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TIDE Tidal River Development

Management of Estuaries

The need to understand nature & society

TIDE summary report

TIDE Project Partners

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Executive Summary

The big challenge of estuarine management is to maintain existing estuarine natural structure and functioning, to rectify historical damage and negative impacts of human actions which produced socio-economic problems, and at the same time to guarantee present and future economic development. At the same time it is widely accepted between scientists as well as estuarine policy implementers that the only way to master the challenge is to apply a multidisciplinary and functional, holistic approach in order to maintain a healthy natural system. In addition such a management strategy can reduce management costs and increase benefits for the actual existing society by avoiding conflicts between different interests.

We have applied the Ecosystem Approach as a strategy for the integrated management of estuaries as it promotes conservation and sustainable use in an equitable way. Further it recognises that humans are an integral component of ecosystems and leads to benefits for ecology, economy and society. Following this, we have used the Ecosystem Services Approach as a means of quantifying the potential benefits of a well-functioning and sustainable estuary.

We show how and which ecosystem services are delivered with spatial variability among habitats and between the different case estuaries Elbe (Germany), Humber (UK), Scheldt (The Netherlands, Belgium) and Weser (Germany). A precondition for applying the Ecosystem Services Approach is a fundamental knowledge of the system functioning in relation both to natural and anthropogenic features as well as its transfer to the responsible estuarine policy makers and implementers. Furthermore, the application of appropriate scientific methodologies has focused on levels of biological organisation which encompass the essential processes, functions and interactions among organisms and their environment. We used various techniques and existing knowledge of regional working groups and tested new approaches for describing and comparing the four case estuaries. These investigations show that although having basic structures and processes in common, each estuary has unique functional characteristics.

Based on the analyses of the four estuaries, for example, water quality parameters and the occurrence of birds, we highlight the fact that the connectivity of estuarine systems both with adjacent areas and with a network of habitats at a larger spatial scale is of major importance in ensuring that the estuarine functions are fulfilled. Estuarine ecosystems not only provide local processes but also sustain biodiversity at a wider scale, e.g. via the net export of energy to other ecosystems, or the input of various substances from the catchment and their transport to the sea. The maintenance of the connectivity with other systems is considered as an important element in the management of these systems e.g. for compliance with EU directives, the identification of potential user conflict scenarios as well as in the identification of suitable and effective mitigation and compensation measures.

For the assessment of management measures being carried out in the four case estuaries the Ecosystem Services Approach has been applied as one criterion. As a result we have shown that, for example, in addition to their main goal to create, restore or conserve estuarine habitats, managed realignment measures often have positive impacts on several ecosystem services, for example, on those related to recreation or flood protection which can improve the measures acceptance by the wider stakeholder audience. A 10-step approach has been developed to evaluate the impact of any particular management measure. Based on the available data the impact of the management measure on the different estuarine services could be calculated both in bio-physical and in monetary terms. These results can be used in decision making processes.

The evaluation of the development of single services, the success of management measures as well as that of any management strategy depends on whether its outcome is monitored appropriately, i.e. the right amount of the right parameters at the right location. In times of financial shortcomings it is important that monitoring programmes are cost-effective and fit-for-purpose. The latter relies on the fact that the chosen indicators should be ecologically relevant, be understandable and interpretable also by non-scientists, and reflect the changes against the system natural variability. Hence we have to have sufficient data which should be maintained in a common, widely-available way. They should not only allow the evaluation of a management strategy or operational objective, but lead to a true understanding of the functioning and development of the whole system. We propose a standard monitoring approach that can be used to cover all purposes with detailed, fully described methods: the Pyramid approach.

Finally it is self-evident in heavily used systems such as estuaries that there are many conflicts between different users. However, whilst many high level management needs are generic across these estuaries, there are clear differences in priorities for specific management actions, and these vary both between estuaries and, as the usage potential is not uniform, also along any single estuary. As such, management needs to reflect the spatial and sectoral interaction variability and then target resources at specific areas. We consider estuary-specific surveys which identify stakeholder issues a useful tool to confirm key areas of conflict, and incorporate local variations in both spatial and sectoral severity. Such surveys also have the potential to identify areas where wider public participation and education may assist the integration process. Such methods, i.e. the ´Conflict Matrix Approach´ can include the Ecosystem Services Approach which allows a value-based comparison of differing services (and thus uses), including those with no readily evident economic value such as aspects of nature conservation, heritage and landscape. Furthermore, the application of the Ecosystem Services and Conflict Analysis Approaches employed in this study has the potential to be combined to assist in effective management, particularly when used in combination with targeted measures.

Due to the dynamic nature of estuaries, an adaptive management approach is needed which accommodates natural development and anthropogenic demands and changes and which can accommodate changing boundary conditions e.g. requirements based on environmental legislation, developments in public opinion or the current financial situation. An adaptive approach also requires the implementation of a long-term forum with stakeholders for reporting results or any other vigorous follow-up mechanism. For example, competent public bodies are authorised to implement changes to a programme of mitigation or compensation and to take additional (predetermined) compensatory measures on the basis of the results of monitoring programmes (flexible approach). In order to be successful, integrated management plans should be implemented which should bridge existing gaps between different stakeholders and seek synergies between the natural environment and socio-economic requirements. Consequently we have analysed the strengths and weaknesses of management plans (SWOT analysis). As a result, the adoption of a Natura 2000 management plan, as a consequence of the implementation of the environmental European legislation i.e the Natura 2000 network, is already meeting a holistic approach. In addition to meeting environmental targets it also recognises the demands of society, in order to achieve the most sustainable outcome and to avoid conflicts between different uses.

The studies reported here were carried out from partners of the EU INTERREG IV B project TIDE (Tidal River Development). The supporting results and products for this summary report can be found at www.tide-toolbox.eu.

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1 Background and Introduction

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1.1 General considerations leading to the start of the TIDE project

Estuaries and the surrounding areas have long been important for mankind as they are preferred places for settlements and trade as shipping routes, and provide fertile agricultural soils, food and raw material. Estuaries are considered among the most productive ecosystems and are known for the delivery of many ecosystem services (Costanza et al. 1997; Elliott and Whitfield 2011).

As estuaries form the interface between the sea and their riverine catchment, they are therefore exposed to various influences and characterised by a highly dynamic environment and a high diversity of valuable habitats (e.g. marsh, intertidal mud- and sandflats, shallow and deep water areas, and rocky shores), and species. The constantly changing abiotic parameters, e.g. salinity, current velocity, water level, content of suspended matter, but also changes in morphology and habitat structures, form a challenge for the biota present (Day et al. 1989; Elliott and Quintino, 2007), requiring a high physiological adaptation of estuarine organisms and resulting in the occurrence of more generalists than specialists (Elliott and Whitfield 2011).

Estuaries are ecologically very valuable environments as they provide important migration routes for many fish species moving between freshwater and marine habitats, as well as serving as nursery, breeding, feeding and resting areas for many different species of fish and wading birds (McLusky and Elliott 2004). They additionally have great socio-economic value as they provide ideal sheltered locations for the establishment of settlements and trade hubs. Since settlement in these areas many centuries ago, the shape of estuaries has modified according to a societal demand for more space, supplies and trade. Consequently, these human activities and modifications (e.g. land claim, channel deepening and straightening for navigation, and the use of the water course for other diverse purposes such as discharging domestic waste water, or use as cooling water for industries and power plants), have been the source of many pressures on estuarine structures and processes. Even within the past century, valuable habitats such as marshes have been largely lost in many estuaries, and some estuarine species such as the sturgeon (*Acipenser sturio*) have become extinct in many estuaries (Lepage and Rochard 1995).

Given these pressures and losses, by the latter part of the 20th Century the need for co-ordinated governmental environmental protection was clear, and this resulted in the adoption of regional and national legislation and global agreements, including amongst others the Ramsar Convention (1971), Convention on Biological Diversity (CBD, 2000), the European Water Framework Directive (2000/60/EC), the Habitats & Species Directive (92/43/EEC), and the Birds Directive (2009/147/EC), which have set pivotal boundary conditions for estuarine management in Europe.

As a consequence, the implementation of the (inter)national environmental legislation led to conflicts between the multiple uses and users of estuaries, for instance, shipping, trade, tourism, fisheries, industry, human settlement, and their ongoing economic development. EU legislation, implemented through respective national enabling legislation, therefore requires, for example, an Environmental Impact Assessment (EIA), a Strategic Environmental Assessment (SEA) or an Appropriate Assessment (AA) to be undertaken for new developments in order to assess the impacts of a plan or project on the environment or specific features of the area prior to development, and with specific mitigation measures put in place as part of the development consent in order to address any areas of impact. These statutory assessment processes can often be time consuming with the outcome of the assessment not always entirely predictable and open to a degree of interpretation. In some cases, a final decision on whether a project has significant negative impacts or not – which is often not easy to decide because of a lack of knowledge or uncertainty of system response – requires a legal decision, for instance in recent cases of the deepening of the shipping channel of the Elbe and Weser estuaries (Germany).

It is therefore evident that estuary managers face many challenges as they need to ensure that the natural characteristics of their estuary are protected and maintained whilst at the same time safeguarding the present and future delivery of ecosystem services and benefits required by society such as ensuring the provision of valuable, productive and safe living, working and recreational space (Elliott 2011). Guidelines and/or recommendations on how to most effectively manage an estuary in order to fulfil economic aims as well as to safeguard ecological integrity are therefore required, and these are a focus of delivery for the TIDE project.

This chapter introduces the TIDE project and its approach. Both fundamental and other related considerations for the establishment of the project are then explained, including aspects of estuarine functioning, the delivery of ecosystem services, and estuarine management. Finally, the basic characteristics of the four case estuaries are described. We will provide links to the following chapters that present the results obtained for the four case estuaries, as well as conclusions or recommendations related to the topics in question.

1.2 The TIDE project

In order to address the challenges described above as well as providing the necessary ingredients for a sustainable estuarine management strategy, the TIDE (Tidal River Development) project was developed via funding from the EU through the framework of the INTERREG IV b programme. The ecological, economic and societal complexity of estuaries requires integrated management which is fundamental to achieving the Ecosystem Approach as defined by the global Convention on Biological Diversity (CBD 2000). The project has applied the concept of the Ecosystem Approach as a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way and eventually leads to benefits for ecology, economy and society. 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 basis of this approach is to understand the ecological structure and functions of the system which includes analysing its historical evolution. Inter-estuarine comparisons may provide a valuable approach for gaining a better insight into estuarine processes which eventually lead to the provision of ecosystem services (for a description of the concept and definition see Chapter 1.3) that in turn, result in the delivery of societal benefits.

In order to ensure the supply of ecosystem services, management initiatives and governance are required. However, within a multi-user system, it is necessary to identify ´what occurs where amongst estuarine users´, and to identify and analyse the existing conflicts amongst users in relation to the use of finite resources and legislative requirements. The knowledge obtained then can be used for the resolution of conflicts and the establishment of focussed management.

Successful estuarine governance relies on the implementation of management plans in which management measures are often required, in order to meet the targets of the plan. The implementation of the management measures as well as the plan itself requires dissemination with information provided to stakeholders and the local community in order to gain their acceptance. The TIDE project followed the approach shown in Figure 1.1. in order to contribute to an increased understanding of estuarine structures and processes and the delivery of ecosystem services, as well as to the provision of examples of good/best practice in the implementation of management measures. This increased understanding of the estuarine system has allowed us to derive recommendations for estuarine decision makers.

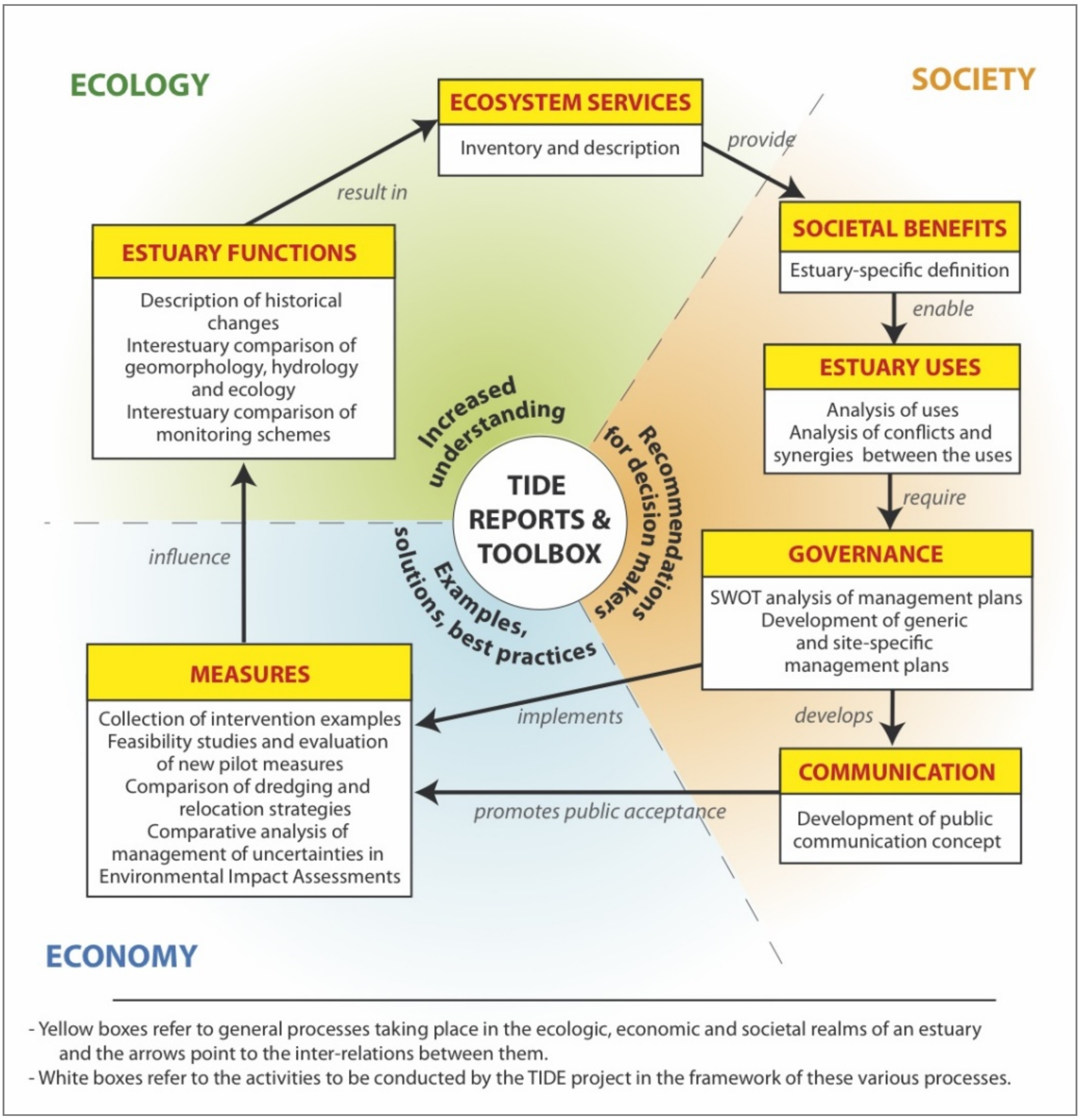

Figure 1.1. The TIDE Approach of Integrated Estuarine Management

The TIDE project has brought together relevant interdisciplinary scientific expertise and partners from various institutions related to estuarine science and management, such as environment agencies, port authorities, universities and waterways administrations. The work of the project partners was supported by Regional Working Groups consisting of representatives of administrative institutions and various stakeholders. The knowledge gained from this process has been, and will increasingly be, transferred to the broader public by conferences, workshops, lectures, and a website (www.tide-toolbox.eu). The project ran from January 2010 until September 2013, with the budget financed 50% by the INTERREG IVB North Sea Programme and 50% by the partners themselves.

The four estuaries Elbe, Humber, Scheldt and Weser in the North Sea Region were chosen as case studies as they face similar broad 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, i.e. the Habitats and Bird Directives (92/43/EEC, 2009/147/EC) because of their habitats, large fish nursery areas and large populations of over-wintering waterbirds (examples of the case estuaries are shown in Section 3.3).

1.3 Estuarine functioning and ecosystem services

The wealth of information on estuarine functioning and the large uses to which those estuaries are put have led to the agreement for a set of paradigms (Table 1.1). These paradigms indicate the essential connectivity of estuaries but also the links between the natural processes and the ecosystem services and societal benefits emanating from estuaries (Elliott and Whitfield 2011). Most importantly, in order to understand the causes and consequences of anthropogenic changes, there is the need to understand the natural functioning of the systems.

Table 1.1. Challenging paradigms in estuarine ecology and management (Elliott and Whitfield, 2011)

Topic	Subtopic	Paradigm Number
Natural science-based paradigms	Definitions, scales, ecotones and linkages	1: An estuary is an ecosystem in its own right but cannot function indefinitely on its own in isolation and that it depends largely on other ecosystems, possibly more so than do other ecosystems.
		2: As ecosystems, estuaries are more influenced by scale than any other aquatic system; their essence is in the connectivity across the various scales and within the water body they are characterised by one or more ecotones.
	Hydromorpho-logical and organic functioning	3: Hydromorphology is the key to understanding estuarine functioning but these systems are always influenced by salinity (and the resulting density/buoyancy currents) as a primary environmental driver.
		4: Although estuaries behave as sources and sinks for nutrients and organic matter, in most systems allochthonous organic inputs dominate over autochthonous organic production.
	Variability, resilience and redundancy	5: Estuaries are physico-chemically more variable than other aquatic systems but estuarine communities are less diverse taxonomically and the individuals are more physiologically adapted to environmental variability than equivalent organisms in other aquatic systems.
	Diversity, tolerances, stress, productivity	6: Estuaries are systems with low diversity/high biomass/high abundance and their ecological components show a diversity minimum in the oligohaline region which can be explained by the stress-subsidy concept where tolerant organisms thrive but non-tolerant organisms are absent.

Management -based paradigms	Pressures, valuing, valuation and management	7: Estuaries have more human-induced pressures than other systems and these include both exogenic unmanaged pressures and endogenic managed pressures. Consequently their management has to not only accommodate the causes and consequences of pressures within the system but, more than other ecosystems, they need to respond to the consequences of external natural and anthropogenic influences.
	Delivery and protection of ecosystem services	8: Estuaries provide a wider variety of ecosystem services and an increased delivery of societal benefits than many other ecosystems. Hence estuaries are one of the most valuable aquatic ecosystems serving human needs but for this to occur they require functional links with the adjoining terrestrial, freshwater and marine systems.

Societal economy, health and survival depends entirely, although often indirectly, upon the provision of many natural resources (Millennium Ecosystem Assessment MA, 2005) which are supplied by natural ecosystems - defined as a ‘dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit’ (CBD 2000). The capacity of ecosystems to regulate essential ecological processes through their structure, functions and biogeochemical cycles generates many ecosystem services (Rönnbäck et al. 2007). The resources and so-called ecosystem services have been defined in MA (2005) as ‘the benefits humans derive from ecosystems’. More recently they have been defined as ‘the direct and indirect contributions of ecosystems to human well-being’ (TEEB, The Economics of Ecosystems and Biodiversity 2010). Even more recent thinking (Atkins et al. 2011) considers that ecosystem services lead to and are required for the benefits taken by society even though they are not the benefits *per se*. As there are different definitions of these terms, these are discussed in detail in section 1.3.2. Despite this, the proper functioning of an ecosystem is a precondition for humans to be able to benefit from the system in many ways.

