have to comply with various policies, developmental and management plans, and sectoral strategies and so we have analysed these in the TIDE estuaries to determine good management practices that can be applied elsewhere. These include:

- water quality (Water Framework Directive (WFD) & Urban Waste Water Treatment Directive);
- nature conservation (Habitats & Species Directive & Wild Birds Directive (HBD));
- flood protection and coastal protection (Flood Risk Management Directive (FRMD));
- integrated coastal zone management;
- shipping, ports and pollution prevention;
- economic development (including agriculture, forestry, tourism); and
- the Maritime Strategy Framework Directive (MSFD).

The proposed EU Directive on Marine Spatial Planning and Coastal Management may also affect estuary management if adopted, but we have not yet considered it as its implementation details are unknown.

Implementation of EU Directives

Schematic frameworks produced for each estuary show how the directives have been implemented from a top-down basis over the past two decades and there is considerable guidance on the requirements and implementation of these directives at an estuary level. The TIDE countries have also made good progress with the implementation of the newer directives e.g. MSFD and the FRMD into national law, meeting the deadlines set by the European Commission.

Our analysis has revealed the following **examples of best practice**:

- **Management plans which engage all users and uses of the estuary**
  Although non-statutory in nature, successful plans have been implemented in all four estuaries to ensure that the habitats and species within the estuaries maintain their favourable condition. These plans enable the different users and stakeholders to harmonise the requirements of Natura 2000 and Water Framework Directive objectives. Examples of best practice include the **Humber** Management Scheme, the Integrated Management-plan **Elbe**, Integrated Management-plan **Weser** and the Nature Development Plan for the **Scheldt** Estuary.

- **The creation of unified management decisions and the avoidance of overlapping plans**
  The Master Plan Coastal Defence in the **Weser** has demonstrated that a unified management framework for coastal protection can be developed despite the number of different federal states and authorities involved. In response to the Flood Risk Management Directive, all four estuaries have comprehensive flood risk management plans in place derived through their environment protection agencies and local authorities/federal states. These management plans have been developed on a whole estuary scale, instead of on an administrative basis, which avoids duplication of effort and possible overlap and omissions.

- **Open communication between statutory authorities, stakeholders and users within an estuary will lead to common goals being met**
  All four estuaries have shown good practice in using stakeholder and advisory networks to develop many of the plans, for example the River Basin Management Plans (RBMPs) and other programmes of measures as required under the Water Framework Directive. The RBMPs have been successfully developed both at the local scale (e.g. the **Humber** estuary), and at the international scale (e.g. the **Elbe**) thus overcoming administrative boundaries.

SWOT Analysis

As the TIDE estuaries each have various management plans each covering a particular sector (use or feature), we carried out a SWOT analysis to assess best practice within the estuary management systems.

internal

Strengths

- What are the highlights of the management plan?
- Are unique (or unusual) resources being drawn upon (and, if so, what are they)?
- What factors would be central in the management plan approach being adopted or transferred to plans in the future?

Weaknesses

- What aspects of the management plan could be improved?
- What apparent pitfalls within the management plans have led to limited implementation?

external

Opportunities

- Does the management plan provide opportunities to incorporate future changes?
- Will opportunities arrive by changes in relation to 'new' technology, environmental changes or changes in government policy or societal wishes?

Threats

- Is the management plan threatened by funding, long term vision or political will?

A plan's **strengths** is that it should have the legislative power to enforce its aims, be multi-sectoral, have defined funding and have sufficient spatial coverage to provide a broad management remit for the estuary. However, the SWOT analyses show that plans can be successful even if they are not statutory, e.g. the Integrated Management-plan **Elbe**, especially where there is a good implementation structure. Other strengths include multi-user management, stakeholder/user commitment/buy-in to the plan aims and for the plan to be regularly updated to keep up with changing legislation or environmental conditions.

The main **weaknesses** highlighted across the plans include their lack of financial support/funding when non-statutory; for example, lack of funding is often a major hurdle in delivering the policies put forward within shoreline management plans. Plans which have non-specific targets, and restricted plans that are not multi-sectorial are considered weak in achieving holistic solutions. Despite this, to be effective, a multi-sectorial plan should not lose focus of the key management issue and while it should not override the other interests, it needs to be multi-functional and holistic thus getting acceptance by all groups. The plan should present **opportunities** to be forward-thinking with the need to integrate new or changing issues, e.g. climate change. It should provide a framework for future management needs and provide conflict resolution between different sectors to give a win-win situation in estuarine management.

We have highlighted the following **threats** across the four estuaries: limited funding thereby making a plan short-lived or including the initial stages of defining the needs but then a lack of resources for implementation; too many stakeholders with different goals can threaten a plan's success, and the limited spatial coverage of a plan.

Common strengths, weaknesses, opportunities and threats identified within the management plans of the four TIDE estuaries

Best Practice – towards the sustainable management of estuaries

Strengths	Weaknesses	Opportunities	Threats
statutory in nature	lack of financial support/funding when non-statutory	to be forward thinking to integrate new issues e.g. climate change	limited funding therefore making a plan short lived
multi-sectoral	plans which have non-specific targets	to be framework for future management needs	too many stakeholders with different goals can threaten a plan's success
sufficient spatial coverage to provide a broad management remit for the estuary	plans which are very narrow in focus lacking multi-sectoral inclusiveness	conflict resolution between different sectors and provide win-win situations	limited spatial coverage of a plan

Environmental Assessment

Here we emphasise two main axioms of environmental assessment: firstly, that all developments with a potential to harm the environment, such as new or increased infrastructure (e.g. industrial complexes or ports), require permission. Secondly, that *'while a regulating body does not have to prove that a development will harm the environment, the developer does have to show that it will not do so'*.