The term ´estuary functioning´ refers to activities, processes or properties of ecosystems that are affected by its biota but also abiotic structures (Naem et al. 2002) but also functioning is described as relating only to rate processes rather than the presence of structure (Elliott et al. 2007). The functioning of an estuarine ecosystem is on one hand governed by the structure of its physical, chemical, and biological components, in which the physical and chemical factors play a fundamental role as forcing variables. On the other hand, ecosystem functioning is controlled by processes or anthropogenic activities (e.g. discharge of pollutants or nutrients and morphological adaption) occurring in the system and its catchment. This means that there are complex interactions between various components (structures and processes) of the estuarine system and human influences resulting in consequences for humans such as affecting safety issues (Figures 1.2 and 1.3).

In essence the physico-chemical system creates the water column and substratum fundamental niches which are then colonised by the biota to produce the biological structure as the assemblage (the so-called environment-to-biology relationships); the structural biological community then becomes modified by interactions such as predator-prey relationships, competition, etc, to produce the community functioning (the so-called biology-to-biology relationships); finally the biota then can modify the physico-chemical environment through bioturbation, removal of oxygen and nutrients etc, (the so-called biology-to-environment relationships). Superimposed on these three sets of relationships are the anthropogenic influences (Gray and Elliott 2009; Figure 1.2). Figure 1.3 gives a specific example of these relationships as related to port developments.

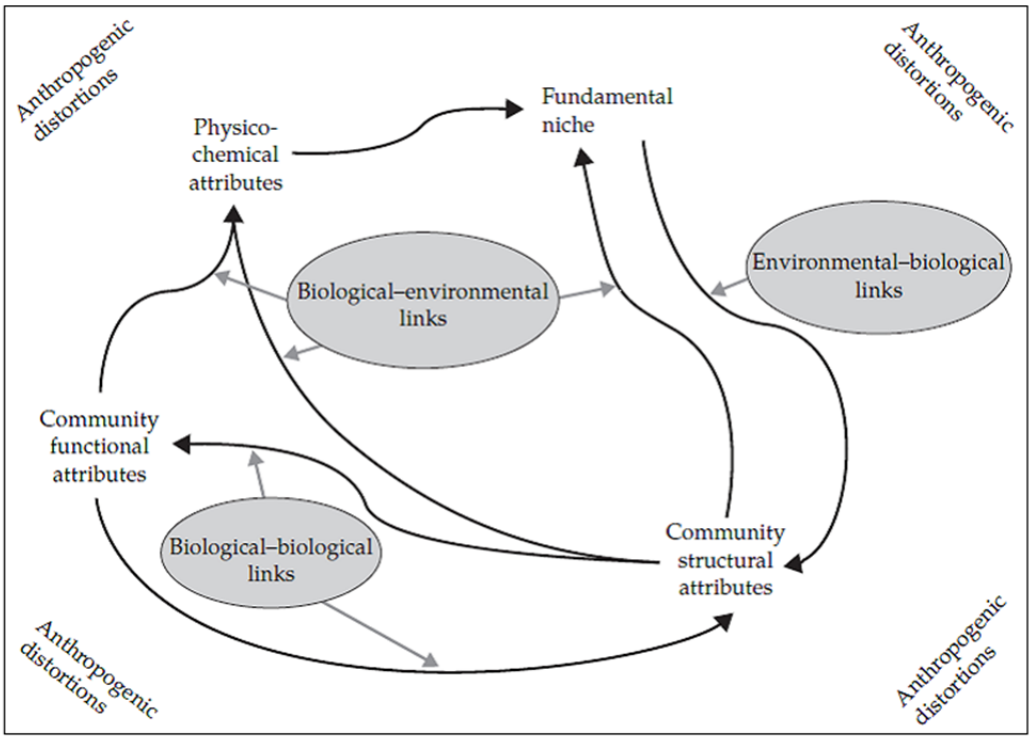

Figure 1.2. Interlinked environmental and biological relationships structuring an ecosystem (Gray and Elliott, 2009).

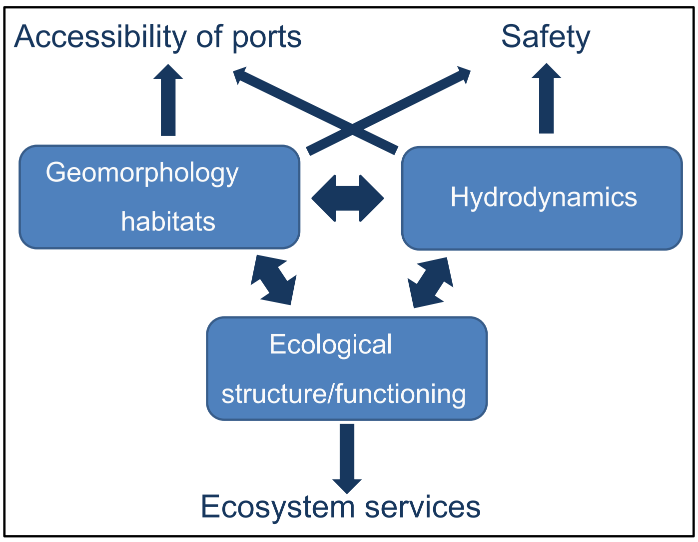

Figure 1.3. Example of complex interactions between estuarine components

1.3.1 Structure and processes

Essentially, the structure of an ecosystem relates to the quantity and composition of its biotic and abiotic components at any particular time. In the case of estuaries, the essential features of its functioning are related to their connectivity with the adajacent marine and coastal areas and the freshwater catchment (Elliott and Whitfield 2011). Estuarine physical structures consist of many different subsystems: pelagic and benthic; deep and shallow subtidal, intertidal, and marsh areas; marine, brackish and freshwater areas. Within these subsystems even more different habitats can occur which are closely interrelated and influenced by interacting physical, chemical and biological parameters and processes. Ecosystem processes result from the functioning of multi-species assemblages of organisms and their interactions with the abiotic environment, as well as the abiotic environment itself. A process implies pathways or transfers of material/energy fluxes or rate changes (Elliott et al. 2006a), i.e. changes with time and space. The building-blocks of ecosystem functions are the interactions between structure and processes, which may be physical (e.g. infiltration of water, sediment movement), chemical (e.g. reduction, oxidation), or biological (e.g. photosynthesis and denitrification), whereby 'biodiversity' is implicit in all of them, although the precise detail of the relationship is often unclear or limited. The functioning of ecological processes as well as habitat formation and distribution are controlled by hydro-geomorphological variables and their interactions with ecology. For example, the estuarine hydro-geomorphological 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 refugia for fishes (Elliott and Hemingway 2002).

Processes can occur on large but also very small temporal and spatial scales. They can be extrinsic (externally operating) or intrinsic (internally operating) and affect estuaries as a whole but also the different components of the biota within the system. For example, estuaries are characterised by a high production of organic matter within the system (autochthonous production), as well as a large import from outside the estuary both upstream from the catchment and downstream from the sea (allochthonous production). As nutrients and other chemical substances are transported from the catchment to the sea, estuaries execute a filter function which is mainly performed by the vegetation cover and (soil) biota.

In conclusion, ecosystem functions can be considered as a subset of the interactions between ecosystem structure and processes that underpin the capacity of an ecosystem to provide goods and services (De Groot et al. 2002), e.g. the appropriate water conditions and sediment will support invertebrates which in turn provide food for fish taken for human consumption.

1.3.2 Ecosystem services

Ecosystem functions (processes and structures) provide the ecosystem services, i.e. aspects of ecosystems which are used to produce human wellbeing and which are essential for Man´s economic prosperity. In turn the ecosystem services enable the delivery of societal benefits but only following, in economic terms, the input of complementary assets and human capital (Atkins et al. 2011). For example, the natural processes can ensure suitable fish populations but human energy, skill and funds are required to produce those fish as food. TIDE applied the approach of the Millennium Ecosystem Assessment (MA 2005) which was prepared under the coordination of UNEP. In this approach ecosystem services are classified in four broad categories:

- Supporting/habitat services
- Provisioning services
- Regulatory services
- Cultural services

Supporting or habitat services that consist, according to de Groot et al. (2010), of ´nursery habitat´ and ´genepool protection´ which provide the basic infrastructure of life and processes essential to maintenance of the integrity, resilience, and functioning of ecosystems. They include habitat formation and biodiversity. All other ecosystem services – regulating, provisioning and cultural – ultimately depend on them. Their impacts on human well-being are indirect and mostly long-term in nature: the formation of soils or habitats, for example, takes place over decades or centuries. Supporting services are strongly interrelated to each other and generally underpinned by a vast array of physical, chemical and biological interactions (UK National Ecosystem Assessment 2011).

Provisioning services have the potential to lead to the goods people obtain from ecosystems, such as food (commercial and recreational fisheries), raw materials and extractable resources (sand and clay for construction works).

Regulating services steer essential processes that regulate the natural environment, e.g. the transformation of energy (primary production) and biogeochemical cycles. They provide many services including nutrient and water cycling, filtering and removal of nutrients of pollutants in terrestrial and aquatic ecosystems, and protection against flooding.

Cultural services are defined as ´non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences´ (MA 2005) and can affect human health, provide educational values and fuel tourism industry.

This approach does not particularly emphasise ´biodiversity´, but shows that it is closely related to the delivery of ecosystem services and/or societal benefits, as a wide variety of raw material is provided by biodiversity. Furthermore, a reduced biodiversity would result in a reduction of the number of species available for commercial exploitation (Beaumont et al. 2008). The large loss in biodiversity in recent decades will have reduced the ecosystem services and in turn their societal benefits.

The importance of these losses in ecosystem services, not only in terms of biodiversity loss, but also in economic loss has been shown during the current project. In general, economic values are used to direct management decisions. The calculation of the economic value of an ecosystem service could be used by decision makers to assess the changes in the delivery of a particular ecosystem service that results from the implementation of a policy decision or a management measure. Current ecological management and legislation is primarily enacted through the application of several EU Directives, notably the species and habitat based approaches of the European Birds and Habitat Directives (2009/147/EC and 92/43/EEC). Assessing ecosystem services during (estuarine) management can potentially assist in the comparison of several development scenarios regarding efficiency, sustainability and equity (see also Chapters 4 and 6). This opens up a new perspective for estuarine restoration and management based around societal costs. Ecological restoration has mostly been seen as a cost, necessary to fulfill environmental legislation, but without a real link to economic development and with only relatively small public support. However, ecological restoration is not only required to preserve biodiversity or species richness, but it is clear that ecosystems also deliver potential benefits to society that can be translated into monetary values.

Since the publication of Costanza et al. (1997), ecological economics has become an important field of study (De Groot et al. 2002) making it possible to place an economic value on the different ecosystem services.

The concept of ecosystem services was taken up very quickly by different environmental organisations such as the IUCN, but also by large bodies including the World Bank and several governments. During the last few years, the typology of the ecosystem services has evolved. The TEEB study (2010) forms an important step in the development and the application of the concept, as it aims at providing a bridge between the multi-disciplinary science of biodiversity and the arena of international and national policy as well as local government and business practices, i.e. by the valuation of biodiversity. However, the economic valuation of ecosystem services is not a simple task as a variety of economic valuation methods have been developed, refined, and applied to biodiversity and ecosystem services in a range of different contexts. Valuation of ecosystem services can be divided approximately into three types: ecological, socio-cultural and economic values (De Groot et al. 2002). There are direct approaches, i.e. the use of market values which may be used for extractive goods such as sand and fish, and indirect ones, e.g. avoiding costs for building dykes or sewage plants (prevention of erosion by marsh habitat or water quality regulation by marsh vegetation), including the willingness to pay (WTP). TEEB (2010) has reviewed the main methods, which all have their advantages and disadvantages.

Some ecosystem services such as the maintenance of biodiversity or aesthetic value cannot easily be expressed in monetary terms and thus require a non-market valuation. The former can only be expressed in the value they have for other processes or the whole ecosystem functioning whereas aesthetic value can be determined using contingent valuation techniques. Furthermore, values may be subjective, e.g. assessing the value of cultural services such as aesthetic benefits from a landscape is related to the perception of the observer (Gee and Burkhard 2010).

It is also of note that ecosystem processes and services do not always consist of a one-to-one correspondence. On the contrary, they are often present in an intertwined web of structures and processes making it difficult to avoid double counting. For valuation, Fisher et al. (2009) suggest a classification sequence from fundamental processes to ecosystem services which in turn are divided into intermediate services and final services and these lead to benefits; to avoid double-counting requires either only one step in this chain to be valued or only final benefits will be valued. In this classification, processes and structures are required to produce ecosystem services, but according their degree of connection to human welfare they are intermediate or final services. According to Fisher et al. (2009) a service only becomes a benefit after the introduction of complementary assets such as time, money, energy and skills. For instance, fish food is a benefit of several – human and capital - inputs; the ecosystem services could be a number of ecological components including different habitats.

Recently, a new classification has been introduced: CICES (Common International Classification of Ecosystem Services 2012; Haines-Young and Potschin 2013). The focus of the CICES approach is on the provisioning, regulating/maintenance and cultural components. Habitat services are included in ´regulating and maintenance´. Additionally, it excludes the supporting services in order to avoid the problem of double counting when the ´final outputs´ from ecosystems which are used and valued by people have to be identified and described (Haines-Young and Potschin 2013). CICES clearly distinguishes between:

- Services: that are the contributions that ecosystems make to human well-being and that are connected to the underlying ecosystem functions.
- Goods and benefits: that are things that people can create from ecosystem services and that are not functionally connected to the system.

The scheme below (Figure 1.4) illustrates the connection between environmental and socio-economic aspects. The environmental part consists of supporting or intermediate services including physical or biological structures and processes, and functions. They result in the delivery of one or more final services, as structures and processes are not exclusive to one single service. As an example, the ecosystem service 'Food provision, fisheries' depends on the function of a viable fish population production; in turn the latter depends on an adequate ecological structure (amount, diversity) of the respective suitable habitats and functioning (rate processes such a primary production, nutrient cycling, oxygen production) as well as hydrodynamic conditions, e.g. not too high currents.

Within the socio-economic part, the production boundary to the environment is passed when ecosystem services lead to the provision of goods and benefits which contribute to human well-being which arises from adequate access to the basic materials for a good life (Haines-Young and Potschin 2013). The benefits finally generate an economic value, and can, for example, be estimated by using the willingness-to-pay (WTP) approach (i.e. the real or hypothetical amount that consumers of a benefit undertake to pay to maintain that benefit). The different aspects, applications and problems of the valuation of ecosystem services will be discussed later and in chapter 4. The use of certain ecosystem services, or the perception of their value, will then influence (the consumption of) a certain service via the sum of pressures on the underlying structures and processes that potentially can be limited by policy actions.

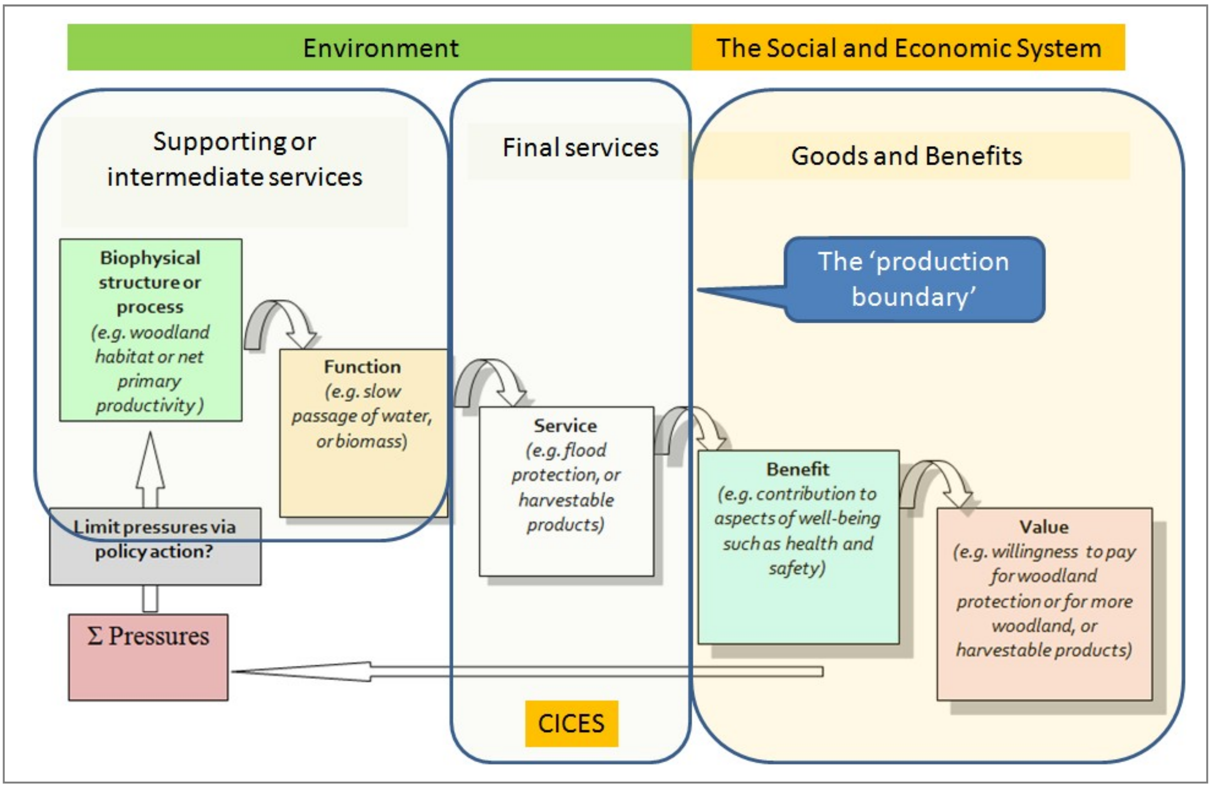

Figure 1.4. The ES cascade: link between environmental and socio-economic aspects (Potschin and Haines-Young 2011)

Each of these parts can be described as being linked to the natural and socio-economic carrying capacity thus giving the socio-ecological system (Figure 1.5, Elliott et al., unpubl.). The upper part of the system indicates the natural physic-chemical system leading to its support of the ecological system. The central part indicates the fundamental processes or the intermediate and final ecosystem services as discussed above. The lower part of the diagram, nested within the other parts, indicates the valuation system.

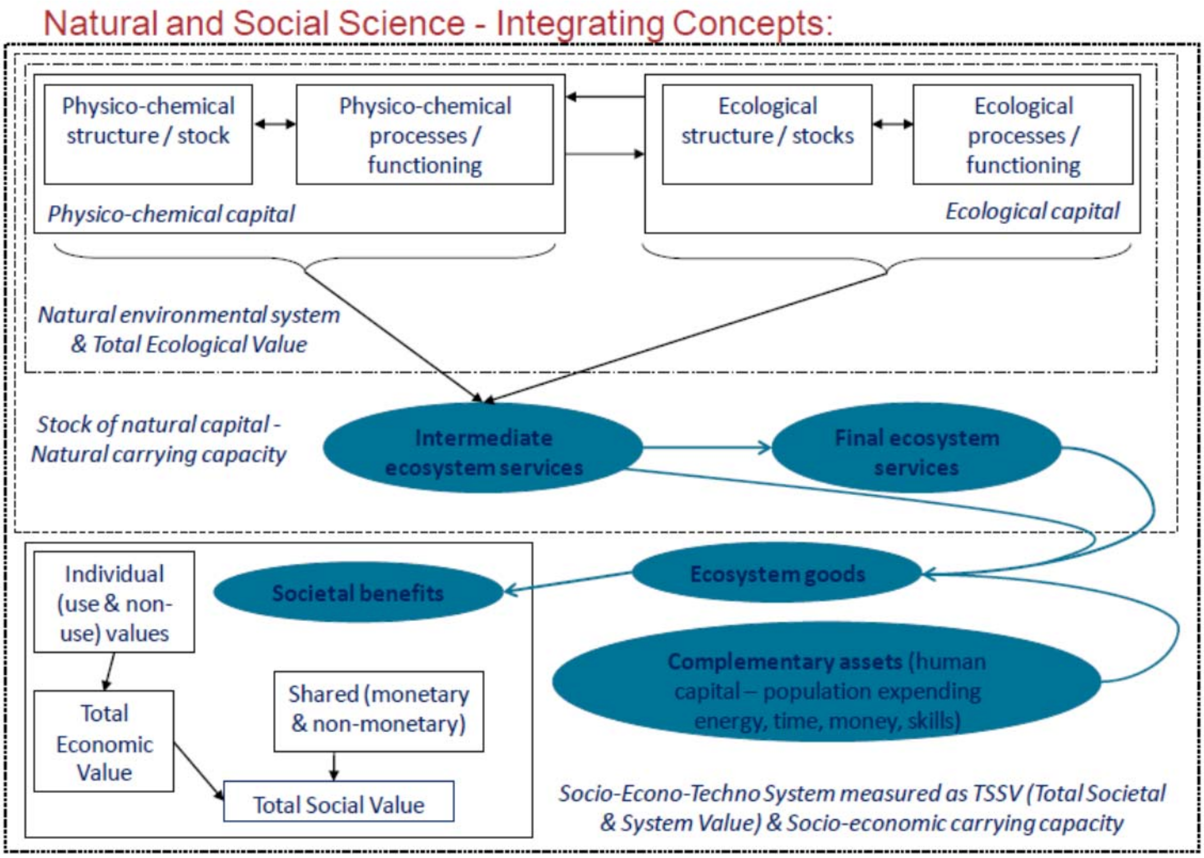

Figure 1.5. The socio-ecological system (Elliott et al, unpubl.)