Hence under EU Directives, all major developments require an **Environmental Impact Assessment (EIA)** and the production of an **Environmental Statement (ES)**. An EIA is defined very precisely 'what is the impact of this activity, carried out at this time, in this place and in this way, with this level of mitigation and/or compensation and communicated widely'. Similarly, plans and projects in Natura 2000 sites require an **Appropriate Assessment (AA)** which is very precisely 'what is the effect of the development on the features and conservation objectives of a designated Natura 2000 site'.

However, and again following the EU Directives, both of these require a **precautionary approach**, especially as there is uncertainty in determining impacts in a highly variable environment such as an estuary. TIDE considered how Belgium, Germany, the UK and the Netherlands cope with these uncertainties.

Differences/similarities in dealing with EIA/AA in different countries

	Belgium (Flanders)	Germany (Bremen)	The Netherlands	UK (England and Wales)
General/Definitions	EA and AA regimes are precise implementation of the EU Directives			
	EA and SEA are implemented by the same act and regulations (very similar procedures)			EIA and SEA are separate regimes but closely linked
Screening	Formal screening procedures have been put in place			
	ECJ: screening procedure with mainly thresholds focusing on extent of activity are incorrect implementation of Annex III of EIA Directive		ECJ: screening procedure with mainly thresholds focusing on extent of activity are incorrect implementation of Annex III of EIA Directive	Navigation dredging not EIA Maintance Dredging Protocol
Content Assessment	Minimal content of EA and AA (incl. overview knowledge gaps and other uncertaintles)			
Consultation/Participation	Provisions of formal consultation during scoping and consideration of ES			
			Independent Expert body (NCEA)	System of statutory consultees
Decision/Monitoring	Specific EIA/SEA procedure, not integrated Specialised central authority approves EIA/SEA, advises on AA	EIA/SEA integrated in existing permit and planning procedures Permitting or planning authority approves EIA/SEA, but a specialised commission acts as independent expert body	EIA/SEA integrated in existing permit and planning procedures Permitting or planning authority approves EIA/SEA, but independent Expert body gives advice	SEA not applicable to port related activities Implemented into sectorbased and overarching development control regime
	Courts exercise marginal control			

We analysed as examples the enlargement of the navigation channels in the Ems and **Scheldt** estuaries, dredging of the approach channel to the port of Immingham (**Humber**), several major port development and capital dredging projects in the Stour and Orwell estuaries, and the construction of Container Terminal 4 in the **Weser**.

Our recommendations for good practice and innovative solutions on how to manage uncertainties take into account the different phases of a project (the current situation, project assessment, permits and derogation, mitigation and compensation, and monitoring and evaluation). These in general follow those of good integrated management.

Management Initiatives and Governance

Summary

The management and resulting management plan should be:

- based on a good knowledge not only of the natural science but also the administrative and legislative framework;
- based on a logical approach and founded on priorities and agreed objectives;
- aware of national and European implementation of Directives and their overlap;
- cross-sectoral in preference and integrated but if they are sectoral they must still engage all users;
- enacted at the level of the whole estuary;
- supported by legislation where possible but non-statutory plans may still be successful;
- adequately funded and with commitment by stakeholders not only to derive the plan but also its implementation.
- understand and share information on the baseline conditions e.g. the physical processes and morphological evolution
- have early consultation with relevant stakeholders, in order to involve stakeholders from the start of the project;
- use an adaptive strategy to overcome knowledge gaps;
- choose an appropriate communication strategy, e.g. appropriate language;
- find synergies or at least increase awareness of conflicts and consider regional differences, and
- use conditions on permits to deal with scientific uncertainty.

In addition, we need to take precautionary compensation into account for the potential failure of an untested mitigation measure. This can be: an adaptive strategy, a long term forum with stakeholders for reporting financial safeguards, a legal agreement for corrective measures and, under extreme cases, stopping the project.

7 Management measures

42 Management Measures

Evaluation of Measures

Aspects related to Sedimentation, Site Selection and Design of Management Measures

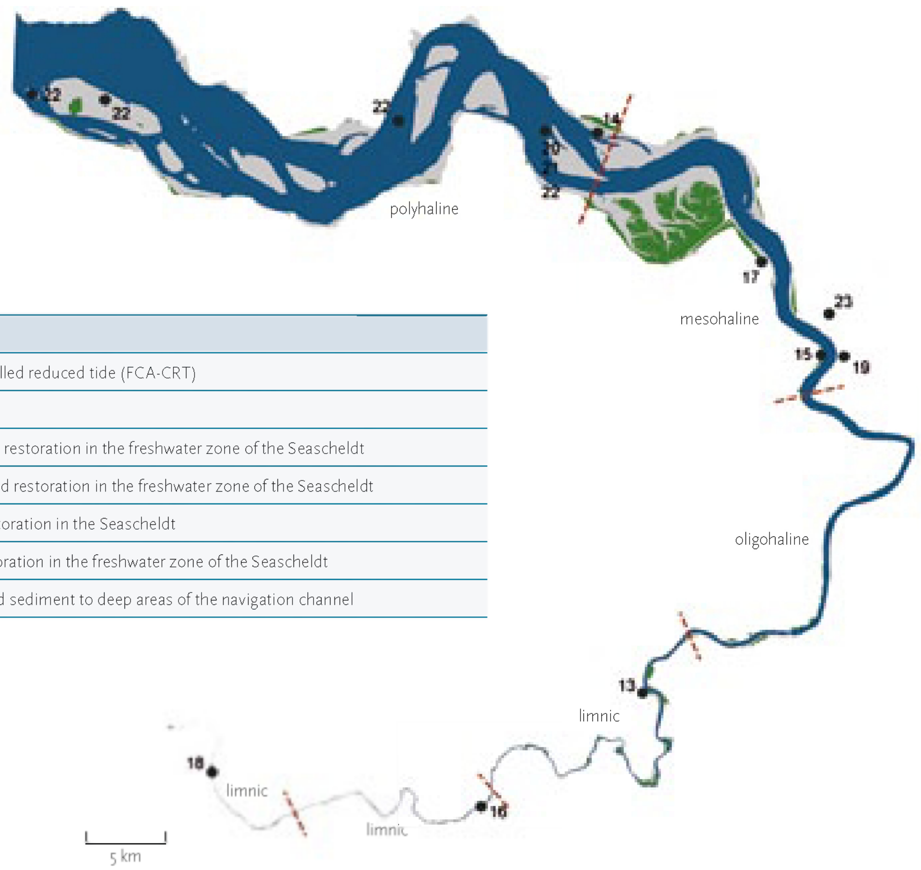
Recommendations

Management measures

42 Management Measures

The many demands on estuaries and challenges faced by estuarine users produce actual or potential problems which must be addressed using management measures. In TIDE, we have considered 42 management measures which either have already been implemented or are at a firm planning stage (for example, 11 measures for the **Scheldt**).

Locations of management measures in the Scheldt



Nr.	Measures
13	Lippenbroek – flood control area with controlled reduced tide (FCA-CRT)
14	Groynes at Waarde
15	Ketenisse wetland – small scale tidal wetland restoration in the freshwater zone of the Seascheldt
16	Paddeback wetland – small scale tidal wetland restoration in the freshwater zone of the Seascheldt
17	Paardenschor – small scale tidal wetland restoration in the Seascheldt
18	Heusden LO – small scale tidal wetland restoration in the freshwater zone of the Seascheldt
19	Schelde pilot project 2: Relocation of dredged sediment to deep areas of the navigation channel
20	TIDE pilot: Relocationof dredged sediment to shallow water area at the edge of the Walsoorden sandbar (2004)
21	TIDE pilot: Relocation of dredged sediment to a shallow water area at the edge of the Walsoorden sandbar (2006)
22	TIDE pilot: Relocation of dredged sediment to four shallow water areas at the edge of sandbars (2010)
23	Vispaaiplaats – Fish spawning pond

The **measures are related to different targets**, for example to develop and/or protect specific habitats or species (measure category 'Biology/Ecology'), to reduce tidal energy, tidal range, tidal asymmetry and tidal pumping effects, to improve morphological conditions or for flood protection. Most measures aim at biological and ecological development targets whilst others are assigned to the measure categories 'Hydrology/Morphology' and 'Physical/Chemical Quality'.

Pilot projects
Throughout TIDE, we have analysed specific aspects of several pilot projects:

- Evaluation of the Sediment trap near Wedel (**Elbe**): effectiveness of related monitoring programmes;
- Potential Alternative uses of Dredged Material in the **Humber**: using both capital and maintenance dredged materials for uses other than targeted beneficial disposal;
- Sediment relocation to shallow water near Walsoorden sandbar (**Scheldt**): feasibility of sediment disposal near the sandbar aimed at improving the physical and ecological status;
- Morphological management of estuaries (**Scheldt**): the concept of using morphological management aiming to harmonise various estuarine functions;
- Restoration of a tidal foreland in the Werderland region (**Weser**): developing uniform foreland pasture into typical tidal aquatic habitats related to coastal protection and port accessibility using of stakeholder involvement;
- Hard substratum Habitats in the Outer **Weser**: field study on ecological significance of geo- and biogenic habitats;
- Anabranch Revitalisation of the Lower **Weser** Estuary: the ecological effectiveness of various revitalisation scenarios;
- Secondary channels in European estuaries (**Weser**): occurrence and importance of secondary channels; boundary conditions of self-sustaining systems;
- Mitigation measures at the estuarine mouth (**Elbe** and **Scheldt**): the suitability of the chosen location.

The pilot projects primarily address a particular question for a given estuary but they also provide results transferable to other similar estuaries elsewhere.

7

Evaluation of Measures

In TIDE, we have determined the effectiveness of measures relating to **development targets**, according to monitoring and/or modelling results and 'expert knowledge'. Furthermore, we investigated the effect of the measure on the **delivery of ecosystem services**, the achievement of conservation objectives for **Natura 2000 sites** and attaining Good Ecological Status under the **Water Framework Directive (WFD)**. Estimating potential conflicts and synergistic effects of the actual or planned measures related to WFD targets was based on identifying the main pressures in single estuary zones. We included the success or failure of the measure, implementation costs, potential co-benefits, i.e. win-win opportunities, lessons learned and gaps in knowledge.

Achieving Natura 2000/WFD Requirements

Although most measures were originally not designed to meet WFD or Natura 2000 requirements, we have identified multiple positive effects targeting the main pressures. Neutral effects were also stated but negative effects were not indicated. In many cases, we found several potential synergistic effects related to WFD requirements especially in the measures assigned to the category 'Biology/Ecology'. However, despite the dynamic nature of estuaries, measures were sometimes aimed at a static target. As sedimentation, erosion and the development of vegetation are natural processes of restored estuarine habitats, the character of the estuarine habitat will inevitably change (e.g. a mudflat will evolve to marsh). Therefore, the measure's success can be improved by formulating dynamic goals (e.g. marshland with mudflats and creek development). This needs an **adaptive management** approach which accommodates natural development and anthropogenic demands and changes.