It is evident that estuaries are very important for humans who depend on their delivery of estuarine ecosystem services. At the same time estuaries are exposed to large anthropogenic pressures, often resulting in system modifications of variable severity which then require a response in the form of management measures for protection and restoration. The relationship between the factors - Drivers, Pressures, State changes, Impacts and response - is described in the DPSIR framework, a systems-based approach which captures key relationships between society and the environment (Atkins et al. 2011, see also Section 1.4).

Although further research is required on this, as well as on the understanding of estuarine functioning and on the valuation of ecosystem services, the Ecosystem Services Approach appears to be a suitable mechanism to maintain and increase ecosystem services for the societal benefit. The way in which it can be used for estuarine management will be described in Chapter 4 and 6. Based on the assumption that the delivery of one or more ecosystem services, amongst others, is related to the quantity and quality of certain habitats, then the management of these habitats will have an impact on the potential benefits humans can receive from estuaries. However, society - in this case estuarine residents, governmental institutions and policy makers - has to make choices over which services are most important and thus how their individual estuary looks and functions.

1.4 Estuarine management

1.4.1 Challenges of estuarine management

Estuarine management is extremely complex in that it has to accommodate multi-sectors, multi-users, multi-uses, multi-agencies and so on (Figure 1.6). It has to accommodate 'moving-baselines', the judging of whether an estuary has changed due to small-scale, local human activities against a background of underlying change, for example due to climate change. It also has to accommodate large spatial scales and what we might call 'unbounded-boundaries', for example, to manage an area in the temperate latitudes while considering the ecology of some of its organisms (such as birds and marine mammals) in the polar regions.

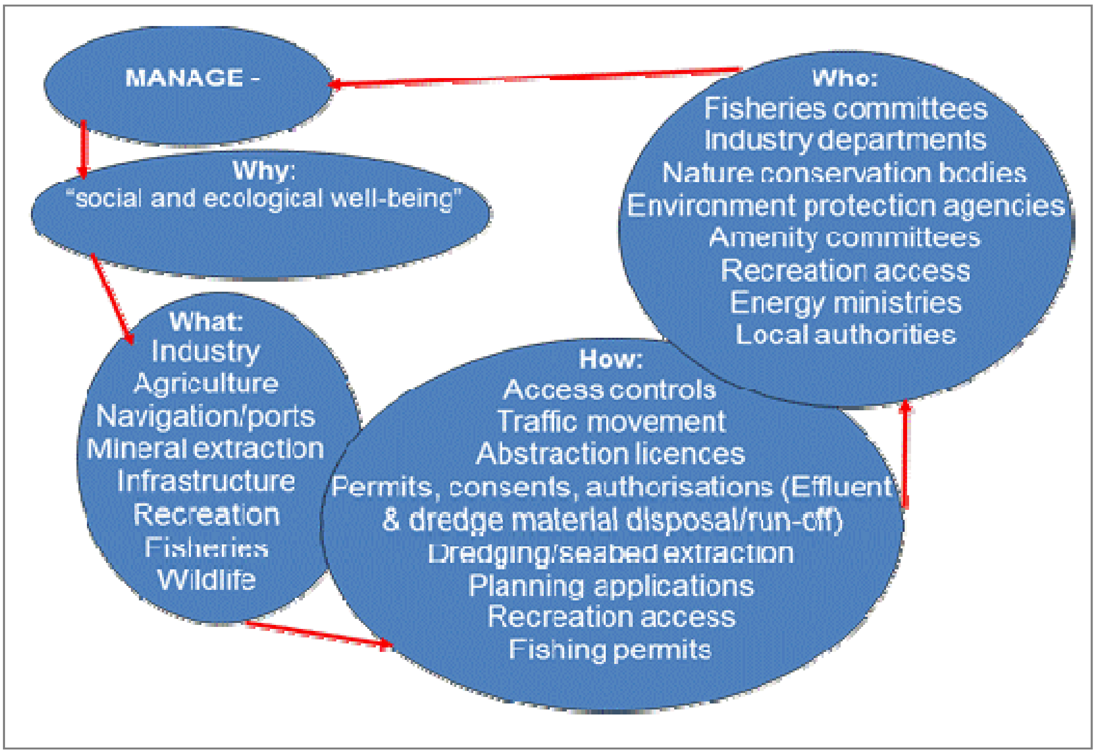

Figure 1.6. Overview of Estuarine Management (Elliott 2013)

As mentioned earlier (Elliott 2011), there is only one big idea in estuarine management: that we have to protect and maintain the natural ecological characteristics and processes and conservation features while at the same time deliver the ecosystem services and benefits required by society. This can be regarded as the Ecosystem Approach.

The overarching accepted framework required to achieve the Ecosystem Approach has been described as the 'three-legged stool' or the 'three pillars of sustainability', for example, for ecology, economy and society. These have been expanded to be summarised as a set of 10-tenets (Figure 1.7) which are required to be included for successful and sustainable estuarine management (Elliott 2013). These should be used to tackle any one environmental stressor and even cumulative or in-combination stressors. Of course, while we talk of 'estuarine environmental management', it is emphasised that we are not trying to manage the environment but more importantly to manage human behaviour.

Box 1: The 10-tenets - to be successful, sustainable management measures or responses to changes resulting from human activities should be:
• Ecologically sustainable • Technologically feasible • Economically viable • Socially desirable/tolerable • Legally permissible • Administratively achievable • Politically expedient • Ethically defensible (morally correct) • Culturally inclusive • Effectively communicable

Figure 1.7. The 10 tenets for integrated, successful and sustainable marine management (Elliott 2013)

As mentioned above, estuarine management should have an overall aim to ensure a healthy ecosystem while at the same time delivering societal benefits. Safeguarding a healthy ecosystem requires an integrated approach that comprises social, economic, and environmental aspects (Munawar 1993) and that considers structures and functions of the system as well as its resilience. Emergent properties of the ecosystem thus include its resistance to stress, i.e. its ability to withstand adverse change, as well as its resilience, its ability to recover from the effects of a stressor (Elliott et al. 2007). An ecosystem can be considered as healthy if it is sufficient resilient to keep its structural and functional characteristics when exposed to stress or to restore within a given time (Kolosa and Pickett 1992). According to Elliott (2011), the ´health of the system´ can include several levels: health of the cell, the tissue level, the population, the community and the whole ecosystem. The aim of estuarine management should be to ensure that all levels are ´fit-for-survival´ which implies that estuarine management has the tools to assess or predict potential changes of the system and to conduct management measures to restore the health.

Due to the dynamic nature and the complexity of estuaries and their multi-use by humans, it is a challenge for estuary managers to allow socio-economic activities and development to continue within and outside the estuarine system against a background of various natural and anthropogenic changes, for example large scale habitat losses, on-going coastal squeeze (i.e. gradual loss of intertidal and marsh habitat due to ongoing sea level rise and the presence of an artificial or other fixed landward boundary), and the possibility of more frequent storm events as a result of climate change.

Additionally, natural and anthropogenic structures and processes are linked and often there are no obvious dependent and independent variables, or clear cause-effect hierarchies. This complexity and interdependence means that changes in one part of the natural and human system can cause responses elsewhere in the estuary. However, changes or pressures within the estuary can most probably be managed, whereas it will be difficult or impossible to manage exogenic pressures (Elliott 2011). For instance, aspects of climate change such as rise of temperature or sea-level may increase the risk of abrupt and non-linear changes which in turn would affect structures and processes of estuaries, and finally lead to a decrease in the delivery of ecosystem services for humans. In addition, the inherent variability of the estuarine system has the potential to absorb or buffer those adverse effects (Elliott and Quintino 2007).

In addition, the handling of several projects related to different activities (e.g. fairway deepening, construction of a marina, or installation of wind turbines) over differing project delivery timescales forms another challenge for estuarine management, together with the integration of a range of existing sectoral plans or policies on different horizontal and vertical levels. These will be described in more detail in Section 1.4.2. However, the implementation of the EU Natura 2000 Integrated Management Plan through national enabling legislation can be considered as a first step to overcome this problem (see also Chapter 5).

Another consideration is that whilst for some management actions such as a fairway deepening, the planning and implementation of the process may take a relatively long period of time, whereas projects which have a high economic or public interest such as flood protection works will require to be implemented rapidly.

Finally, and continuing the health analogy, environmental assessment and management follows the same sequence as any other health assessment and management – there is an assessment of cause and effect (the diagnosis), a prediction of response (prognosis), a prescription of treatment (the management measures to be taken), and the indication of future prevention of effects (as future measures to prevent degradation) (Elliott 2011). Given the complexity of the estuarine system, estuary managers often have to operate within an inherent level of uncertainty of prediction in terms of system development outcomes. As such, they have to include this uncertainty into the management objectives and tools as well as ensure that these uncertainties are adequately communicated to users and stakeholders (see also Section 7.4).

1.4.2 Governance (policies, politics, administration and legislation)

The horizontal and vertical integration across the bodies/administrations, policies, processes and laws is a particular challenge for estuarine management. Vertical integration requires that the progression of laws and policies arising from global and international agreements (e.g. UNCLOS, OSPAR), through multi-state regional ones (e.g. EU), to national (at the Member State level) and within-state regional (e.g. municipality, province, region etc.) is followed. Horizontal integration is necessary across the various sectoral plans and practices (e.g. flood protection, tourism, fisheries, ports, etc.) and bodies (government, agencies, NGOs, etc.). In general, legislation seeks to regulate specific activities or operations, and to a large degree determines the management aspects most relevant to estuaries, including planning and consents procedures. Within estuaries, legislation influences management decisions being made at a number of stages; it encompasses the assessment process and provides context to the decision-making process (www.estuary-guide.net (ABPmer)). Each part of this broad body of legislation is then required to be enacted by administrative bodies (ministries, agencies, departments, etc.).

Many countries have an unnecessarily complex estuarine legislation and administration framework (e.g. Ducrotoy and Elliott, 1997; Fernandes et al., 1995; Boyes et al. 2003a, b; Boyes and Elliott, 2003, Elliott et al. 2006b) which can lead to complex management systems in estuaries and coastal/marine areas which include the estuary mouths. The interlinked nature of land, freshwater, estuary (transitional waters), coastal waters and the open sea and the number of activities to be managed requires an increasingly complex governance framework. Countries have internal regional and national policies, laws and agreements, external regional agreements such as the Oslo and Paris Commission for the NE Atlantic, the International Council for the Exploration of the Sea and, within Europe, those Directives of the European Union (e.g. the Marine Strategy Framework Directive and the Water Framework Directive). In addition to this, they are signatories to global initiatives such as the UN Convention of the Law of the Sea (UNCLOS), the International Maritime Organisation (IMO) and the Convention on Biological Diversity (CBD). They have laws, agreements and administrative bodies which control the many marine sectors such as pollution disposal, fisheries, seabed extraction of sand and gravel, oil spill response, habitat use and protection, etc (Elliott et al. 2006).

For estuaries, such as the four case-estuaries, a large number of development and management plans, sectoral strategies, European Directives and other regional and national policies are developed in order to address the very diverse sectors of uses and activities. Plans are largely sectoral and occasionally spatially constrained, with the main problems often relating to the absence of coordination and integration between these differing management approaches, fine-tuning of focus to avoid overlaps or gaps, and the awareness of stakeholders to the existence the many plans.

The obligation to implement European legislation into national law is the same for all European Member States. For example, relating to existing environmental legislation, all EU Member States have to carry out Environmental Impact Assessments (i.e. an assessment of the possible impacts that a proposed project may have on the environment, consisting of the environmental, social and economic aspects as dictated by the EU EIA Directive), or Appropriate Assessments (for plans or projects likely to affect conservation objectives, under the Habitats and Birds Directives). However, the way in which EU Directives are implemented within the national legislation of individual Member States may differ between states, as any state may have tighter controls than those laid down by a Directive but they cannot be less strict than the Directive requirements. In order to understand the context and requirement of individual member state estuarine planning and governance, it is necessary to understand the individual Member State legislative management frameworks, including both the high level and local drivers, the organisations and groups tasked with the application of the management requirements and their legal responsibilities.

1.4.3 Management approaches: Ecosystem approach and DPSIR

Due to the complexity of estuarine systems, it is clear that a strategic approach to estuary management must consider the estuary as a whole, managed within the spatial context of the estuary and beyond. In order to encompass all aspects of the estuarine area, including natural, geographical and political boundaries in a sustainable way, an integrative approach is required. Since the 1990s, there has been a move towards the implementation of a holistic management approach to our estuaries and costs. For example, the concept of Integrated Coastal Zone Management was developed from around 1992, when the Earth Summit of Rio de Janeiro took place.

The ‘Ecosystem Approach´ which relates to the management of ecological and socio-economic benefits (CBD 2000; Elliott 2011) provides a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way by considering humans as an integral component of ecosystems. The implementation of the ecosystem approach requires an understanding of the ecological functioning of the system as well as the understanding of how society manages the exploitation of ecosystems and the potential effects of its activities, including mitigation and compensation (Atkins et al. 2011). The approach has become widely accepted, e.g. by OSPAR (http://www.ospar.org), and integrated in several legislative documents such as the European Marine Strategy Framework Directive (2008/56/EC).

The DPSIR framework (Figure 1.8) is a systems-based approach which captures key relationships between society and the environment (Atkins et al. 2011). It aims to describe a framework for assessing the causes, consequences and responses to changes in a holistic way. When adapted for estuarine systems, it includes socio-economic drivers - the societal demands (D), which in turn create physico-chemical pressures (P), resulting in physico-chemical and biological state changes (S) of the estuary, which can then create socio-economic impacts (I), leading to the requirement for management responses (R) such as laws and economic instruments (Atkins et al. 2011). Drivers can be diverse societal demands for ecosystem services, e.g. water for industry or transportation, fish for food, or sand for construction. The term 'pressure' can describe a whole range of factors resulting from activities at different levels (land claim for industrial or port development, high nutrient and pollutant input/concentrations, fisheries etc.) that cause impacts on natural systems such as the change of the state of the system, e.g. it may become eutrophic with further implications for organisms of other trophic levels. Pressures can be natural factors that have been altered by human activity (e.g. increases in nutrient loads), or they can be entirely anthropogenic factors (e.g. fishing). Activities often lead to pressures although the use of mitigation should prevent the pressures from being created.

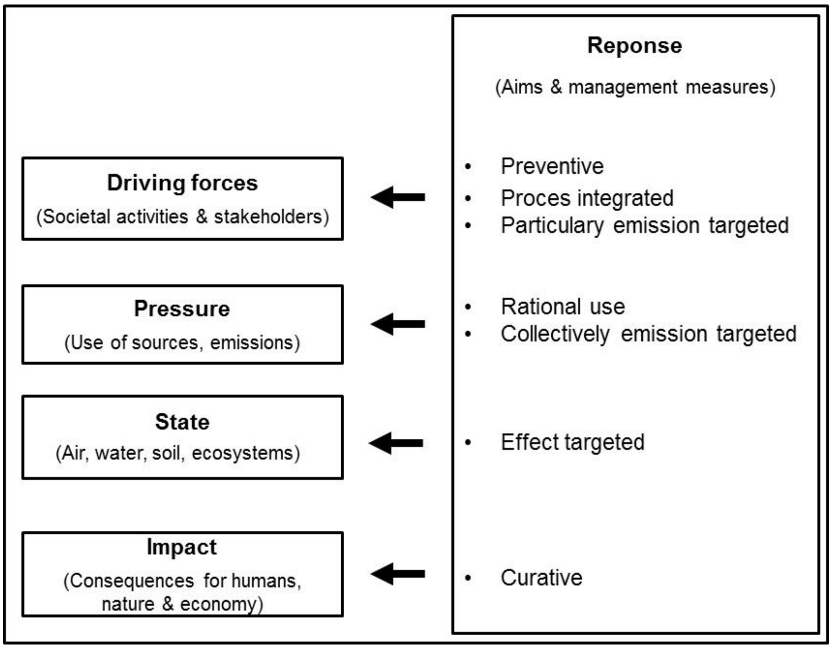

Figure 1.8. DPSIR framework

The pressures may be Exogenic Unmanaged Pressures, by which they originate from outside the area being managed and hence management can only respond to the consequences rather than the causes. Alternatively, they may be Endogenic Managed Pressures, emanating from inside the area being managed and so enabling both the causes and consequences to be managed (Atkins et al. 2011). The Exogenic Unmanaged Pressures may be in the catchment of estuaries, such as nutrient run-off from agriculture, or even further afield such as global climate change and relative sea-level rise. Hence, these require addressing by national or international responses. An example of an impact on the socio-economy can be the loss of a fishing area which may have a subsequent impact on the local fishermen and fish processing companies.

The following list of drivers and related management responses (legislation at different levels) have been identified across the four estuarine systems investigated in the TIDE project.

Drivers:

- Global trade, ocean traffic
- Industrial development
- Installation of infrastructure within areas at risk
- Use of fossil fuels
- Extraction of mineral resources
- Fishing, aquaculture
- Generation of energy

Related management responses then emanate from the following topics (for details see Section 5.3):

- Water quality (EU Water Framework Directive & Urban Waste Water Treatment Directive)
- Nature conservation (EU Habitats & Species Directive & Wild Birds Directive)
- Flood protection and coastal protection (EU Flood Risk Management Directive)
- Integrated coastal zone management (Trilateral Wadden Sea Plan, Denmark, Germany and the Netherlands; recommendation of the EU Parliament and the Council on the implementation of European Integrated Coastal Zone Management in May 2002)
- Navigation, ports and pollution prevention (Oslo-Paris Convention (OSPAR); London Convention)
- Economic development including agriculture, forestry, tourism (country-specific spatial and strategic plans)
- Integrated and holistic approach for the sustainable exploitation of the marine environment to achieve Good Ecological Status (Marine Strategy Framework Directive)[1]

[1] The proposed EU Directive on Marine Spatial Planning and Coastal Management may also affect estuary management if adopted

1.4.4 Management requirements

In order to develop holistic management planning frameworks for estuaries building on existing structures and using a multi-manager sectoral framework, it is necessary to understand:

- The management issues and aims
- The methods used to deliver the management
- The basis that management is delivered (e.g. financial and legal aspects)
- The efficacy of the management tools
- The best tools/plans available to meet these needs
- The gaps in management

In order to assess the appropriateness of the above mentioned tools and methods, but also the indication of gaps, the development of indicators and an integrated estuary assessment framework is required.