Delivery of Ecosystem Services

The different measures also contribute to the delivery of ecosystem services and so to show the potential co-benefits of the studied management measures, we translated the targets into ES terms.

Translation of measure targets into ES terms

Target	Corresponding Ecosystem Service
Safety	R1 – Water quantity regulation: dissipation of tidal and river energy R4 – Reg. of extreme events: flood water storage R12 – Erosion and sedimentation regulation by water bodies
Habitat conservation/restoration	S – Habitat services
Compensation	S – Habitat services
Research	C3 – Cult. Information for cognitive development
Access opportunity and education	C4 – Cult. Opportunities for recreation and tourism

ES benefits were identified for most of the measures including high positive scores for habitat, regulating and cultural services. Only the expected impact on provisioning services is limited. The expected impact of the measures on the different beneficiaries is mainly indirect, related to the future use of the area, and on a local or regional scale. Overall, the measures generate many co-benefits for ES are positively impacted and the largely positive ES assessment for most TIDE measures results from the measure selection. Since most measures considered are biodiversity-targeted and examples of good practice, high scores for supporting, regulating and cultural services are expected while the anticipated impact on provisioning services is limited.

ES analysis results for all TIDE measures

Legend: expected impact*	
3	very positive
2	positive
1	slightly positive
o	neutral
-1	slightly negative
-2	negative
-3	very negative
X	Targeted ES

				Ecosystem services																			
				"Biodiversity"	Erosion and sedimentation regulation by water bodies	Water quality regulation: reduction of excess loads coming from the catchment	Water quality regulation: transport of polutants and excess nutriënts	Water quantity regulation: drainage of river water	Erosion and sedimentation regulation by biological mediation	Water quantity regulation: transportation	Water quantity regulation: landscape maintenance	Climate regulation: Carbon sequestration and burial	Water quantity regulation: dissipation of tidal and river energy	Regulation extreme events or disturbance: Wave reduction	Regulation extreme events or disturbance: Water current reduction	Regulation extreme events or disturbance: Flood water storage	Water for industrial use	Water for navigation	Food: Animals	Aesthetic information	Inspiration for culture, art and design	Information for cognitive development	Opportunities for recreation & tourism
Estuary	Measure	Zone	Categ.	S	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	P1	P2	P3	C1	C2	C3	C4
Elbe	Spadenlander Busch	Fresh	HB	3	3	1	1	1	1	o	1	1	1	o	1	1	1	o	o	2	3	3	2
Elbe	Medemrinne Ost	Meso	H	1	1	o	1	o	o	1	o	o	o	o	o	o	o	o	o	1	1	1	1
Elbe	Current deflection wall	Fresh	H	1	1	o	1	o	o	o	o	o	o	o	o	o	1	1	o	1	1	1	1
Elbe	Current direction control	Fresh	H	1	1	o	1	o	o	o	o	o	o	o	o	o	1	1	o	1	1	1	1
Elbe	Sediment trap Wedel	Fresh	H	1	1	o	1	o	o	o	o	o	o	o	o	o	1	1	o	1	1	1	1
Elbe	Hahnöfer Nebenelbe	Fresh	HB	-1	o	o	1	o	-1	o	-1	-1	1	-1	o	-1	o	o	1	-1	o	o	1
Elbe	Wrauster Bogen	Fresh	B	3	3	3	o	o	2	o	2	3	o	1	1	3	o	o	o	3	3	3	2
Elbe	Hahnöfer Sand	Fresh	B	3	3	1	o	1	2	o	2	2	1	1	1	1	o	o	o	2	2	2	1
Elbe	Spadenlander Spitze	Fresh	B	3	3	3	o	o	2	o	2	3	o	1	1	3	o	o	o	3	2	2	2
Elbe	Reed settlement Haken	Fresh	B	3	2	3	o	o	2	o	2	3	-1	1	1	3	o	o	o	2	2	2	2
Elbe	METHA	Fresh	B	1	1	o	1	o	o	o	o	o	o	o	o	o	1	1	o	1	1	1	1
Elbe	Managing Reiherstieg sluice	Fresh	P	1	1	o	1	o	o	o	o	o	o	o	o	o	1	1	o	1	1	1	1
Schelde	Lippenbroek	Fresh	HB	3	3	3	o	o	2	o	2	3	o	1	1	3	o	o	o	3	2	2	2
Schelde	Groynes Waarde	Meso	B	2	1	1	o	o	1	o	1	1	1	1	1	o	o	o	o	1	1	1	1
Schelde	Ketenisse wetland	Meso	B	2	2	1	o	o	1	o	1	1	1	1	1	1	o	o	o	1	2	1	1
Schelde	Paddebeek wetland	Fresh	B	3	3	3	o	o	2	o	2	3	o	1	1	3	o	o	o	3	2	2	2
Schelde	Paardenschor wetland	Meso	B	3	3	2	o	o	2	o	2	2	2	2	1	o	o	o	o	3	3	2	2
Schelde	Heusden LO wetland	Fresh	B	3	3	3	o	o	2	o	2	3	o	1	1	3	o	o	o	3	2	2	2
Schelde	Sediment relocation Ketelplaat	Meso	H	1	1	o	1	o	o	1	o	o	o	o	o	o	o	1	o	o	1	1	1
Schelde	Walsoorden 2004	Meso	B	1	o	1	-1	o	1	-1	1	1	2	o	1	o	o	o	o	o	o	o	o
Schelde	Walsoorden 2006	Meso	B	o	o	1	-1	o	o	-3	1	o	1	o	o	o	-2	-3	1	o	o	o	o
Schelde	Sandbars 2010	Poly	B	1	o	1	-2	o	1	-3	2	1	3	o	1	o	-2	-3	1	o	o	o	o
Schelde	Fish pond	Meso	B	3	3	1	2	1	1	o	2	1	3	o	1	o	o	o	1	2	2	2	2
Weser	Tegeler Plate	Oligo	B	3	3	2	o	o	2	o	3	3	2	2	2	3	o	o	1	3	3	3	2
Weser	Shallow water area Rönnebecker Sand	Fresh	HB	3	3	3	1	o	2	1	2	2	o	1	1	2	o	1	o	2	2	2	2
Weser	Vorder- und Hinterwerder	Fresh	HB	3	3	2	1	o	1	1	1	2	o	o	1	1	1	1	o	2	2	2	2
Weser	Kleinensieler Plate	Fresh	B	3	3	3	o	o	2	o	2	2	o	1	1	2	o	o	o	2	2	2	2
Weser	Cappel-Süder-Neufeld	Poly	B	3	3	3	1	o	3	o	3	3	1	2	1	1	o	o	o	3	3	3	3
Weser	Werderland	Poly	B	3	3	3	1	o	3	o	3	3	2	1	1	1	o	o	o	3	3	3	3
Humber	Alkborough SM	Meso	HB	3	2	2	o	o	2	o	2	2	1	1	1	1	o	o	o	2	2	2	2
Humber	PHS SM	Poly	B	3	3	3	1	o	3	o	2	3	1	1	1	1	o	o	o	2	2	2	3
Humber	MudBug SM		B	1	1	o	1	o	o	o	o	o	o	o	o	o	o	o	o	1	1	1	1
Humber	Choweder Ness ABP mer SM	Meso	B	2	2	1	o	o	1	o	1	1	2	1	1	o	o	o	o	2	2	1	1
Humber	sluice at Doigs Creek at Grimsby		B	2	1	o	o	o	o	o	o	1	1	1	o	o	o	o	o	1	1	2	1
Humber	Welwick		B	3	2	2	o	o	2	o	2	2	1	1	1	o	o	o	o	2	1	2	2
Humber	Beacon Lagoon		B	1	1	1	o	o	1	o	o	1	o	1	o	o	o	o	o	1	1	1	1