As the natural system responds to societal actions (Van Buuren et al. 2010), it is not only essential for policy making and managing the system that there is a detailed knowledge about the development of the natural system, but that there is also the knowledge of societal and economical activities and demands. 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.

Furthermore, it is important that managers are aware of potential and existing conflicts resulting from the diverse uses of the system, as well as having a good communication strategy in order to produce a better understanding and acceptance of management actions by stakeholders including the residents around the estuarine system.

The Scheldt estuary provides a good example of conflicting societal demands. The system is shared between the Netherlands and Belgium (for details see Section 1.5, 7.3 and 7.4) and consequently, management challenges in the Scheldt are, to some extent, related to the cross-border nature of the management activities. Although a treaty between Belgium and the Netherlands guaranteed the free access for vessels to the port of Antwerp, the adaptation of the fairway to meet increasing ship size demands has always been a matter of dispute between both countries, in particular during the 1990s. Related to this issue, two other main policy topics concerning the management of the estuary arose: the need for human safety, i.e. the prevention of flooding, and ecological sustainability. After some negotiation, the Netherlands and the region of Flanders (Belgium) worked together to deliver a solution to this and set up a common strategy for the sustainable management of the

Scheldt up until 2030: the “Long Term Vision for the Scheldt Estuary” (LTV, 2001) together with a joint development plan with a time horizon of 2010, the “Scheldt Estuary Development Outline 2010” (2005). The plan not only integrates goals for nature conservation, accessibility to the port of Antwerp, and flood safety issues, but also includes consultation with various groups of stakeholders. It is also the starting point for joint policy making by the Flemish and Dutch governments, aiming towards a more sustainable development of the Scheldt estuary. In order to create such management ´win-win´ scenarios, a new natural multi-functional environment should be established, e.g. management of the estuarine environment should provide opportunities for combining natural environmental aims with other objectives such as safety, agriculture, marine aquaculture, recreation, and residential/employment initiatives, for instance, the use of Flood Control Areas meeting the management needs both for flood protection and the natural environment. Furthermore, the development of a new approach for the disposal of maintenance dredged material on tidal shoals has the potential for positive management actions towards Natura 2000 goals whilst meeting navigational safety and access needs. In addition to the technical aspects of this strategy, an extensive communication program formed an important part of the ‘Development Outline 2010’.

1.5 Introduction of the case estuaries

A considerable body of information is already available on the characteristics, functioning and management of estuaries (e.g. see Dyer 1997; McLusky and Elliott 2004; Nienhuis 1992; Patterson and Black 1999). However, a broad analysis and inter-comparison of estuarine features such as their specific functioning, governance and management measures within these areas is not yet available. This chapter describes the development and main characteristics of the four northern temperate estuaries: Elbe (Germany), Humber (United Kingdom), Scheldt (Belgium/The Netherlands), and Weser (Germany) which served as case studies within the EU Interreg IV project TIDE (Tidal River Development). Whilst these estuaries have several characteristics in common, for instance they all drain into the North Sea, have a relatively large tidal range and their management has to cope with similar challenges (see also Section 1.1), there are also a number of differences in pressures associated with these systems, and associated management priorities, providing a valuable background to a series management scenarios relevant to most north-west European estuaries. The following sections should be considered as providing basic background information for the more specific assessment aspects of the four estuaries that are addressed in greater detail in the following chapters.

1.5.1 The Elbe estuary

1.5.1.1 Geographical information

The River Elbe originates in the Karkonosze Mountains of the Czech Republic (1386 m above sea level). It covers a catchment of 148,286 km^2 and has a total length of 1091 km of which 361 km are located in the Czech Republic and 730 km in Germany. The Elbe passes through the German federal states of Saxony, Saxony-Anhalt, Lower-Saxony, Hamburg and Schleswig-Holstein before it reaches the North Sea in the north west of Germany (Figure 1.9). The estuarine part begins at the weir in Geesthacht where the tidal influence starts. The remaining 140 km to the North Sea can be seen as the artery of the Metropolitan Region of Hamburg. The Elbe estuary can be divided into two parts: the Unterelbe (lower Elbe) which reaches from Geesthacht to the city of Cuxhaven, and the Außenelbe (outer Elbe) reaching from Cuxhaven into the Wadden Sea. Approximately 10 km upstream of the port of Hamburg, the estuary divides into two branches, the Norderelbe and the Süderelbe which unite again in the port area. At the Elbbrücken, crossing the Norderelbe and the Süderelbe, water depths decrease from approximately 5 m to more than 12 m according to the requirements of the sea going vessels. The main tributaries of the estuary are the Ilmenau, Este, Lühe, Schwinge, Pinnau, Krückau, Stör and Oste. At Brunsbüttel the Kiel Canal connects the Elbe with the Baltic Sea.

The area along the Elbe estuary is inhabited by more than 2 million people (Statistisches Bundesamt, 2010), and the Metropolitan Region Hamburg has 4.3 million inhabitants.

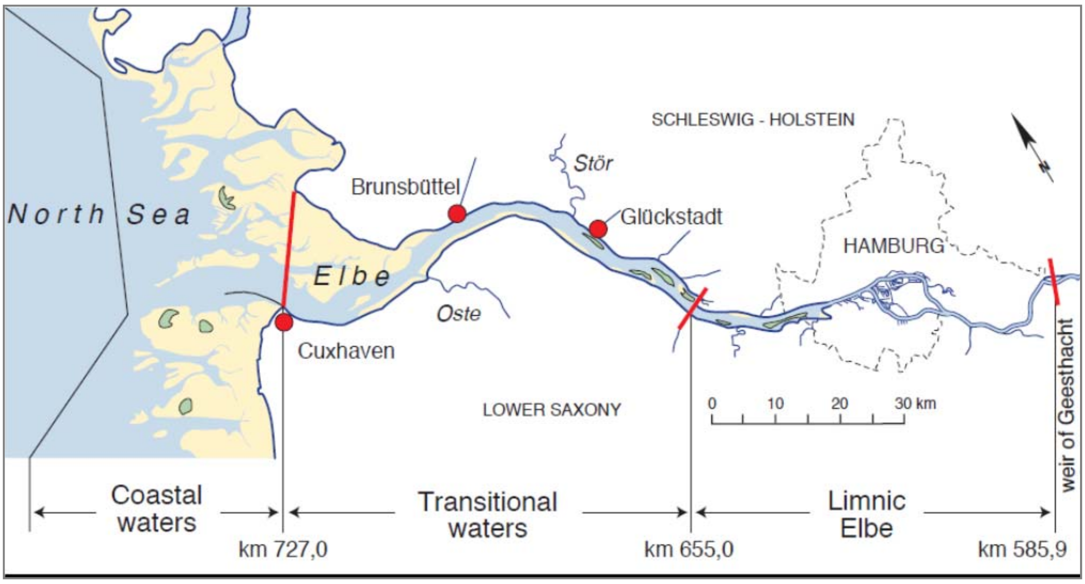

Figure 1.9. Map of the Elbe estuary and the surrounding federal states Schleswig-Holstein, Lower Saxony and Hamburg

1.5.1.2 Historical development

The estuary has been modified since the first settlements with the development of the region for demands of the increasing population. Around 1000 AD the first dykes were built in order to protect the settlements. Since the 13^{th} century, the dyke line has basically been uninterrupted. The process of active land reclamation started in the 15^{th} century. Between 1900 and today 50% of the foreland areas of Schleswig – Holstein and 74% of Lower Saxony were reduced by poldering (Boehlich and Strotmann, 2008). After the severe storm surges in 1962 and 1976, new flood barrages were constructed and large parts of the tributaries were cut off from tidal influence in order to protect the hinterland. However, these measures also prevented the marshlands to keep growing up through periodical sedimentation. In addition to the loss of marsh area, shallow water areas also decreased. In total the estuary evolved to a more rigid system with less space for the dynamic development of natural habitats (Arbeitsgruppe Elbeästuar 2012).

From 1868 on the Elbe estuary was deepened the first time to 5.3 m in the area of Hamburg. As a result of industrialisation and the growth of the merchant fleet at the beginning of the 20^{th} century, extensive river engineering measures were carried out including the modification and expansion of harbour basins. Five more deepenings of the fairway were undertaken in order to keep up with the shipping requirements. The actual depth is 13.5 m dependent on the tide.

1.5.1.3 Hydrogeomorphological characterisation and water quality

The Elbe is classified as a meso-tidal (McLusky and Elliott, 2004) and partially mixed estuary based on its salinity profiles. As a result of the tidal currents and a high sediment transport, the shape of the Elbe estuary is continuously changing. Sea-bed dunes and ripples, intertidal areas, sand banks and islands are constantly shifting. Its mouth is characterised by a steadily moving multi-channel deltaic system and under near-natural conditions dynamic channels and side arms are typical also further upstream.

The tidal asymmetry, with a shorter flood period (about 5 hours) compared to the ebb period (7.20 hours) resulting in the comparatively higher velocity of the flood currents as well as many anthropogenic modifications, have led to a strong upstream transport of sediments, the so-called tidal pumping (Dyer 1997). Transportation of often high loads of sediments is a common feature of estuaries. This process is mainly governed by the characteristics of the tidal currents, erosion – deposition cycles over a tidal cycle, lunar cycles (spring/ neap tides), and seasonal patterns (i.e. changes in fluvial discharge). As a result, the sediment deposits and accumulates in the Hamburg region, as the ebb current is insufficient to take all the sediments back out to the river mouth and the North Sea due to its characteristics described earlier.

The turbidity maximum is mainly located in the area close to the city of Brunsbüttel, but its shape and location relates significantly to the rate of freshwater discharge. Characteristic parameters, calculated within the TIDE project (Vandenbruwaene et al. 2013) are shown in Table 1.2. For the calculation of the flow velocity the cubage technique (Vandenbruwaene et al. 2013; Plancke et al. 2011; Smets 1996) was used.

Table 1.2. Hydrogeomorphological characteristics of the Elbe estuary (Vandenbruwaene et al. 2013)

Parameter	
Tidal range	
Cuxhaven (mouth)	2.9 m
Hamburg (St. Pauli)	3.6 m
Freshwater discharge at Neu Darchau, 50 km upstream of Geesthacht (mean value, 2001-2010)	
Average	722 m^3/s
Range (dry event, 5%percentile and flushing event/95% percentile)	247 – 1709 m^3/s
Residence time (at low and high freshwater discharge)	16-63 days
Mean maximum ebb current	0.2 - 0.9 m/s
Mean maximum flood current	0.4 - 1.3 m/s
Suspended particulate matter (surface, low water, mean value, 2004-2009)	25 - 250 mg/l

Until the early 1980s, the Elbe was heavily contaminated. Today contaminant loads originate mostly from earlier inputs and are sequestered mainly in the sediments. However, since the German Reunification in 1989 and the establishment of the International Commission for the Protection of the Elbe River (IKSE) in 1990, the Czech Republic and Germany have successfully worked together to improve the water and sediment quality status.

However, during the summer months, periods of low oxygen levels still occur regularly downstream of Hamburg. It is assumed that they relate to the morphology in combination with high nutrient loads of mainly agricultural origin, the latter resulting in high biomass production of phytoplankton with a pronounced peak in early spring. The algae die when reaching the deeper parts of the Elbe and the port basins, and subsequent microbial degradation of the algal biomass leads to the oxygen depletion (Kerner 2007).

1.5.1.4 Ecological features

In addition to many national protected areas and also several Ramsar sites, approximately 90% of the area of the Elbe estuary is designated as Natura 2000 sites regarding its outstanding international value for many endangered habitats and species, some of them even endemic, such as the Elbe Water Dropwort (*Oenanthe conioides*). Due to major improvements in water quality, fish diversity and abundance have increased since the early 1990s. With 79 species, the Elbe has a very high fish diversity. Important and protected species are the twaite shad (*Alosa fallax*) and two lamprey species (*Lampetra fluviatilis, Petromyzon marinus*). A seal population, which follows the migrating fish into the estuary, lives permanently on the sandbanks near the city of Brunsbüttel. Porpoises (*Phocoena phocoena*) can also be found occasionally. The wetlands, mudflats and foreshore areas, reeds and alluvial forests are used by migratory birds such as barnacle geese (*Branta leucopsis*) and breeding birds, such as one of the last colonies in North West and Central Europe of the Gull-billed Tern *(Gelochelidon nilotica*). The mouth of the Elbe is part of the Wadden Sea which is declared a UNESCO World Heritage site, and it is located in the German Wadden Sea Nationalpark. In terms of the Water Framework Directive, the limnic and transitional parts of the Unterelbe are considered as a Heavily Modified Water Bodies.

1.5.1.5 Economic importance

The Elbe estuary functions as an important shipping channel to the Port of Hamburg which is the most significant economic driver in the region and which directly and indirectly employs about 166,000 people in the Hamburg metropolitan region and 275,000 in Germany. The Port of Hamburg, located 130 km inland, is the largest port in Germany. More than 10,000 ships annually, half of them container ships (Hafen Hamburg Marketing) call at the port from worldwide destinations. The goods are distributed to and from the hinterland via railway, truck and inland navigation vessels. In addition to Hamburg, there are other seaports along the Elbe estuary: Stade, Cuxhaven in Lower Saxony and Glückstadt, and Brunsbüttel in Schleswig-Holstein. Industry, e.g. chemical and oil industry, and power stations (nuclear power stations are successively replaced by mainly coal), are located within or near the Port of Hamburg or near the above mentioned cities Stade and Brunsbüttel.

Agriculture is the most prevalent land utilisation, with internationally-important orchards in the region of ´Altes Land´, downstream of the City of Hamburg. Agricultural land is drained into the Elbe and the Elbe water is used for irrigation. Based on the very fertile marshland soils farming in the area is highly productive.

Fishery is a traditional use of the Elbe estuary and prawn fishing is typical in the mouth. Eel (*Anguilla anguilla*), and the spring-caught smelt (*Osmerus eperlanus*), are economically the most important fish.

The tidal river Elbe is also relevant for recreation and tourism. Approximately 120 marinas are situated along the estuary and the Port of Hamburg is becoming an ever more important hub for cruise ships. In addition, water sports, angling and beach life, especially at the mouth, play an important role.

1.5.2 The Humber estuary

1.5.2.1 Geographical information

The Humber Estuary is located on the north-east coast of England and borders the North Sea (Figure 1.10). Its catchment area is the largest of the British Isles having an area of approximately 26,000 km^2 and drains one fifth of the English land area (24,472 km^2). It provides the largest single freshwater input to the North Sea from the English coastline. Its major tributaries are the Trent, Ouse, Aire, Don, Derwent, Wharfe, Hull and Ancholme (Boyes and Elliott, 2006). The estuary stretches for 62 km from Trent Falls where the two main tributaries (Rivers Trent and Ouse) meet down to Spurn Point/Donna Nook at the estuary mouth. Tidal influence on the main tributaries is restricted by the presence of weirs at Gainsborough on the Trent and at Naburn on the Ouse (shown by a red line in Figure 1.10).

A population of over 1.5 million people live and work within the Humber floodplain with approximately 11 million people within the overall catchment area. With 450 inhabitants per km^2, the Humber is the most densely populated large European estuary (Kempe et al. 1991).

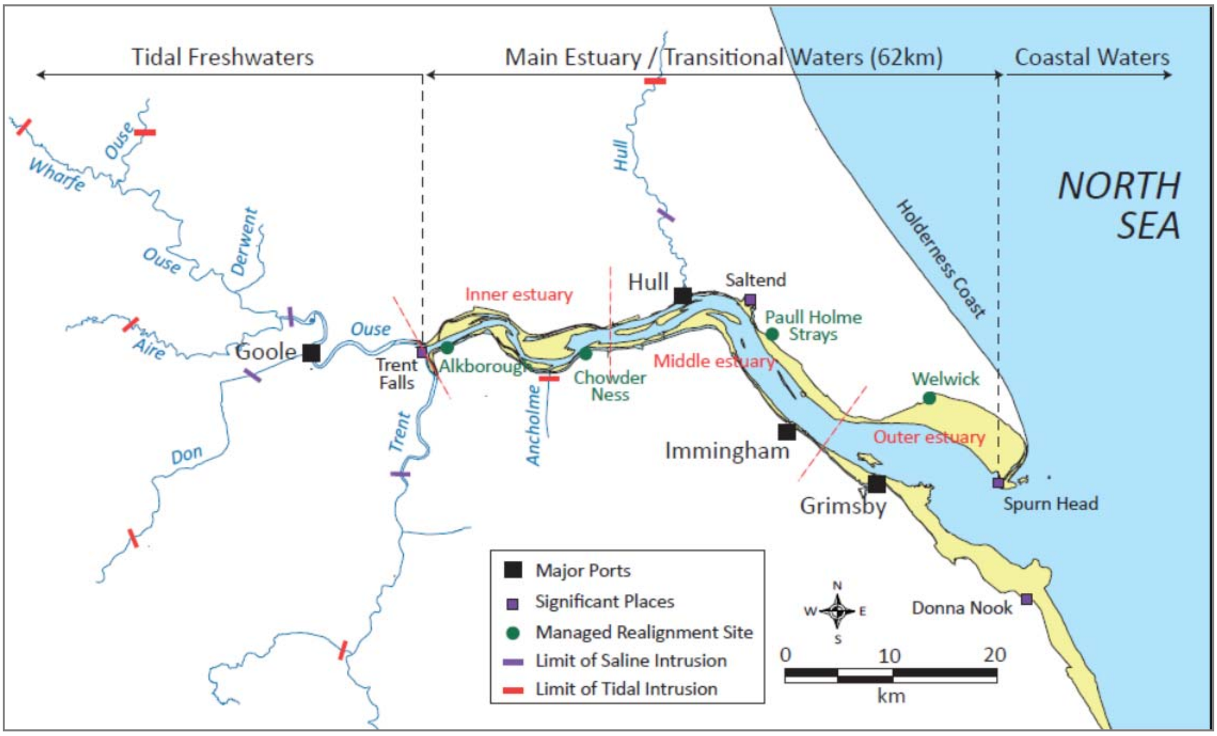

Figure 1.10. Map of the Humber estuary

1.5.2.2 Historical evolution

The Humber estuary has been heavily modified by human activities for over 2,000 years. Approximately half of its intertidal area has been lost due to land claim for agricultural and industrial developments. Its shape has also changed over time, initially through gradual drainage of land around the estuary head, with more substantial modifications in the main estuary since the 17^{th} century. The area of tidal Humber has been reduced from over 90,000 ha to an area of approximately 30,000 ha today, with about 50% of its intertidal area having been lost since the early 1700s (Murby 2001, in Boyes and Elliott 2006).

Subtidal habitat has not been lost on the same scale as in the intertidal zone, although small areas of the estuary bed are subject to modification through maintenance dredging work.

In addition, the channel shape within the estuary and its tributaries has been modified for flood defence purposes with the profile of important tributaries also modified to improve navigation access. The estuary is currently subject to a process known as 'coastal squeeze' whereby the presence of hard flood defences mean that the natural landward migration of the upper shore as a response to relative sea level rise is not possible, with a concomitant 'squeeze' of the intertidal area as the low shore gradually increases elevation and moves landward.

1.5.2.3 Hydrogeomorphological characterisation and water quality

The Humber can be classified as a well-mixed, macro-tidal estuary. An important feature of the Humber is its large tidal range with a range of over 7m encountered in the middle estuary (Table 1.3). Turbidity can increase up to 5000 mg/l, measured near Brough upstream from the city of Hull, and is due to suspended sediment which is derived mainly from the North Sea (approximately 60% of the annual input into the estuary) and the eroding boulder clay cliffs along the Holderness coast (Mortimer et al. 1998), as well as from sediment carried into the estuary from its rivers. The estuarine turbidity maximum can be found in the lower River Ouse tidal tributary downstream to its confluence with the Humber estuary, although the turbidity maximum zone migrates up and down the system depending on spring:neap and winter:summer cycles. It is estimated that up to 1.26 million tonnes of sediment may be present in the water column and the deposited sediments provide essential material to maintain important habitats within the estuary such as mudflats, sandflats and saltmarshes. Due to the high SPM concentrations in summer and autumn, primary production is considered negligible (Jickells et al. 2000).

Table 1.3. Hydrogeomorphological characteristics of the Humber estuary (Vandenbruwaene et al. 2013)

Parameter	
Tidal range	
Mouth	4.3 m
Ouse up-estuary boundary	1.3 m
Upstream of the city of Kingston upon Hull	5.0 m
Freshwater discharge into the Humber inclunding all tributaries (mean value, 2001-2010)	
Average	209 m^3/s
Range (dry event, 5%percentile and flushing event/95% percentile)	34 – 253 m^3/s
Residence time (at low and high freshwater discharge)	13-69 days
Mean maximum ebb current	0.1 - 1.5 m/s
Mean maximum flood current	0.1 – 2.0 m/s
Suspended particulate matter (depth average, mean value of a tidal cycle, 2004-2009)	20 - 720 mg/l

The estuary is considered to be hypernutrified, however Boyes and Elliott (2006) considered that this did not lead to undesirable disturbance of the balance of organisms and water quality, as primary production is controlled by turbidity.

The heavily modified estuary is divided in three transitional waterbodies by the EU Water Framework Directive: Humber Upper, Humber Middle and Humber Lower.

1.5.2.4 Ecological features

The Humber is recognised as one of the most important estuaries in Europe because of its ecological importance for a number of habitats and species. The entire estuary is protected as part of the Natura 2000 network, designated as a Special Area of Conservation (SAC), a Special Protection Area (SPA), and a Ramsar site, and together the estuary forms the Humber Estuary European Marine Site. In particular, the intertidal mudflats provide an internationally important feeding and roosting resource for migratory and wintering waterfowl, with an average 5 year maximum (2006-2011) of 144,000 birds using the estuary in winter. The waterfowl assemblage includes a mean 5 year maximum (2006-2011) of over 5,500 Shelduck (*Tadorna tadorna*), over 40,000 Eurasian Golden Plover (*Pluvialis apricaria*), and over 41,000 Red Knot (*Calidris canutus*) (Holt et al., 2012). Reedbeds surrounding the system are used by breeding Marsh Harrier (*Circus aeruginosus*), and brackish pools and other wetlands support breeding Eurasian Bittern (*Botaurus stellaris*) and Pied Avocet (*Recurvirostra avosetta)*. The mudflats and saltmarshes also provide nursery habitats for fish such as bass (*Dicentrarchus labrax*), and flatfish species including plaice (*Pleuronectes platessa*), sole (*Solea solea*) and flounder (*Platichthys flesus*). The estuary is a migratory route for fish species such as lamprey (*Lampetra spp*.), shad (*Alosa spp.*) and salmonids. The Donna Nook area on the South Bank of the outer estuary supports one of the largest grey seal (*Halichoerus grypus*) breeding colonies in England with over 1,300 pups produced per year.

1.5.2.5 Economic importance

The Humber estuary is one of the most important estuaries in the UK for commerce, with its expanding port complex and extensive bank-side industries. Major industrialised cities such as Birmingham, Leeds, Sheffield, Nottingham, Hull and Bradford are located within its catchment. The four main ports on the estuary are Grimsby, Hull, Immingham and Goole. They constitute the country’s largest port complex in terms of tonnage moved, handing over 40,000 international shipping movements each year and almost one quarter of the UK's seaborne trade (including 25% of the country's natural gas and 25% of its refined petroleum products) (ABP 2013). Further, smaller, facilities are operated by independent port operators around the estuary and along its tributaries. Hull is the UK’s seventh busiest container port and the Port of Immingham, handles more bulk cargo than any other UK port and ranks fourth in size in northern Europe after Rotterdam, Antwerp and Hamburg. In 2009 the combined Humber Ports handled almost 20% of the UK's imports and almost 25% of the UK's car imports and exports.

Industry on the Humber estuary includes chemical works, oil refinery complexes and power stations, with most of this activity located on the south bank of the middle estuary and around the City of Hull on the north bank. Power generation is also undertaken within the wider Humber catchment and in total, generative capacity on the Humber and its tributaries produces almost 20% of England's electricity needs. In addition, a series of offshore wind farms are currently under construction off the mouth of the Humber, with further sites planned.

The Humber is also the landing point for the longest sub-sea gas pipeline in the world, capable of delivering 20% of the UK's natural gas requirements from Norway. With the development of a series offshore windfarms off the east coast of England, the Humber is additionally expected to become a major construction and service hub for the offshore wind industry over the next decade, with two purpose designed facilities for this emerging industry planned for the estuary.

The Humber catchment includes important agricultural areas, with approximately 40% of the land around the estuary classed as Grade 1 or 2 (compared to around 17% for England as a whole) (EA 2011). This land is predominantly used to produce cereal crops, some of which are now being used in bioethanol production at the Saltend petrochemical complex, the feed grade wheat being converted into 420 million litres of bioethanol and 500,000 tonnes of animal feed each year (Vivergo Fuels 2013). The region is also an important pig rearing area, providing 13.5% of the total English pig production, and is also important for glass-house crops with almost 8% of the English production from around the Humber (EA 2011).

The Humber region is additionally a tourist destination with over 2.5 million people undertaking traditional beach-based recreation at Cleethorpes each year (NELC 2007), whilst the City of Hull provides a cultural destination with a range of museums and galleries (it is notable that Hull is designated at the UK City of Culture for 2017). Nature-based recreational activity is conducted around the estuary, with over 400,000 visits to the main nature reserves on the Humber each year (EA 2011), whilst there is also a considerable amount of informal recreation along the long distance footpaths that fringe the estuary for a range of activities such as dog walking, fishing and bird watching.

1.5.3 The Scheldt estuary

1.5.3.1 Geographical information

The Scheldt originates at St. Quentin (France) and its catchment of approximately 21,863 km^2 is situated in the northwest of France (31%), the west of Belgium (Flanders, 61%), and the southwest of The Netherlands (8%) (Figure 1.11). The 355 km long river can be divided into the non-tidal Upper Scheldt and the tidally influenced part which extends from the sluices at Gent until the mouth at Vlissingen (160 km). The lower and middle estuary, the Western Scheldt, is located in the Netherlands. From the Dutch/Belgian border the estuary is called Zeeschelde (Sea Scheldt) which is further divided into the Beneden Zeeschelde, stretching from the border until Antwerp, and the Boven Zeeschelde, stretching from Antwerp to the upstream boundary at Gent. Three main rivers join the Scheldt: the Dender, the Durme, and the Rupel. Within the Rupel, there are also inputs from the Zenne, Dijle and Nete sub-tributaries. The Canal Gent- Terneuzen connects with the Scheldt in the saline part of the Western Scheldt. Most of the river basin area is urban; the total population of the catchment numbers more than 10 million people, with an average density of 477 inhabitants km^2.

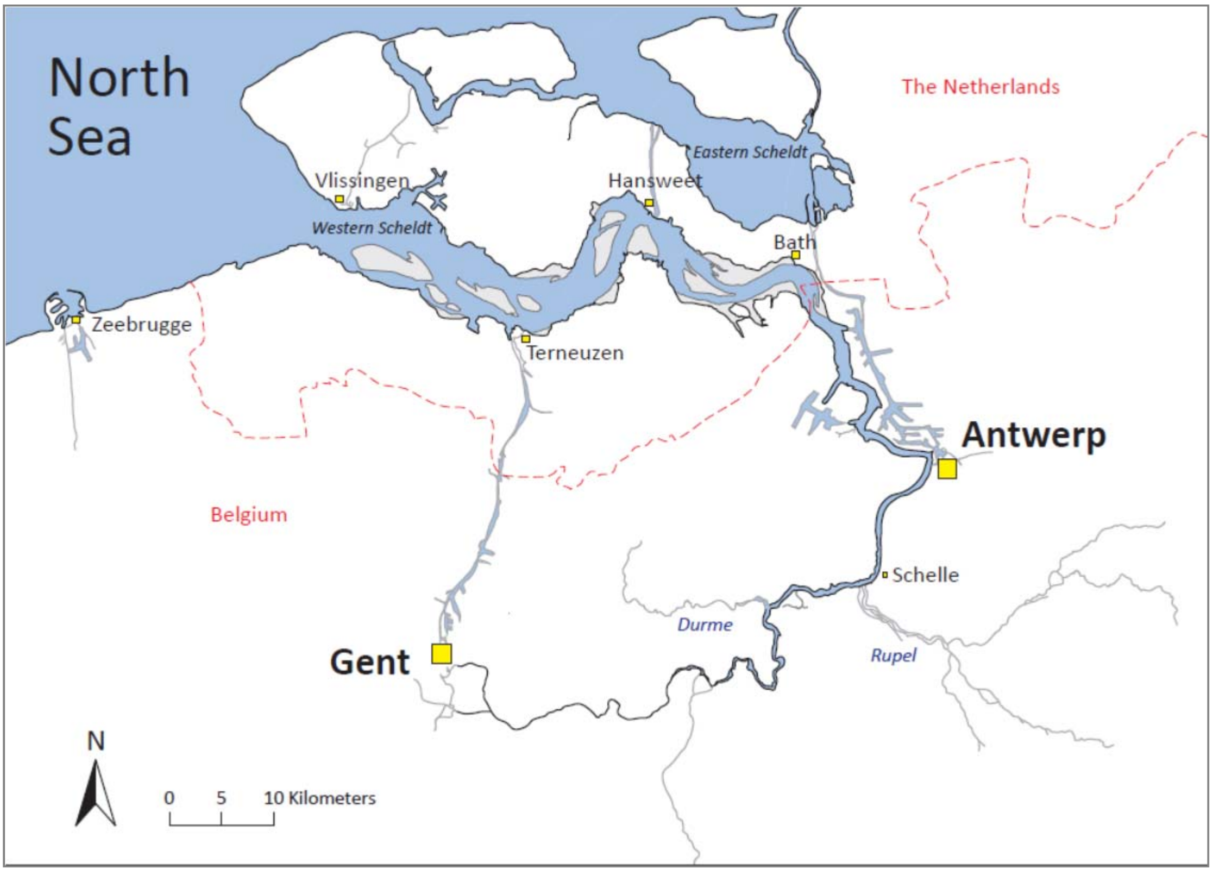

Figure 1.11. Map of the Scheldt estuary

1.5.3.2 Historical evolution

Since the early middle ages tidal marshes of the Scheldt were claimed for agricultural areas. In order to protect themselves against storm surges, people built the first dykes in the 10th century. Between the 14th and 16th century several severe floods occurred which influenced the appearance of the delta of the Scheldt, and since the 16th century, major land claim have has occurred. The importance of the Scheldt for shipping purposes increased in the 19th century which led to several deepenings of the estuary, and since the middle of the 20th century, major industrial and urban developments have taken place. Around 16% of the total surface of the whole estuary was lost in the last century (Meire et al. 2005); and in particular, the surface of the Westerscheldt decreased from 45,000 ha in 1800 to its current area of approximately 30,000 ha. The evolution of habitats in the Westerscheldt shows two different trends: a decrease of low dynamic areas such as mud flats and shallow water, and an increase of high dynamic areas, e.g. deep water and sand flats.

However, a severe storm surge in 1953 with over 1800 casualties in the Netherlands led to the establishment of the Dutch Deltaplan. Further flooding in Belgium (Ruisbroek) led to the setting up of a Belgian version of the Deltaplan, the Sigmaplan, which was established to prevent further flood events. The latter resulted in the construction of combined dike height increases and several flood control areas in Belgium.

1.5.3.3 Hydrogeomorphological characterisation and water quality

The Scheldt is a macro-tidal and relatively turbid estuary (Table 1.4). Mean depth varies from approximately 14 m at the mouth to 3 m at low tide and 7 m at high tide near Gent. The Westerscheldt is well-mixed and characterised by a complex morphology with flood and ebb channels surrounding several large intertidal mud and sand flats (Van Damme et al. 2005), but the upper estuary (Belgian part) forms a more narrow, single tidal channel and may be slightly stratified during high peak discharges. As a result of tidal asymmetry, sediments accumulate in the upstream part of the Scheldt, as more sediment is transported upstream during the flood tide than is exported during the ebb tide. The cross-sectional area increases smoothly from the river to the mouth (Figure 1.11), giving the estuary a funnel shape.

Table 1.4. Hydrogeomorphological characteristics of the Scheldt estuary (Vandenbruwaene et al. 2013)

Parameter	
Tidal range	
Vlissingen (mouth)	3.8 m
Upstream of Antwerp (close to Burcht)	5.5 m
Freshwater discharge at Schelle (mean value, 2001-2010)	
Average	107 m^3/s
Range (dry event, 5%percentile and flushing event/95% percentile)	34 – 253 m^3/s
Residence time (at low and high freshwater discharge)	50 - 247 days
Mean maximum ebb current	0.1 - 1.0 m/s
Mean maximum flood current	0.25 – 1.5 m/s
Suspended particulate matter (depth average, mean value of a tidal cycle, 2001-2010)	30 - 300 mg/l

Water quality was assessed as moderate to bad according to the Water Framework Directive - a result of the discharge of untreated domestic wastewater, industrial pollution with heavy metals and organic micropollutants and extensive nutrient load from agricultural sources. However, major improvements have occurred in recent years. Since 1996, the water treatment of household effluents has changed significantly reducing phosphorus loads (Van Damme et al. 2005; Soetaert et al. 2005), whilst from 2007, water from the Zenne, entering the Scheldt estuary via the Rupel, which carries the wastewater from the densely populated Brussels region, was treated to a level corresponding to 1 million inhabitants (Aquiris 2010). Water quality and the concentrations of dissolved oxygen improved due to the treatment of waste water, for example the freshwater Scheldt has rapidly recovered from hypereutrophication, and has increasingly become autotrophic (Cox et al. 2009). A peak of primary production can be observed in summer and autumn. In 2009 for the first time, oxygen concentrations did not drop below 5 mg/l along the whole estuarine gradient. Nevertheless, a deficiency in the oligohaline zone persists.

1.5.3.4 Ecological features

The Dutch Western Scheldt as well as the Zeeschelde in Belgium function as an important area for water birds, migrating fish species, porpoises and diverse habitat types (Natura 2000 Integrated management plan Westerscheldt & Saeftinghe, in press). The estuary accommodates about 3000 ha of tidal marshes of which the most important ´Saeftinghe´ is located in the brackish area and covers approximately 2700 ha. The Scheldt is a designated Ramsar site and is of international importance for 21 water birds species (van den Bergh et al. 2005, in Meire et al. 2005). In general, these species exceed the 1% norm of the convention, i.e. the required threshold for the designation of a Ramsar site in all months of a year. Therefore, large parts of the Scheldt estuary are designated as international Ramsar sites as well as SPAs or SACs under the EU legislation, i.e. the Habitats and Bird Directives (92/43/EEC and 2009/147/EC). Due to the improved water quality, the numbers of protected fish species such as *Allosa fallax* are increasing and the reproduction cycle of migrating fish has been restored, e.g. for *Lampetra fluviatilis* (Meire et al. 2005).

As with the other TIDE case study estuaries, the Scheldt estuary is designated as a heavily modified water body (HMWB) according to the Water Framework Directive.

1.5.3.5 Economic importance

The catchment of the Scheldt is mostly urban with intense industrial activity. Shipping and nature are considered as the most important functions (Natura 2000 Integrated management plan Western Scheldt & Saeftinghe, in press). The port of Antwerp plays a significant economic role and in 2012, the volume of maritime freight handled in Antwerp amounted to 184.1 million tons. The port accounts for about 60,000 direct and 85,0000 indirect jobs (http://www.vnsc.eu/themas/scheepvaart-en-economie/industrie.html). Further ports are located at Gent (Belgium), Terneuzen and Vlissingen (The Netherlands).

Industry and power plants are located near the ports of Antwerp, Gent and Vlissingen (Van der Zee et al. 2007). Together with industrial plants they extract water for cooling purposes and other uses and in the Westerscheldt, sand extraction also takes place.

In addition to industry, agriculture (i.e. stock farming, crop and fruit-growing), plays an important economic role along the Scheldt estuary, as well as in the region of Flanders (Belgium) and in the province of Zeeland (The Netherlands). Tourism is especially important around the estuary mouth, and the Scheldt is intensely used for water sports, beach activities, walking, biking, camping, etc.

1.5.4 The Weser estuary

1.5.4.1 Geographical information

The 477 km long river Weser (Figure 1.12) is located in the central region of Northern and Central Germany. Its source is at the city Hannoversch Münden at 116.5 m above sea level formed from the junction of the rivers Fulda and Werra and reaches the North Sea 452 km further downstream. The catchment area of the Weser covers approximately 36,560 km^2. Together with the Werra and Fulda the catchment totals 49,000km^2, of which the largest areas belong to the Federal States of Lower Saxony, Hessen, North Rhine-Westphalia, Thuringia and minor areas to Saxony-Anhalt, Bremen and Bavaria. The Weser estuary extends from the tidal weir at Hemelingen located in the vicinity of the city of Bremen to the mouth in the North Sea (approximately 120 km) and is divided in two parts. The Unterweser (lower Weser) reaches from the weir until the city of Bremerhaven, and the Außenweser (outer Weser) is located between Bremerhaven and the North Sea. The biggest tributaries are the Werra, Fulda, Diemel, Aller, Hunte, Ösper and Lesum rivers. About 1 million people live in the catchment (Schirmer and Schuchardt, 2001) which includes the main cities along the Unterweser, in particular Bremen and Bremerhaven.

Figure 1.12. Map of the Weser, its tributaries and catchment area

1.5.4.2 Historical evolution

In order to prevent settlement areas from flooding, dykes were first built on the lower reaches of the Weser River about 1000 AD. Major parts of the floodplain were thereby separated from the estuary. Since the end of the 19th century, overflow dams have been built to transform outer dyke areas into agricultural land. The course of the estuary was first modified between 1887-1895 (Lange et al. 2008). Port facilities were created and the river fairway was deepened a number of times during the 20th century. As supporting measures, groynes and bank reinforcements were built and maintenance dredging was undertaken. At the end of the 1970s, storm surge barriers were built at the mouth of the Hunte, Lesum and Ochtum tributaries.

1.5.4.3 Hydrogeomorphological characterisation and water quality

The Weser is considered to be a well-mixed, predominantly meso-tidal estuary. The estuary and the surrounding Wadden Sea are still subject to morphological changes, as tidal gullies and sand banks can move up to 100 m per year (Lange et al. 2008). Suspended matter concentration can reach up to 1500 mg/l (Villars and Delvigne 2001).

The estuarine turbidity maximum zone is found in the low salinity area near Nordenham, and its formation can be associated with tidal asymmetry effects. The exact position depends greatly on freshwater discharge (Grabemann and Krause, 2001 and references therein). Characteristic hydrogeomorphological parameters of the Weser are presented in Table 1.5.

Table 1.5. Hydrogeomorphological characteristics of the Weser estuary (Vandenbruwaene et al. 2013)

Parameter	
Tidal range	
Mouth	3.8 m
Upstream of the city of Bremen	4.1 m
Freshwater discharge at Intschede (mean value, 2001-2010)	
Average	331 m^3/s
Range (dry event, 5%percentile and flushing event/95% percentile)	122 – 798 m^3/s
Residence time (at low and high freshwater discharge)	7 – 27 day
Mean maximum ebb current	0.1 – 0.6 m/s
Mean maximum flood current	0.12- 1.3 m/s
Suspended particulate matter (surface, low water, mean value, 2001-2010)	20- 100 mg/l

Due to salt mining in the catchment, the freshwater part of the estuary can reach salinities of up to 2 PSU, depending on the freshwater run-off (Grabemann and Krause 2001; Villars and Delvigne 2001). Nitrogen and particularly phosphate from river inputs have decreased significantly since the 1980s.