Managed Realignment Measures

We paid particular attention to Managed Realignment Measures (MRM) as habitat restoration which account for almost half of the estuarine measures studied. Two specific types of MRM were analysed:

- Basic managed realignment ('dyke-realignment', 'de-polderisation') involving the 'setting back of the line of actively maintained defences to a new line inland of the original and promoting the creation of intertidal habitat between the old and new defences', this habitat being open to regular tidal exchange.
- Regulated tidal exchange (RTE) where a similar process to the basic managed realignment technique is used, but with tidal inundation being manipulated for a specific management aim (e.g. increased or reduced sediment deposition within the site).

In the TIDE estuaries, we assessed 17 managed realignment measures (MRM) with an average size of 63ha, ranging from 1.6ha to 440ha (only two cases had areas larger than 100ha).

Elbe | Spadenlander Busch/Kreetsand
© HPA

Scheldt | Lippenbroek FCA-CRT
© APA

Weser | Shallow water zone Kleinensieler Plate
© WSA Bremerhaven

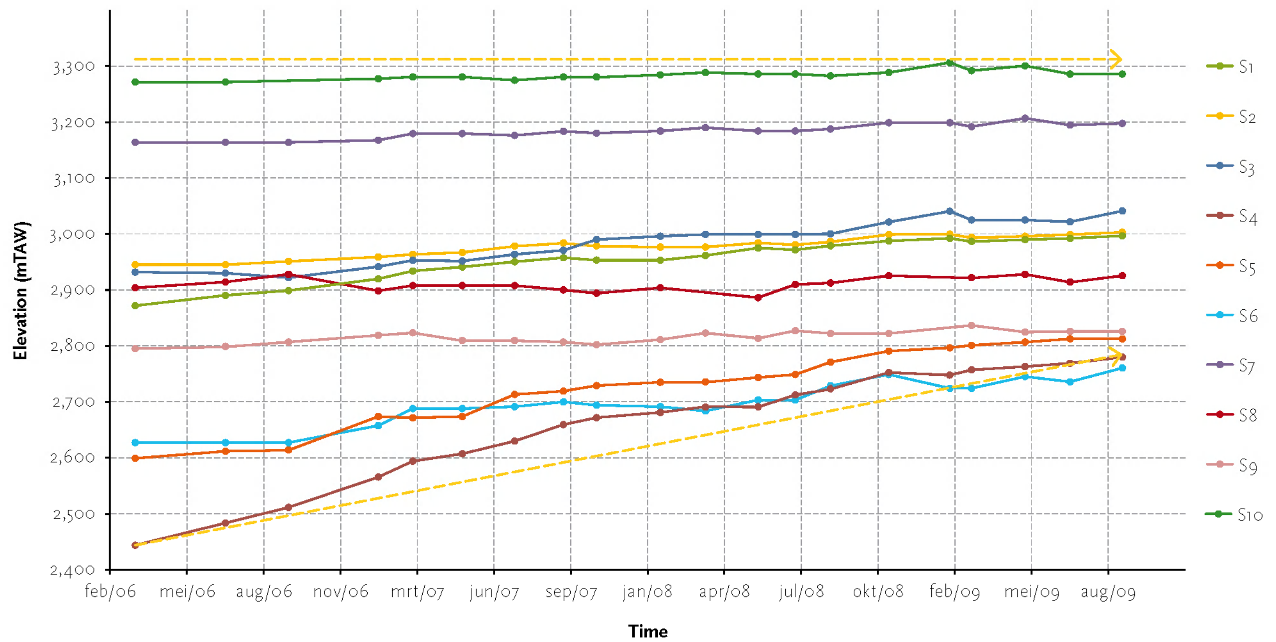
Humber | Creation of ~13 ha intertidal habitat at Chowder Ness © Environment Agency

Half of the TIDE MRM are located in the **freshwater zone** of the estuaries and the other half spread along the remaining three salinity zones. The MRM have been implemented for different targets such as habitat conservation, restoration or creation. Only a few cases combined this conservation target with a safety target (flood storage capacity), research target, and/or recreation opportunities.