1.5.4.4 Ecological features

More than 90% of the tidal Weser surface area and floodplains belong to the European Natura 2000 network of protected areas. For example, brackish grasslands of the Wurster coast are home to a unique feature of the Weser estuary: the Bulbous Foxtail grass *(Alopecurus bulbosus)* is only found in this area. The Juliusplate, a nature protection marshland area located just downstream from Bremen, is characterised by large groups of the threatened Snake's Head Fritillary plant *(Fritillaria meleagris).* Migrating fish species such as the Twaite Shad (*Alosa fallax*), River Lamprey (*Lampetra fluviatilis)* and Sea Lamprey (*Petromyzon marinus*) use the largely continuous outer and lower Weser as a link between their spawning and breeding areas. Harbour (or Common) Seals (*Phoca vitulina*) can be found resting on the sandbanks of the outer Weser, whilst porpoises (*Phocoena phocoena*) feed in the estuary. The Weser estuary also provides an important habitat for many species of birds. For example, the Pied Avocet (*Recurvirostra avosetta*) can be present in large moulting flocks in the shallow waters of the Weser, before continuing their migration south in autumn. The mouth of the Weser estuary north of Bremerhaven is part of the Wadden Sea which is declared a UNESCO World Heritage site, and it belongs to the Wadden Sea National Park of Lower Saxony. According to the EU Water Framework Directive, the transitional and limnic waters of the Weser estuary are designed as Heavily Modified Water Bodies (HMWB).

1.5.4.5 Economic importance

The Weser is an important navigation route serving the main port of Bremerhaven / Bremen which is the second largest of Germany. In 2011, the volume of maritime cargo amounted to 80.6 million tons, and in 2010, the port complex generated (either directly or indirectly), employment for 74,000 people in the area (pers. communication, Free Hanseatic City of Bremen). Further harbours are located at the cities of Brake and Nordenham, and via the Hunte tributary, the city of Oldenburg can be reached. Coal and gas power plants deliver energy, but also extract cooling water. The area is considered an important economic area of Northern Germany. The main industries are renewable energies such as wind energy, maritime economy and the air and space industry.

The land along the estuary is used for agriculture (3800 ha, NLWKN and SUBV 2012), farmed mostly as grassland for cattle and sheep. Large parts of the outer and lower Weser region are still dominated by relatively sparsely populated, agriculturally-used marshland. Recently, fishing activities are restricted to the outer part of the estuary, where shrimps are the main catch.

The Weser and its tributaries are frequently used for recreation, mainly for water sports, camping and biking. Tourism is an important source of revenue in the area and the river and sea attract thousands of tourists each year, primarily visiting the coastline. Throughout the outer and lower Weser region there are numerous marinas, camping sites and holiday houses. For water sports enthusiasts a vast amount of creeks and canals link the Weser to other European waters. Many people also explore the Weser marshes by bicycle. The 'Weser bike trail' is one of the most popular cycle routes in Germany with 150,000 cyclists each season.

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2 Historical Evolution of Habitats

K. Hamer, N. Cutts, K. Hemingway and N. Liedtke

2.1 Zonation approach as a basis for interestuarine comparisons

A fundamental knowledge of the physics, chemistry and biology of the estuarine system is required to effect successful and sustainable management. Comparisons of the development and functioning of different estuaries can deliver new insights useful for estuarine management. Such comparisons have been performed previously and proven to be useful (Heip and Herman 1995; Kennison et al. 2003). Anthropogenic pressures such as land reclamation, harbour development, shipping navigation and waste discharges can strongly alter the morphology, hydraulics and ecology of the estuarine system (Kerner 2007; Antwerp Port Authority 2012). These pressures differ between estuaries, and therefore, a comparison of estuarine use and morphology development of the four TIDE case study estuaries was considered an important basis for the project, the comparison based around the salinity zonation approach which is briefly described below. This inter-estuarine comparison was facilitated through the development of a series of historical hydro-geomorphological and land use datasets, together with new analysis methods, allowing hydro-geomorphological and ecological processes, such as tidal damping, primary production or the distribution of habitats to be identified and comparisons made between the four TIDE case study estuaries as they are important key parameters for the understanding of estuarine functioning.

Given the highly variable nature of estuaries, such a comparison requires a clear definition of comparable units. Therefore, a classification (Table 2.1) according to the Venice system (1959) based was developed (Geerts et al. 2012). In the approach chlorinity data were used, and the common used conversion factor to salinity in order to relate the data to the Venice classification.

Table 2.1. Common classification of zones (indicated in TIDE km; km 0 means the inner boundary of the estuary) within the four case estuaries (Geerts et al. 2012)

<table>
<tr><th>Chlorinity range</th><th colspan="2">Elbe</th><th colspan="2">Weser</th><th colspan="2">Scheide</th><th>Humber</th></tr>
<tr><td rowspan="3"><300 mg Cl/L
Freshwater zones</td><td rowspan="3">0-91</td><td>0-24</td><td rowspan="3">0-44</td><td rowspan="2">0-31</td><td rowspan="3">0-58</td><td rowspan="2">0-31</td><td rowspan="3">Trent: 0-45 TIDE$_{Trent}$-km+
Ouse till confluence with
the Aire: 0-34 TIDE$_{Ouse-Humber}$-km</td></tr>
<tr><td>24-46</td></tr>
<tr><td>46-91</td><td>31-44</td><td>31-58</td></tr>
<tr><td>300-3.000mg Cl/L
Oligohaline zone</td><td colspan="2">91-118</td><td colspan="2">44-69</td><td colspan="2">58-89</td><td>Trent: 45-85 TIDE$_{Trent}$-km +
Ouse further downstream:34-60 TIDE$_{Ouse-Humber}$-km</td></tr>
<tr><td>3.000-11.000 mg Cl/L
mesohaline</td><td colspan="2">118-141</td><td colspan="2">69-84</td><td colspan="2">89-116</td><td>Humber: 60-93 TIDE$_{Ouse-Humber}$-km</td></tr>
<tr><td>>11.000 mg Cl/L
polyhaline</td><td colspan="2">141-171</td><td colspan="2">84-119</td><td colspan="2">116-160</td><td>Humber: 93-123 TIDE$_{Ouse-Humber}$-km</td></tr>
</table>

2.2 Changing patterns and sizes of habitats influenced by human activities

Estuaries form the interface between open sea and freshwater, so that a continuum of limnic (freshwater), brackish and marine environments are often present in close proximity. This connectivity is a prerequisite of the ecological functioning of estuaries (Elliott and Whitfield 2011). Organisms living in an estuary depend on the occurrence, extent and quality of diverse habitats, characterised by water depth, bed substratum, oxygen concentration, salinity and light penetration. These factors are directly linked to hydrology, especially currents, wave action, tides and water residence times, as well as position and extent of the turbidity zone (Uncles et al. 2002).

Whilst in such a dynamic system overall sediment erosion and deposition is in balance, this natural balance can be interfered with by external processes, either of anthropogenic or natural origin.

2.2.1 Sustainability and ecosystem services

The concept of sustainability developed when mankind became aware of limited resources and the strong links between economy, society and ecology (e.g. Meadow 1972). A sustainable development is defined as a process that ensures that today´s use of ecological resources and ecosystems provides economic growth to meet the needs of the present, but without compromising the needs of future generations.

Nevertheless, due to the broadness of the concept it has been difficult to incorporate into legal frameworks, whilst the comparison of economy, ecology and social welfare at an estuary scale is complicated as very different types of information relevant to support decision-making procedures need to be considered (Costanza et al. 1997; Farber et al. 2002; Pirrone et al. 2005).

In order to quantify the “value” of estuaries, it should be emphasised that coastal and estuarine areas belong to the most productive environments, with almost 28% of total global primary production taking place in coastal and estuarine areas which comprise only 8% of the world’s surface (de Jonge and Elliott 2001).

Examination of information on the loss of these very productive habitats from North Sea estuaries such as the Elbe (Schuchardt et al. 2007), the Ems (Herrling and Niemeyer 2008), the Humber and the Scheldt (HARBASINS project) as well as the Weser (Schuchardt et al. 2007; Elsebach et al. 2007) emphasises the need for the incorporation of the sustainability concept in tools to assist in applied estuary management.

2.2.2 Changes in the North Sea estuaries: natural and anthropogenic

Climate is a dynamic system in geological as well as historical time scales. Following the last ice age, the melting of glaciers and inland ice shields induced a sea level rise of 120 m, resulting in the flooding of the North Sea basin and the step-wise development of associated coastal morphology (Streif 2004).

Since measurement of sea-level commenced, the German Bight has seen an increase in sea-level of 25 cm since 1890 (Fickert and Strotmann 2007).

Sea-level rise predictions have been developed for a series of climate change scenarios (IPCC 2001), and for the North Sea the recent rate of rise of 4 mm per annum is assumed to increase by up to 12 mm per annum by end of the 21st Century (Environment Agency 2011). As part of the climate change scenario predictions, the patterns of precipitation are expected to alter, and such changes will have the potential to influence the hydraulic situation in the estuaries (Atkins 2002; Schuchardt and Schirmer 2005). These changes may affect water residence times leading to the upstream migration of the position of the brackish zone (Schuchardt and Schirmer 2005) with associated modification to the ecology of these zones therefore likely.

In addition to the direct climate related sea level rise, the North Sea estuaries are influenced by isostatic movement of the Earth´s surface, this isostatic rebound differing between regions. In the German Bight, recent subsidence rates range from -5 to -7cm/100 years (Augath 1993; Shennan 1987), whilst in Belgium and The Netherlands, a higher subsidence rate has been identified (Kiden et al. 2002). Along the British North Sea coast, the Scottish coastline is rising whereas the south-east of England is sinking thus exacerbating other causes of sea level rise and storm-surges. Isostatic movement has been identified as contributing approximately 25 cm of the mean sea level rise in the North Sea within the last century.

Anthropogenic modification to estuaries and their hinterlands commenced in Europe well over 1000 years ago with the drainage and conversion of wetlands to provide agricultural land and with dykes (flood banks) built along the marsh edges to prevent settlements and agricultural areas from flooding. Further dyke alignments were subsequently developed within the intertidal areas in order to develop additional land for human use, and consequently, major parts of estuarine floodplains were separated from the estuarine and fluvial action with a corresponding reduction in the available area for tidal inundation (Herrling and Niemeyer 2008).

These measures have led to a habitat loss in estuaries, for instance in the Humber and Scheldt estuaries, up to 80% of the intertidal areas was lost over the last 300 years. Detailed studies including maps of historic times are available for the Humber (de Boer 1970; Pethick 1990; Cutts et al. 2008; Elliott et al. 2008), the Ems (Herrling and Niemeyer 2008), the Weser (Elsebach et al. 2007), the Elbe (Freitag et al. 2007) (Figure 2.1) and parts of the Scheldt (Huijs 1996).

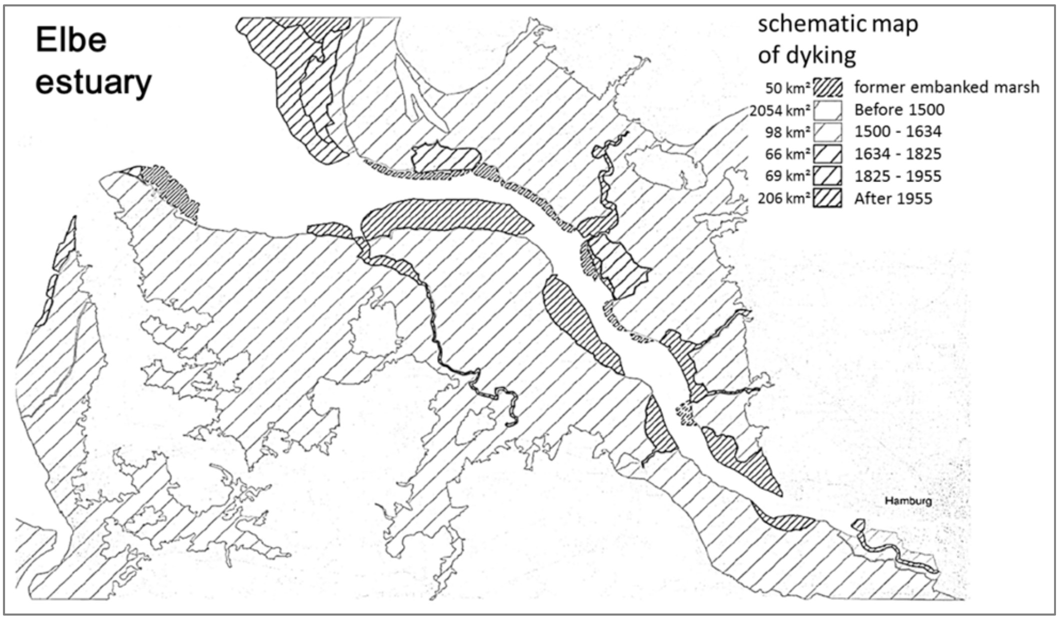

Figure 2.1. Areas of land claim since the 15th century in the Elbe estuary (from Freitag et al. 2007)

Another important factor influencing estuarine morphology has been the increasing demand for navigation over time, as, with the development of inland urban centres based around raw materials, access for bulk trade became necessary. With gradual increase in trading vessel size (including draught), greater waterway depth and width was necessary, which in some estuaries led to channel deepening and stabilisation, waterway construction and inland harbour development. This development continued in many estuarine and fluvial systems in the 19th and 20th centuries, for instance additional port facilities such as Bremerhaven in the Weser were built in 1827 and river fairways were deepened a number of times (Figure 2.2). As supporting measures to navigation developments, groynes and bank reinforcements were built and maintenance dredging has been carried out, these human activities creating the current morphology of many estuaries and rivers (Wetzel 1987; Hamer et al. 2013).

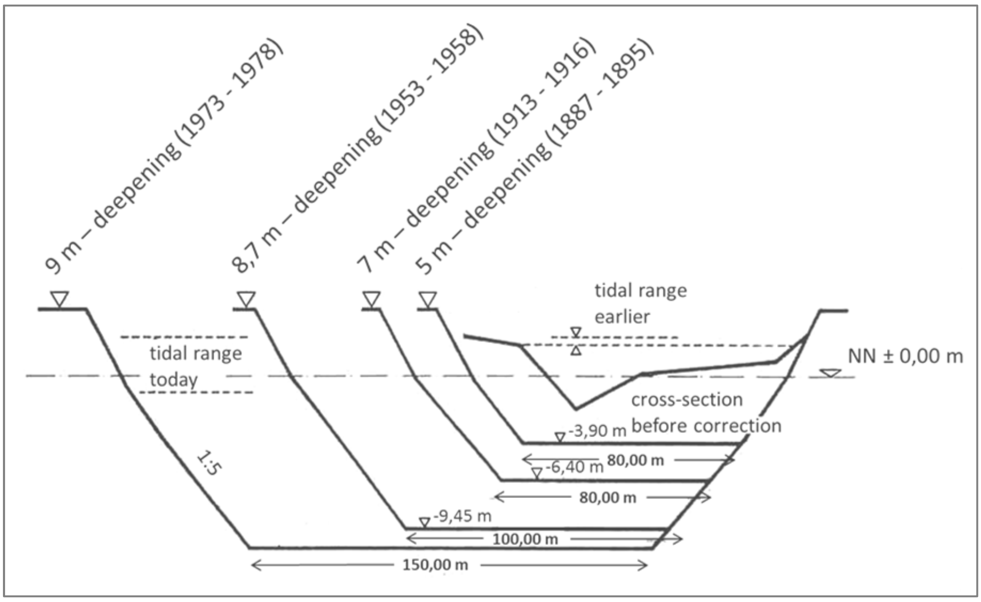

Figure 2.2. Cross-section of the river bed at Weser km 11 near Bremen (from Wetzel 1987). Downstream from km 41 a depth of 11,9 m is available and in the Outer Weser the navigational channel provides a depth of 12,5 m; and a further deepening to 13.5 m is planned.

2.2.3 Hydro- and morphodynamics controlling habitats

In addition to the tidal influence, estuarine morphology is also controlled by both the convergence from the mouth in the upstream direction and by bed friction, the characteristics of these factors depending on the geological substratum of each estuary. Under natural conditions, tidal waves along a riverbed are damped due to friction which results in a reduction of the tidal range upstream until it reaches zero. The development of tidal ranges at different locations in estuaries (Schuchardt et al. 2007, Figure 2.3) reflects the influence of natural processes and human activities on the characteristics of the tidal wave and consequently hydrodynamics and morphology. Due to the straightening and deepening of the estuarine and fluvial systems, the tidal wave reaches upstream regions easier, and thus tidal damping is hindered and amplification of the tidal wave occurs. Further measures such as shoreline protection and the building of dykes (flood banks) have stabilised the artificial bed even further (Herrling and Niemeyer 2008) and can exacerbate this effect.

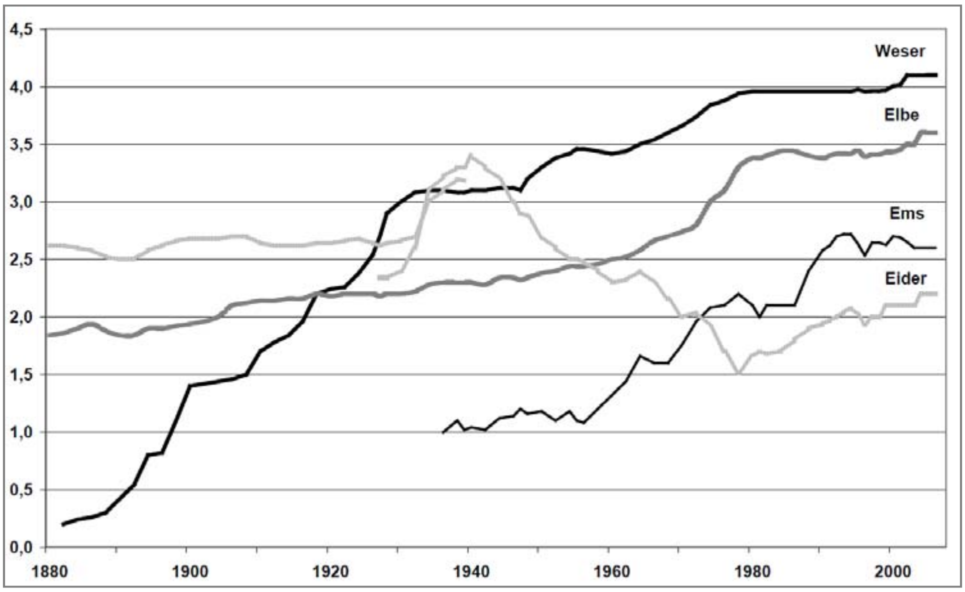

Figure 2.3. Changes in tidal range between 1880 and 2005 in the German estuaries Eider (gauges Tönning and Friedrichstadt), Elbe (gauge Hamburg St. Pauli), Weser (gauge Bremen Oslebshausen) and Ems (gauge Herbrum) (5-year running mean) (from Schuchardt et al. 2007)

Recently, the Elbe, Humber, Scheldt and Weser estuaries have been shown to feature an amplification of the tidal amplitude in a landward direction (e.g. Van Rijn et al. 2011) and in general, an increase of tidal range in North Sea estuaries has been observed since the 19th Century (Figure 2.3 and also Figure 2.7).

2.2.4 Time and spatial scales and habitat types

The changes in habitat patterns of the Elbe, Scheldt, Humber and Weser were analysed over three time steps: (1) at the end of the 19th Century/early 20th Century, (2) at the middle of the 20th Century and (3) in recent times. As the aim of the analysis was to provide quantitative values for changes in estuarine morphology and intertidal habitat from the case study estuaries, given the paucity of historical accurate geomorphological data, the end of the 19th Century or the early 20th Century was used as the reference baseline for the an analysis, this period considered to be the furthest back historically that accurate data would be available across all sites. However, as described above, human activities with often large scale influence on estuarine morphology, commenced a considerable time prior to this reference scenario, and as such, the baseline period used in this analysis should not be considered to provide an indication of 'natural' morphology in the case study estuaries, but rather an indication of more recent modification.

The middle of the 20th century was identified as the next analysis period, as post the second world war, new ships were designed of greater size (including draught) and thus potentially requiring additional fairway modification to ensure capacity and safe navigation. The third analysis period was the 'present' or a recent period where data were available, whilst additional mapping analysis was undertaken for further years in some estuaries where data and/or potential morphological change was identified. Table 2.2 provides an overview of the mapping dates for each estuary based around the three key time periods and associated available data.

Table 2.2. Times considered for calculating habitat areas

	End of 19th C./early 20th C.	Mid of 20th C.	Recent time	Additional analysis years
Elbe	1900	1950	1992-95	
Humber	1910/24	1975	2008	1988 & 1993
Sea Scheldt	1880/87 & 1930	1960/72	2000	1930
Weser	1860/87	1951/52 & 1961/62	2005-20008	

The extent of each key habitat was then digitised from geo-referenced maps of each period for each of the salinity zones (Tables 2.2 and 2.3). As there were limited or no data available describing the historical salinity gradient in the case study estuaries, the zonation extent from the current analysis period was applied to the historical time steps for each estuary, however it is acknowledged that the salinity zonation boundaries may have been different in these historical analysis periods.

This approach allowed a comparison of the overall size and variation in the key habitats of the four estuaries, the data available for each estuary as a whole and for each salinity zone.

In order to compare the habitat status of the different case study estuaries and provide further comparative potential across the North Sea region, one common typology was applied. There are two main groups of classification available; the first group contains the EUNIS classification (Davies et al. 2004) which was developed from the Marine Habitat (Biotope) Classification for Britain and Ireland (Connor et al. 2004); and the second one based on classification systems that are used in The Netherlands and Belgium. Whilst the EUNIS and Marine Habitat Classifications are largely based on the occurrence of species in a habitat, the alternative approach focuses on physical characteristics. However, ultimately it is considered that both approaches utilise the same available information but in a different hierarchical order.

Consequently, if mapping of the habitat status is the main aim, then the EUNIS or Marine Habitat classification type may be preferred, however, if a description of historical habitat change is required, then an approach focussing on physical characteristics may be more appropriate, because information about historical biotic condition are not available at a spatial resolution allowing comparison with current/recent data.

The analysis which has been conducted within the TIDE project applied a classification scheme for tidal influence and salinity regime, as whilst the salinity gradient is crucial for the development of biotopes along the estuary, the amplitude of the tide is important for a differentiation of habitats in lateral direction crossing the river bed.

The habitats identified for the analysis were grouped into those below mean low water level (MLWL), between MLWL and mean high water level (MHWL) and above MHWL. In the TIDE study these zones were then classified as sub-, inter- and supratidal areas, the intertidal areas equating to the main extent of the tidal mud and sand flats present in an estuary and the supratidal areas equating to areas of saltmarsh and grazing marsh (Table 2.3). Additional metrics for the habitat types for tidal flats, shallow waters, sloping channel edges and deep water can be distinguished as high and low energy sub-types, given that velocity, wave action and substratum can differ with varying energy levels. Although not being uses here for further analysis, this differentiation is of interest, because low energy habitats are generally considered to be the most productive ones and show highest biodiversity in estuaries (e.g. Kraft et al. 1999). This energy based sub-class were applied for anabranches and other relevant morphological structures.

In addition to marsh habitat, summer polder and stagnant water habitats above MHWL were also considered. However, the information for these latter two habitat types was restricted to the current/recent analysis period.

Table 2.3. Overview on the applied habitat classification

Depth	Classification according to Elsebach et al., 2008	Further classification	Habitat types	
> MHWL	Supratidal	Marsh	Stagnant water	Summer polder
			Marsh	
<MHWL >MLWL	Intertidal	Tidal flats	Tidal flat	
			high energy	Low energy
< MLWL	Subtidal	Subtidal	Shallow (<MLWL to -2m)	
			High energy	Low energy
			Slope (-2m to -5m <MLWL)	
			High energy	Low energy
			Deep (more than -5m <MLWL)	
			High energy	Low energy

2.2.5 Evolution of areas in different salinity zones

Data limitations for the reference period (e.g. prior to recent human morphologic interventions) and for the middle of the 20th century meant that it was not possible to distinguish between the deep water, slope and shallow water habitats in every estuary, however, the metrics associated with these have been combined as 'subtidal area'. In the same way spatial data for saltmarsh, summer polder and stagnant water areas are treated either as marsh or as 'supratidal area' depending on data availability. All data and maps derived from the analysis process for the four case study estuaries are provided in Hamer et al. (2013). Table 2.4 and Figure 2.4 provide an overview of the changes in spatial extent of the habitats from the different salinity zones within the TIDE estuaries and over the three time steps: (1) at the end of 19th Century/early 20th Century, (2) at the middle of the 20th Century, and (3) in recent times

Table 2.4. Historical development of areas (ha) of zones in the four TIDE case study estuaries

	End of 19th C /	Mid 20th C	Recent	% Change
Elbe				
Freshwater	10481	8982	6886	-34.3
Oligohaline	15286	15686	9553	-37.5
Mesohaline	47376	37910	38905	-17.9
polyhaline	28802	27842	28828	0.1
Σ Elbe zones	101945	90420	84172	-17.4
Humber				
Mesohaline	8704	8578	8585	-1.4
Polyhaline	19719	19552	19631	-0.4
Σ Humber zones[1]	28422	28130	28216	-0.7
Sea Scheldt [2]				
Freshwater	3297	1829	1460	-55.7
Oligohaline	1282	1175	997	-22.2
Mesohaline	2937	2609	2413	-17.8
Σ Sea Scheldt zones [2]	7516	5613	4870	-35.2
Weser				
Freshwater	5943	3761	3912	-34.2
Oligohaline	6211	4494	4524	-27.2
Mesohaline	11014	10386	9990	-9.3
Polyhaline	82121	82404	82288	0.2
Σ Weser zones	105290	101044	100714	-4.3

1 *The Humber estuary utilises a zonation scheme based on management requirements and does not focus on salinity alone (see Geerts et al. 2013). However the majority of the oligohaline and freshwater zones are located within its tidal tributaries rather than the estuary itself.*

2 *Here only the Sea Scheldt data are provided (the polyhaline and part of the mesohaline zone of the Western Scheldt´s estuary). Accordingly, the data do not represent the overall estuary which would cover an area of appr. 35,000 ha*

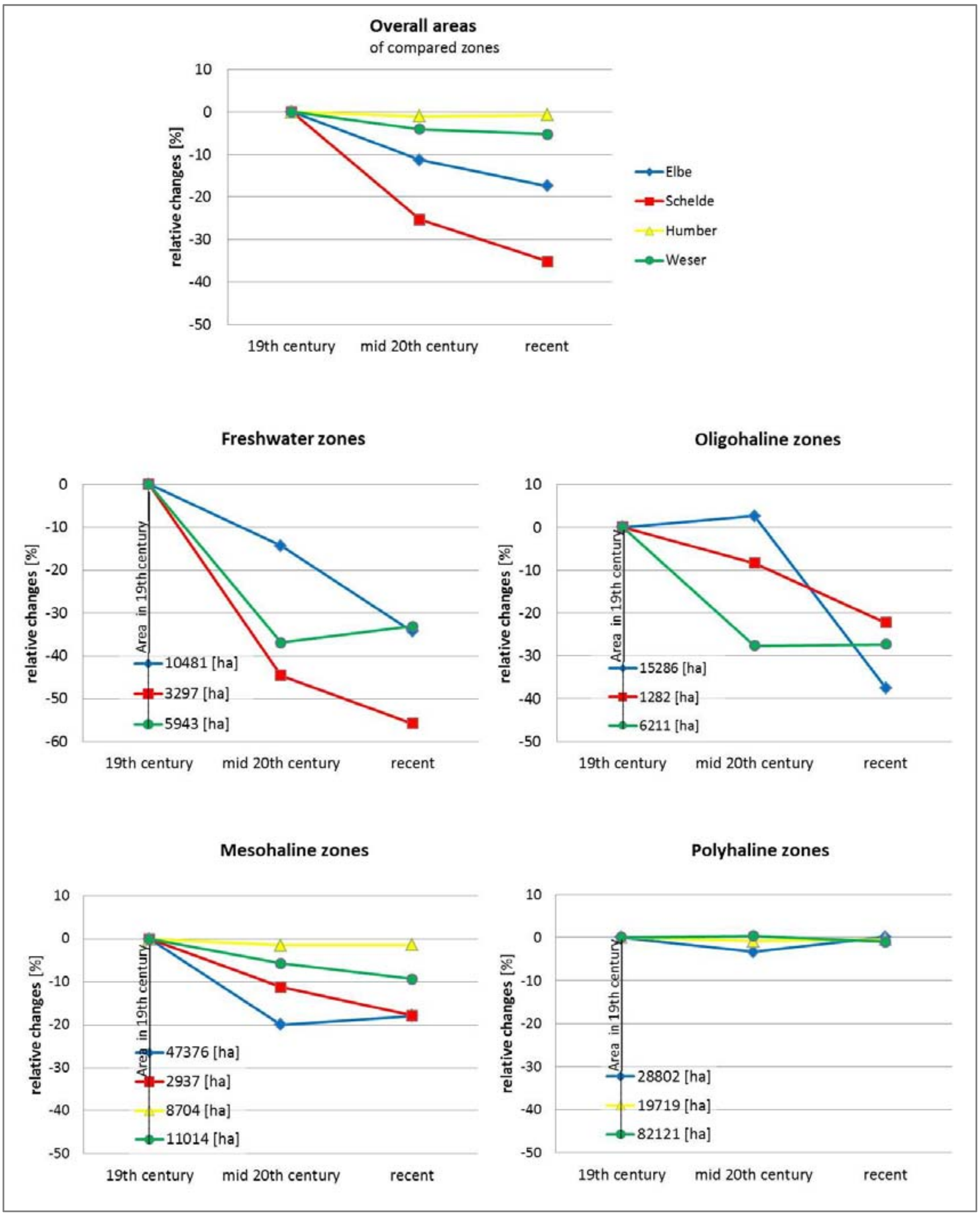

Figure 2.4. Habitat change (%) within the salinity zones of the TIDE estuaries in relation to the 19th/20th C baseline. The Elbe, Sea Scheldt and Weser show the highest loss of areas in the inner zones (freshwater and oligohaline), with a reduction in lost area towards the estuary mouths. Note that the initial area of the zones is displayed in ha. However, the overall extent of freshwater and oligohaline zones in the Humber did not change to any sufficient amount that can be shown within the graphs, with large scale change (habitat loss) having occurred throughout the estuary prior to the baseline period.

The data from the analysis indicate that the overall size of the Elbe, Sea Scheldt and Weser estuaries have decreased in a range from approximately 4% up to more than 30 %, whereas the Humber estuary extent has remained stable since the end of the 19th Century. In fact the overall size of the outer Humber was greatly reduced during the 18th and 19th Centuries, through land-claim for agriculture and port developments, and with additional substantial losses within the freshwater and oligohaline habitats of the upper Humber having occurred over preceding centuries.

The loss of habitat was identified to have mostly occurred during the analysis period from the inner estuarine areas, the level of change (loss) decreasing with distance downstream towards the estuary´s mouth. In the Elbe and the Weser, the analysis indicates that a third of the freshwater habitat was lost over the analysis period (c. last 100 years), with more than half of the freshwater habitat having been lost from the Sea Scheldt. The spatial data for the oligohaline and mesohaline zones show a reduction in the level of loss with progression downstream, however, losses remain within the same order of magnitude (Figure 2.4). However, in the outer parts of the estuaries nett polyhaline habitat area appears to have remained stable over the analysis period (Table 2.4).

2.2.6 Evolution of habitat distribution

The distribution patterns of habitat types differs between the four case study estuaries, in terms of the proportion of marsh (supratidal) and tidal flats (intertidal) area. However, this is an artefact of the relation of the sizes of polyhaline zones to the other salinity zones, with the larger polyhaline area masking any changes of habitat area from the other zones.

The analysis indicates that currently in the Humber and Weser, less than 6 % of the estuarine areas are marsh habitat, whilst the marsh areas of the Elbe and Sea Scheldt represent between 11-15% of the total estuarine extent. Subtidal habitats covers between 50-58% of the overall area for all of the case study estuaries. Analysis of temporal habitat change, indicates that habitat extent has been relatively stable on the Humber over the last 100 years, although prior to that period there has been a considerable loss of intertidal marsh and mudflat, this occurring in the preceding several 100 years in the outer estuary, and over 1000 years ago in the tidal tributary headwaters. The Weser exhibits a broadly similar temporal pattern of habitat loss for the analysis period to that of the Humber (Figure 2.5), however, the overall area of the Weser estuary has decreased, mainly due to a loss of marsh and subtidal habitats (Table 2.5).

Habitat change in the Elbe estuary has been characterised by a relative increase of subtidal habitats, mainly due to a corresponding large reduction of marsh extent from 21% of total area in the 19th Century to 11 % from recent data. However, in terms of total estuarine area, all habitat type areas in the Elbe have decreased.

The temporal change in habitat in the Sea Scheldt is characterised by an increase in subtidal area from 60 to 70%, mainly resulting from an increase in the extent of deep water habitats whereas slope and shallow water habitats have decreased. The extent of marsh habitats in the system have also declined over the analysis period by more than 50% from approximately 1,400 ha to less than 700 ha in recent times and the summer polder area from 1700 ha to zero (Table 2.5).

Table 2.5. Development of habitat types (ha) from the 19th century until recent times

<table>
<tr><th rowspan="2">Habitat</th><th rowspan="2">End of 19th C / Early 20th C</th><th rowspan="2">Mid 20th C</th><th rowspan="2">Recent</th><th colspan="2">Difference</th></tr>
<tr><th>%</th><th>ha</th></tr>
<tr><td>Elbe</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Deep water</td><td>33442</td><td>35632</td><td>33423</td><td>0</td><td>-19</td></tr>
<tr><td>Shallow water</td><td>12359</td><td>10283</td><td>8870</td><td>-28</td><td>-3489</td></tr>
<tr><td>Tidal flat</td><td>34300</td><td>25771</td><td>33000</td><td>-4</td><td>-1300</td></tr>
<tr><td>Marsh</td><td>21843</td><td>18736</td><td>8882</td><td>-59</td><td>-12961</td></tr>
<tr><td>Σ Elbe</td><td>101944</td><td>90422</td><td>84175</td><td>-17</td><td>-17769</td></tr>
<tr><td>Humber</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Subtidal</td><td>17394</td><td>17206</td><td>16298</td><td>-6</td><td>-1096</td></tr>
<tr><td>Tidal flat</td><td>10142</td><td>10291</td><td>11078</td><td>9</td><td>936</td></tr>
<tr><td>Marsh</td><td>887</td><td>632</td><td>840</td><td>-5</td><td>-46</td></tr>
<tr><td>Σ Humber</td><td>28422</td><td>28130</td><td>28216</td><td>-1</td><td>-206</td></tr>
<tr><td>Sea Scheldt</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Deep water</td><td>1659</td><td>1635</td><td>2074</td><td>25</td><td>416</td></tr>
<tr><td>Slope</td><td>1012</td><td>968</td><td>823</td><td>-19</td><td>-189</td></tr>
<tr><td>Shallow water</td><td>676</td><td>638</td><td>432</td><td>-36</td><td>-244</td></tr>
<tr><td>Tidal flat</td><td>929</td><td>889</td><td>824</td><td>-11</td><td>-105</td></tr>
<tr><td>Marsh</td><td>1470</td><td>1021</td><td>682</td><td>-54</td><td>-788</td></tr>
<tr><td>Summer polder</td><td>1720</td><td>398</td><td>0</td><td>-100</td><td>-1720</td></tr>
<tr><td>Stagnant water</td><td>51</td><td>64</td><td>-</td><td></td><td></td></tr>
<tr><td>Σ Sea Scheldt[1]</td><td>7516</td><td>5613</td><td>4834</td><td>-36</td><td>-2682</td></tr>
<tr><td>Weser</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Deep water</td><td rowspan="3">56917</td><td>26202</td><td>24294</td><td rowspan="3">-5</td><td rowspan="3">-2825</td></tr>
<tr><td>Slope</td><td>15924</td><td>16618</td></tr>
<tr><td>Shallow water</td><td>10869</td><td>13176</td></tr>
<tr><td>Tidal flat</td><td>40764</td><td>43255</td><td>40322</td><td>-1</td><td>-442</td></tr>
<tr><td>Marsh</td><td>7609</td><td>4793</td><td>3834</td><td></td><td></td></tr>
<tr><td>Summer polder</td><td></td><td></td><td>2391</td><td rowspan="2">-17</td><td rowspan="2">-1303</td></tr>
<tr><td>Stagnant water</td><td></td><td></td><td>81</td></tr>
<tr><td>Σ Weser</td><td>105289</td><td>101044</td><td>100716</td><td>-4,5</td><td>-4574</td></tr>
</table>

1 *Only data for the Sea Scheldt are given, as the polyhaline and part of the mesohaline zone of the Western Scheldt are excluded from the analysis due to data availability. As such, data do not represent the overall estuary area which would cover 35,000 ha.*

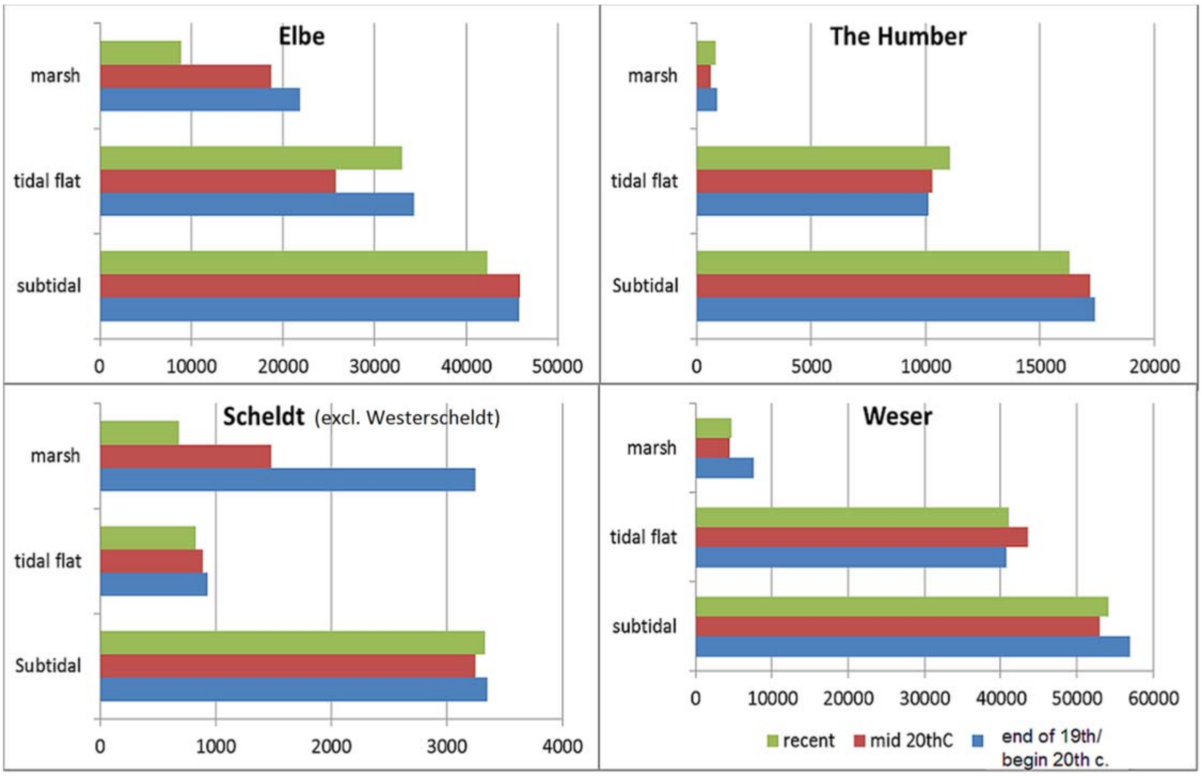

Figure 2.5: Development of habitat areas (ha) in estuaries vs. time.