Overall, the **degree of target achievement of MRM** is high and reached by almost half of the measures whereas not all targets were completely reached in the remainder. However, in some cases the degree of target achievement could be improved by just slightly adapting the MR site e.g. regarding the design of the inlet or the elevation of certain parts of the measure area to increase the effectiveness and minimise siltation.

There are several aspects relating to the location and design of a measure which influence its success such as choosing the appropriate elevation. Spatial **differences in elevation** in the area influence spatial patterns of accretion and saltmarsh vegetation, with implications for the habitat development, benthic invertebrate diversity and bird usage of the site. Elevation and accretion rates inside the realignment site are inversely related as a consequence of the tidal regime, i.e. lower areas of elevation will flood at a higher frequency and for longer periods of time potentially resulting in more sediment being deposited. There is a positive relationship between inundation (frequency and duration) and the accretion rate and hence with elevation, as can be seen for example at the measure Lippenbroek (**Scheldt**). Hence, an inappropriate elevation could mean specific site objectives (e.g. marsh development) are not met. Areas that are located much lower than mean high water level (MHWL) for example are constantly flooded and hence vegetation development is suppressed. Old polders, which are often used as project sites, are however usually located much lower than MHWL due to increasing water levels and their location.

Elevation changes in the time following sedimentation at 10 sites of Lippenbroek (Scheldt)



MRM generate many synergies between nature conservation, flood protection and public safety, port development, recreation and natural resources, but there are also conflicts with agriculture and local inhabitants. They are expensive but could also generate large benefits, for example, the relative implementation cost of the TIDE MRM cases averaged ca. 280,000 €/ha ranging between 16,000 and 1.4 M €/ha, depending on the design, location, local boundaries and need for lowering the site.

The TIDE MRM produce benefits for at least 12 of the 20 ES considered, especially for habitat services and cultural services and partly for regulating services but not for provisioning services for most measures. On average, only 10% of the ES achieving benefits were initially targeted by the measure and although most ES were not targeted by the measure, they still showed benefits.

The **valuation of ES** is proposed as a tool for estuarine managers to assess the overall impact of management measures. It could also help in decision-making to select the most sustainable management measures. Although different monetary valuations of ES exist with often different outcomes, TIDE obtained an approximate indication of the monetary benefits of the MRM. By multiplying available global monetary data for different ecosystems with the habitat created in the MRM, our examples showed an annual average benefit of 133,000 €/ha. This financial gain is limited to the benefits generated within the estuary itself but excludes those from the lost land.

We describe and give guidance on a methodology for the monetary valuation of ecosystem services for estuarine managers. This state-of-the-art methodology is based on best available data.

Aspects Related to Sedimentation, Site Selection and Design of Management Measures

High amounts of suspended sediments (SPM) and their deposition in accreting areas are a common feature in many estuaries, and the resulting problems for estuarine management are increased by developing ports, navigation channels and realignment sites in those accreting areas. Increased accretion in ports and channels increases maintenance costs whereas in shallow habitats this may reduce fish and bird feeding areas and thus the ecological carrying capacity. Further, high sedimentation rates may prevent us achieving the targets of a measure, such as enlarging hallow water habitats. As sedimentation is governed by many factors, there are some ways of reducing its negative consequences. For example, the location of a MRM is important in determining both global and local sedimentation and erosion processes which are key to the success of the MRM. The important processes include the hydrodynamics of the area, salinity gradient, SPM content, location of the turbidity maximum zone in relation to the planned location of the measure, the number and position of breaches, and the tidal elevation and inundation for habitat development and/or for flood storage capacity. A **good understanding** of the relationships between currents, tidal range and sediment transport is needed when attempting to alter the system. This may include applying an **adaptive strategy** based on model forecasts or large scale experiments.

Sediment Management Strategies

Our comprehensive comparison of sediment management strategies of the TIDE estuaries, including for example development of traffic and shipping channels, dredging amounts and types of relocation, shows the optimal dredging location to guarantee port access. Sediment management practice has developed over time especially in those estuaries where unfortunately the ports are located in sediment accreting areas. Such practice has had to adapt to natural, technical, biogeochemical, administrative and boundary conditions and legal requirements but has had the benefit of an improving knowledge base. Therefore site-specific strategies not only include the dredging process itself but also adaptive sediment use and disposal strategies, morphological management, and sediment quality issues.

Successful management requires the greater integration of sediment management approaches to accommodate current changes in the environmental and nature conservation regulations but with also reducing port costs and accommodating more frequent undesired morphodynamic developments such as increased tidal pumping. Therefore modern sediment management strategies need to consider the whole estuarine system. More ambitious strategies aim at influencing sediment transport patterns and amounts or at preventing the entry of sediments into a certain area and contribute, as far as possible, to a balanced development of the estuary.

By comparing the experience in our estuaries, TIDE has been able to make recommendations to both achieve user objectives and reduce potential conflicts.

Recommendations

In general the overall success of a management measure should be judged on the extent to which the different development targets and objectives are met. Hence the targets have to be SMART (specific, measurable, achievable, realistic and time-dependent).

Summary and recommendations for planning and implementing a management measure:

Summary

- **firstly and most importantly, define and stick to SMART targets;**
- **analyse the pressures within the respective estuary section;**
- **analyse conflicts, synergistic effects, benefits and co-benefits related to other targets;**
- **consider the fundamental hydrodynamic, geomorphological and ecological processes;**
- **formulate dynamic goals, including the improved delivery of ecosystem services over time trajectory;**
- **incorporate lessons learned from previous and on-going projects;**
- **work with the natural system, not against it;**
- **minimise land manipulation and accommodate the existing topography;**
- **monitor the development of the measure and demonstrate the degree of target achievement, and**
- **make the results available to other estuary managers.**

8 Monitoring

Types of Monitoring
Opportunities for Standardisation
The Pyramid Approach of Monitoring

Monitoring

It is unquestionable that 'you cannot manage anything unless you can measure it' and hence the success of each management strategy and measure depends on whether the progress is appropriately monitored. The various policy frameworks including EU environmental directives require monitoring whether by a developer or a statutory/competent authority. In most cases, permission is granted for a development or an activity on condition that monitoring is performed.

Therefore, decisions need to be based on good knowledge based on adequate measurements. We have to define beforehand what we want or need to know, then the right parameters have to be measured in the right way, in the right place and with the right frequency. Subsequently the data have to be properly processed, stored and made available.

Types of Monitoring

There are different types of monitoring and each of these are defined in different EU Directives:

- **Situation, condition and trend monitoring** implies an intensive programme to evaluate pressures and assess long term trends.
- **Operational monitoring** implies monitoring the effects and especially the success of implementing a programme of measures.
- **Compliance monitoring** implies the monitoring required to determine whether or not a licence/permit/authorisation/consent has been met.
- **Investigative or diagnostic monitoring** implies further study to determine causal relationships leading to observed changes, thus increasing our understanding and providing the necessary information for drawing up measurement programmes in case of exceptions.

Fieldwork
© Silinski

Additionally, there is a distinction between **effect monitoring** and **system monitoring**. The latter is a long term monitoring programme to collect all necessary data to evaluate the functioning of the system. To evaluate effects of individual measures on accessibility, safety and ecology additional monitoring can be required, limited in space and time. Hence **effect monitoring** consists of an increase in monitoring frequency or additional parameters, a targeted programme nested within the system monitoring scheme.

Opportunities for Standardisation

Apart from the need to integrate policy and monitoring efforts, our inter-estuarine comparison revealed monitoring differences and hence the opportunities for monitoring standardisation. For example, suspended matter, a crucial parameter for interpreting sediment transport, turbidity, primary production, sedimentation, erosion and – as shown for the **Humber** – even water quality, are monitored differently in different estuaries, making the comparison and exchange of knowledge more difficult.

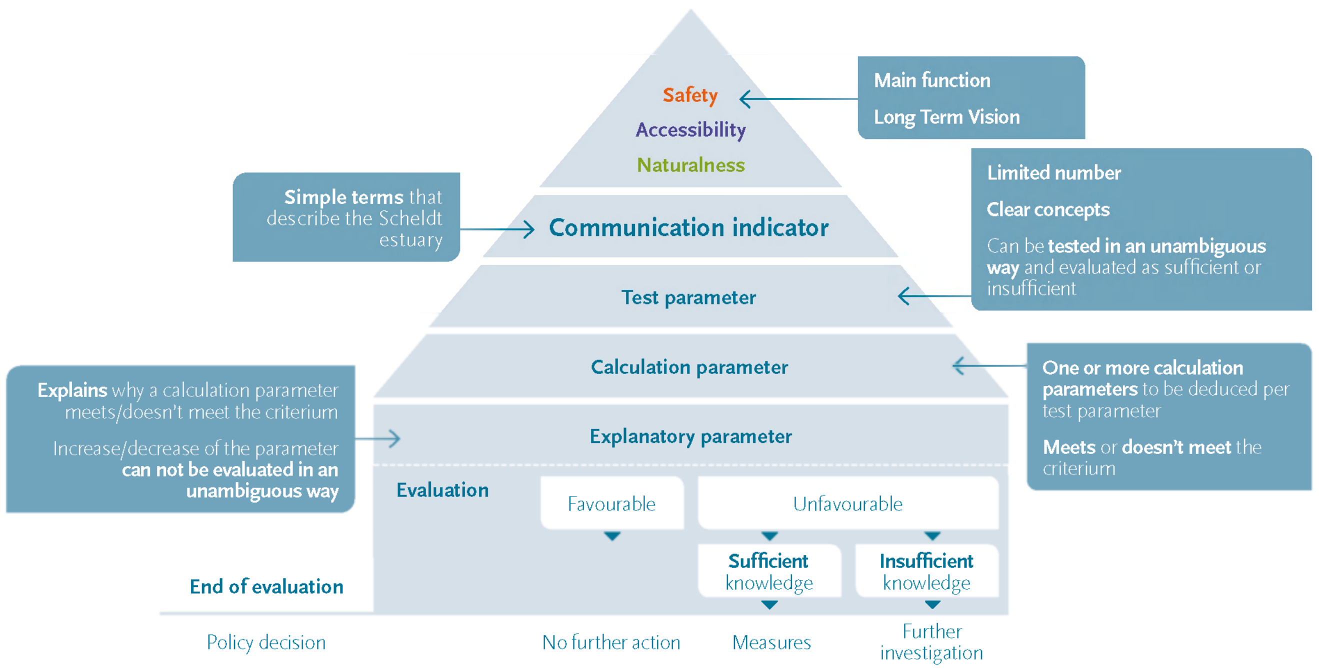
Therefore, in TIDE we have proposed a standard monitoring approach that can be used to cover all purposes with detailed, fully described methods. Experience from the **Scheldt** has shown that the application of standard methods and a well-defined approach can effectively reduce monitoring costs and overlaps and thus optimise the monitoring programme. Furthermore, we have shown that monitoring results can improve communication and the criteria of decision making by a limited set of communication indicators which are built up in a pyramid approach. Therefore the **Scheldt** serves as an example to fulfil the three main functions of estuaries namely accessibility (navigation), safety (against flooding) and naturalness (ecology).

8

The Pyramid Approach of Monitoring

We have shown that monitoring can improve both communication and the criteria of decision-making using a limited set of indicators. A system was developed for the **Scheldt** where the three main functions of estuaries namely, accessibility (navigation), safety (against flooding) and naturalness (ecology), were assessed using a hierarchical approach of indicators presented in the form of a pyramid.

Diagram of the pyramid approach for monitoring



At the top of the pyramid one can find the communication indicator, which is evaluated by the lower levels.

- **Level 1:** Directly below the communication indicator are the test parameters: a limited, yet complete set of parameters which can be used to evaluate unambiguously the status or trend of the communication indicator.
- **Level 2:** Each test parameter consists of one or more calculation parameters. A clear test criterion has been designed for each calculation parameter. All the calculation parameters combined determine whether changes in a test parameter are favourable or unfavourable for the functioning of the system.
- **Level 3:** At the bottom of the pyramid is a set of explanatory parameters aimed mainly to help to understand the observed changes and to a lesser extent to evaluate the changes. The explanatory parameters themselves cannot be evaluated independently.

This tool offers an effects assessment on different scales and proportional to the problem being tackled. It results in monitoring which is scientifically, technically and legislatively defensible, cost effective, and that provide sufficient information to evaluate the impacts of the activities and management measures.

Summary

TIDE provides a scheme giving different monitoring levels that can be used to cover all purposes with detailed, fully described methods. Experience from the Scheldt has showed that the application of standard methods and a well-defined approach can effectively reduce monitoring costs and overlaps and optimise the monitoring.

9

TIDE Toolbox

TIDE Toolbox

Estuarine management, its institutions and stakeholders cover a wide range of aspects and interests, have different levels of knowledge, and different ways of approaching a challenge and may require one or more particular tools.

Much valuable information related to integrated estuarine management has become available. This summary can only give a broad overview of the project results which will support estuarine managers in their work. More information on estuarine functioning, experiences and recommendations related to the implementation of management plans and measures, and tools are presented at the website TIDE toolbox → **www.tide-toolbox.eu** for managers, stakeholder and the general public.

Firstly, essential knowledge on the historical evolution of the four estuaries, their functioning and the delivery of ecosystem services is provided from which societal benefits can be derived. Following this, the existing management initiatives and plans within the TIDE estuaries are made available after being subjected to a SWOT analysis to present good/best practices. We have enabled managers to determine which are the uses and users and whether there are conflicts between these. This knowledge enables the implementation of appropriate management measures and restoration projects. In total 42 management measures and pilot projects related to different management topics, for example habitat restoration or sediment transport, have been evaluated. To be successful, governance initiatives and measures must be embedded in an appropriate communication and information programme, hence we present the relevant experiences and lessons learned.

Tools in this toolbox include

- recommendations concerning certain methodologies, templates,
- specific reports and their summary,
- a generic roadmap for integrated management including the instructions for performing an Environmental Impact Assessment and an Estuarine Planning Support System (EPSS),
- an interactive bird disturbance tool to assist managers characterise the likely impact of a proposed activity on components of Natura 2000 waterbird communities, including both noise and visual disturbance effects mitigation.

Finally an overall summary report brings together all the different aspects as applied for the four TIDE estuaries. The website allows the user to scroll down in a document and enlarge graphs and tables, but the products can also be downloaded freely as .pdf documents and stand-alone tools.

The toolbox provides several ways to approach the diverse TIDE products according to the user's preference:

- select a specific report from the list of reports;
- choose between the summary or the whole report;
- search one or several related reports by keywords compiled in a glossary;
- select your specific question/management issue from a list (management issues);
- browse the list of tools;
- browse the list of management measures that may serve as good practice.

Screenshot of toolbox website

TIDE Project Partners

Ten partners from port administrations, universities, and public and environmental agencies founded the project to propose the integrated management of estuaries leading to benefits for ecology, economy and society:

- Hamburg Port Authority (Germany, Lead Partner)
- Lower Saxony Water Management, Coastal Defense and Nature Conservation Agency (Germany)
- Rijkswaterstaat (Middelburg, The Netherlands)
- Flemish Authorities Department of Mobility and Public Works (Belgium)
- Antwerp Port Authority (Belgium)
- University of Antwerp (Belgium)
- Free Hanseatic City of Bremen (Germany)
- University of Bremen (Germany)
- Institute of Estuarine and Coastal Studies, University of Hull (United Kingdom)
- Environment Agency (United Kingdom)

Although not a funded partner, Associated British Ports (United Kingdom) also contributed greatly to the Humber aspects of the project, as well as the Federal Institute of Hydrology (Germany) for the Elbe aspects.

TIDE aimed to share the knowledge and the experiences made with other interested or responsible people, institutions and stakeholders at a regional, national and international level.

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