For this analysis, only the freshwater, oligohaline and parts of the mesohaline zones of the Sea Scheldt are considered within the overall figure for the Scheldt estuary, due to limitations in the time step data in the Westerscheldt prior to mid of 20th Century (Figure 2.6).

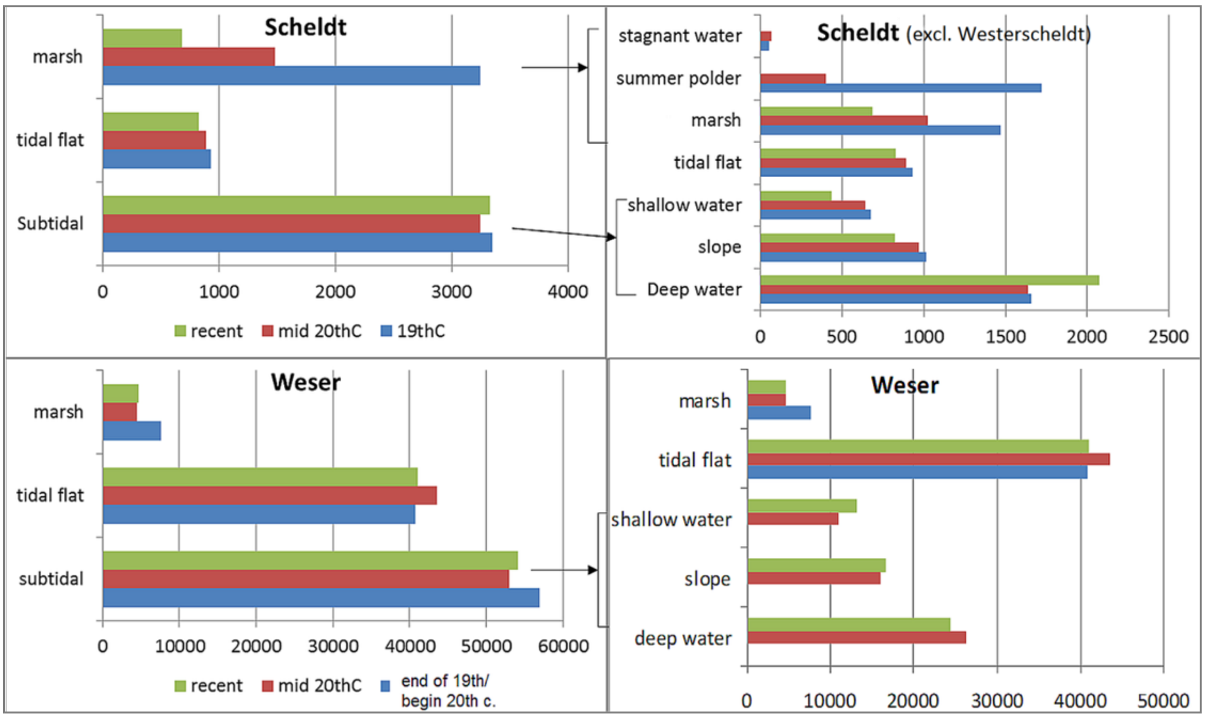

Figure 2.6: Detailed habitat areas (ha) in the Sea Scheldt and in the Weser

In the Sea Scheldt, it was possible to distinguish different subtidal zones such as shallow, slope and deep water habitats, and whilst the subtidal area in the Sea Scheldt within the zones included in the analysis seem to indicate a degree of extent stability additional investigation would suggest that there has been an increase of deep water habitats to the disadvantage of slope and shallow water areas within the broader subtidal area metric.

2.2.7 Evolution of habitat patterns in freshwater and oligohaline zones

The highest loss of habitat area was observed in the freshwater and oligohaline zones of the estuaries (Table 2.4). Over the last 100 years the Elbe, Sea Scheldt and Weser have seen 33%-50% of the overall freshwater habitat area lost, and as such, it was considered valuable to investigate the habitat distribution in those zones (Tables 2.6 and 2.7). It should be noted that a considerable loss of intertidal mud and marsh habitat has also been lost from the tidal freshwater tributaries of the Humber system, however these losses occurred prior to the baseline period set for the analysis, with much of the losses occurring over 1000 years ago.

Table 2.6. Evolution of freshwater zones [ha]

	End of 19thC /	Mid 20thC	Recent	Change [%]	Change [ha]
Elbe					
Deep water	3059	4116	3837	25	778
Shallow water	1964	1111	786	-60	-1178
Tidal flat	860	753	1149	34	289
Marsh	4599	3003	1116	-76	-3483
Σ Elbe	10482	8983	6888	-34	-3594
Sea Scheldt					
Deep water	148	135	264	78	116
Slope	402	360	336	-16	-66
Shallow water	254	228	156	-39	-99
Tidal flat	277	281	250	-10	-28
Marsh	525	347	438	-17	-87
Summer polder	1640	326	0	-100	-1640
Stagnant water	50	66	0	-100	-50
Σ Sea Scheldt	3296	1743	1443	-56	-1853
Weser					
Deep water	589	696	802	36	213
Slope	844	392	455	-46	-389
Shallow water	680	193	170	-75	-510
Tidal flat	689	594	436	-37	-253
Marsh	3141	1886	2053	-35	-1088
Σ Weser	5943	3761	3912	-34	-2031

Note: Data for the Humber are excluded from the analysis due to limitations in temporal data for the freshwater zones of the tributaries. However, the vast majority of habitat loss in this area of the Humber tidal freshwater tributaries occurred over 1000 years ago and thus in any case outwith the current data analysis period.

Within the freshwater area the Elbe analysis for the last 100 years identified an increase of 780 ha in the deep water zone, and a loss of 3,500 ha of marsh and 1,180 ha of shallow water habitat. The freshwater zone of the Weser also featured a habitat loss over the analysis period, mostly due to reductions in marsh area (-35% = -1088ha) and tidal flats (-37% = -253ha) despite an increase of deep water area (+36% = 213ha). Slope and shallow water areas also decreased considerably (-75% and – 46% respectively). The freshwater areas of the Sea Scheldt exhibited a slight increase in deep water area (+116 ha) which was accompanied by the total loss of summer polders and nearly 20% of the marsh area, producing a loss of more than 1,700ha.

In the oligohaline zones, the Sea Scheldt again showed an increase of deep water extent over the analysis period, however, with a total loss of summer polders and over 60% loss of marsh area. The respective oligohaline zone of the Elbe estuary featured a considerable reduction of about 70% of the marsh area but accompanied by an increase of tidal flat extent. Deep and shallow water habitat area also underwent a decrease. The analysis of habitat change in the oligohaline zone in the Weser is of note, with a decrease of 50% in the extent of deep water habitat. Marsh habitat has also undergone a decrease, but with increases in other habitat areas.

Table 2.7: Evolution of oligohaline zones (ha)

	End of 19th C /	Mid 20th C	Recent	Change [%] 19th	Change [ha]
Elbe					
Deep water	5151	4745	4270	-17	-881
Shallow water	1059	1462	848	-20	-211
Tidal flat	1044	1126	1832	75	788
Marsh	8032	8353	2603	-68	-5429
Σ Elbe	15286	15686	9553	-38	-5733
Sea Scheldt					
Deep water	451	450	505	12	55
Slope	183	195	167	-9	-16
Shallow water	136	119	75	-45	-61
Tidal flat	193	165	155	-20	-38
Marsh	241	173	94	-61	-147
Summer polder	79	73	0	-100	-79
Σ Sea Scheldt	1282	1175	997	-22	-285
Weser					
Deep water	2503	1128	1223	-51	-1281
Slope	302	513	393	30	90
Shallow water	267	380	293	10	26
Tidal flat	802	1007	865	8	63
Marsh	2337	1466	1751	-25	-586
Σ Weser	6211	4494	4524	-27	-1687

Note: Data for the Humber are excluded from the analysis due to limitations in temporal data for the oligohaline zones of the tributaries. However, the vast majority of habitat loss in this area of the Humber tributaries occurred over 1000 years ago and thus in any case outwith the current data analysis period.

2.2.8 Processes influencing habitat patterns

Estuarine environments have been modified and managed by mankind through human history and for the case study estuaries, this has been particularly notable in relation to wetland land claim for agriculture and/or settlement and associated flood protection needs, as well as to allow and maintain navigation. In the course of that development history the way our use of these systems has changed, whilst many natural estuarine functions have been incorporated into part of the regional infrastructure.

One aim of this study was to better quantify these changing environmental functions starting with a reference status against which changes can be measured. As noted above, the use of a reference status prior to human impact would have been desirable, but due to data availability the 19th Century was chosen as a pragmatic baseline for quantitative analysis, with more qualitative associations being applied to the research outputs for periods prior to this baseline. For example, the Humber estuary has been heavily modified by human activities for over 2,000 years, with approximately half of its intertidal area having been lost due to land claim for agricultural and industrial developments over this period. Its shape has also changed over time, initially through gradual drainage of land around the estuary headwaters (e.g. the tributaries of the Rivers Trent and Ouse) during pre-historic times through to the middle ages, together with more substantial modifications in the main estuary that have occurred more recently, up until towards the end of the 19th Century.

Morphology within the Humber estuary and its tributaries has been modified over the analysis period both to provide flood protection and to improve the navigation access (Elliott et al. 2008). Whilst flood protection requirements continue to require ongoing management in both the estuary and tributaries, reflecting the low-lying nature of the hinterland together with issues associated with relative sea level rise, active channel management and modification for navigation purposes is relatively low. Occasional maintenance dredge effort occurs along part of the fairway in the outer estuary, with further regular maintenance dredging of the berthing pockets of the Humber Ports complex. Historical measures to modify and maintain the channel morphology for navigation needs in the tributaries remain in place and operative (e.g. the training walls at Trent Falls), but these tributaries are not subject to active fairway maintenance dredging unlike the other TIDE case study estuaries.

It is emphasised that much of the ongoing Humber estuary management focus is therefore centred around the application of effective measures within the main estuary (predominantly the polyhaline and mesohaline areas and to a lesser extent oligohaline zone) rather than the tidal freshwater tributaries, and as such, for parts of the analysis described in this Chapter and covering the limnic and oligohaline zones, the Humber has not been included.

As such, the following commentary predominantly refers to the situations from the Elbe, Weser and Scheldt estuaries, the Humber being atypical in its morphology, history of modification and management priorities within the case study estuary examples.

The analysis in the other case study estuaries has indicated that tidal influence in the inner estuary has increased compared to the baseline situation with, for example, a tidal range of approximately 20cm measured at Bremen on the Weser in 1882 which has now amplified to 420cm, an increase by a factor of 20 (Figure 2.7) which has also had an effect on habitat status.

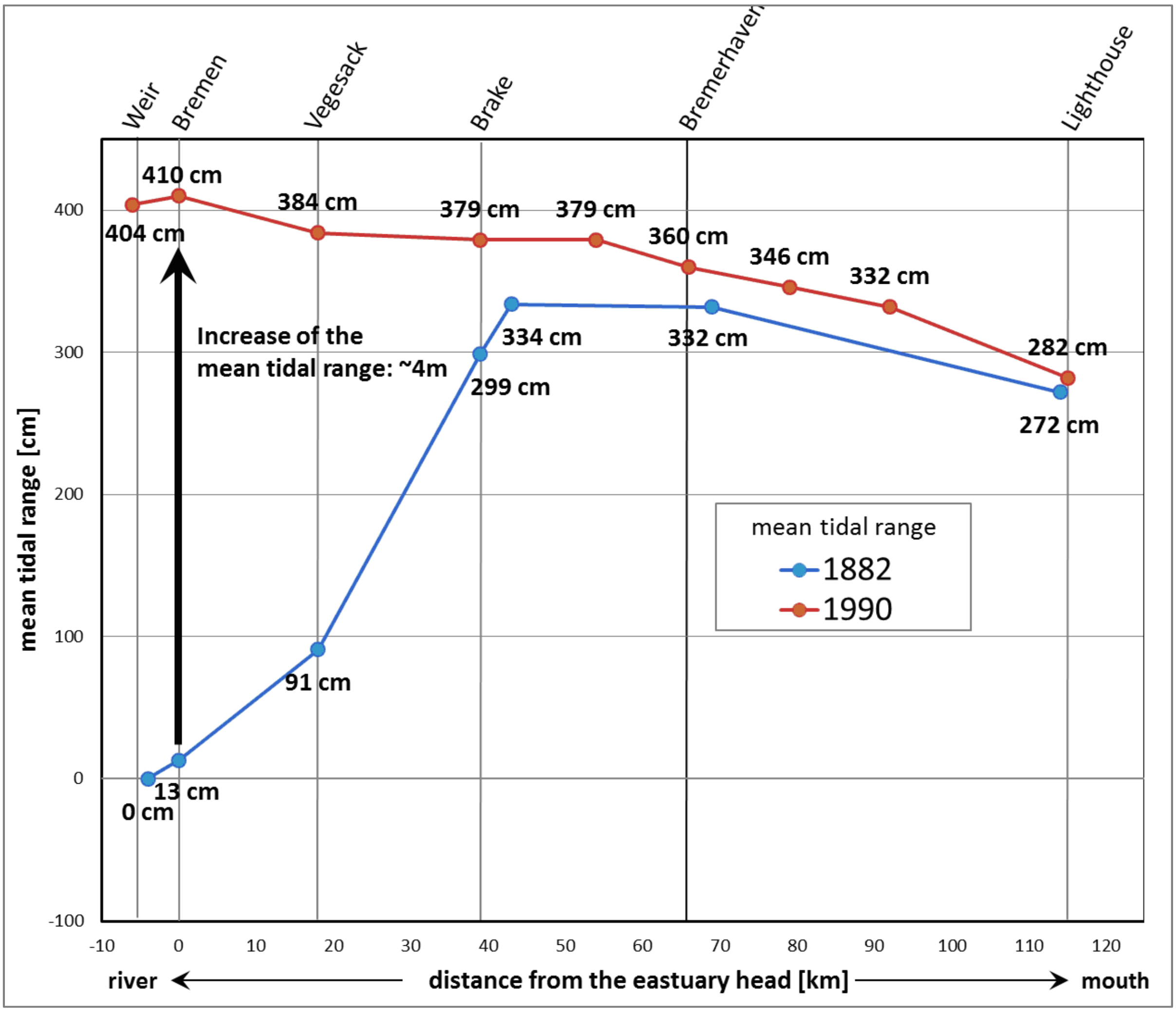

Figure 2.7. Tidal range development along the Weser

At end of the 19th Century (the baseline situation for this analysis), the Weser featured a braided channel with shallow and sloping subtidal habitats in the vicinity of Harrier Sand (Figure 2.8). However, after straightening and deepening of the estuary towards the end of the 19th Century, the tidal amplitude rose enormously with a concomitant increase in tidal velocities as well. This effect was predicted and considered desirable (Franzius and Bücking 1895) in order to reduce maintenance dredging requirements at the time. Further measures were also carried out such as the installation of groynes to stabilise the new channel. Currently the habitats in the Weser at Harrier Sand are characterised by a deep fairway and many dyked areas compared to the 19th Century (Figure 2.8).

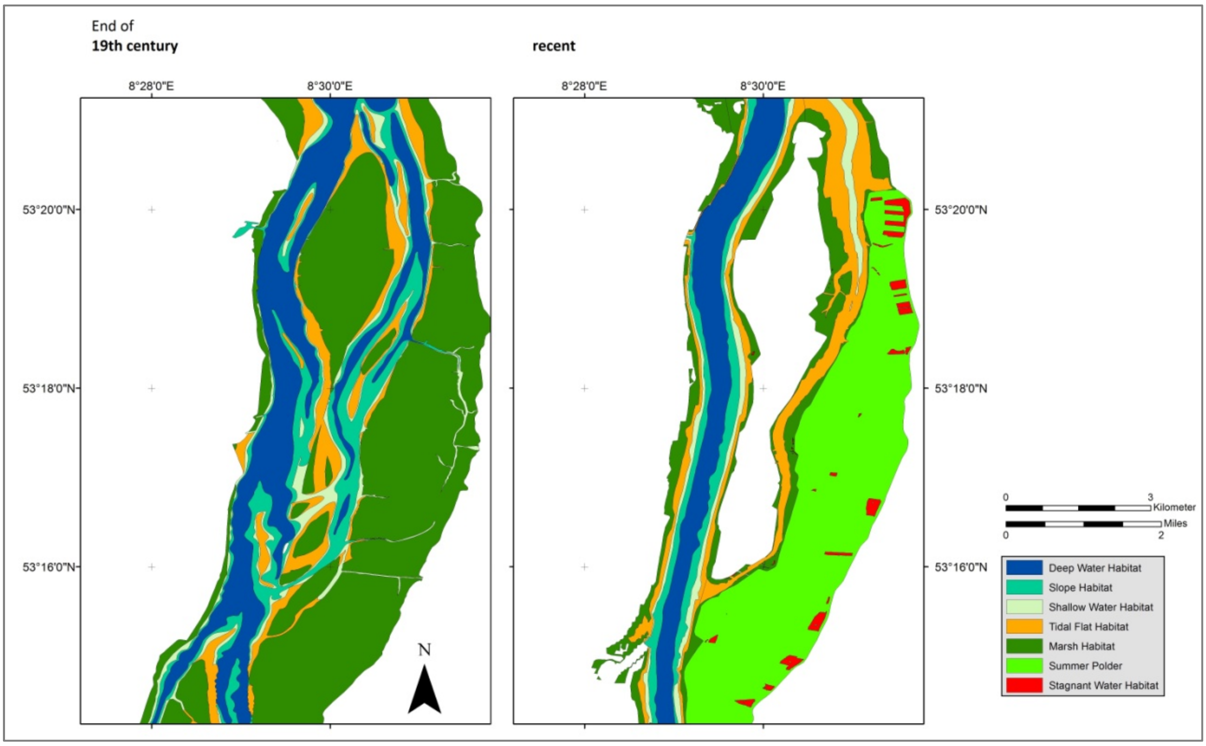

Figure 2.8. Change of habitats in the Weser estuary at Harrier Sand. The white areas are dyked parts. Among all estuarine habitat types, only summer polders and intertidal habitats grew.

Similar measures have been applied to the Elbe and Scheldt (and to a lesser extent the Humber) such us construction of dykes (flood banks), channel straightening and deepening, the removal of tributaries and shoreline protection.

For instance, in the Durme tributary of the Scheldt (Figure 2.9), the total subtidal area was reduced due to channel straightening, and whilst the area of tidal flat habitat remained almost stable, the location of the habitat shifted and summer polder areas were completely lost. This resulted in the overall estuary area of the Durme being reduced from nearly 1,000ha at the beginning of the 20th Century to only 15% of that figure today (Figure 2.9).

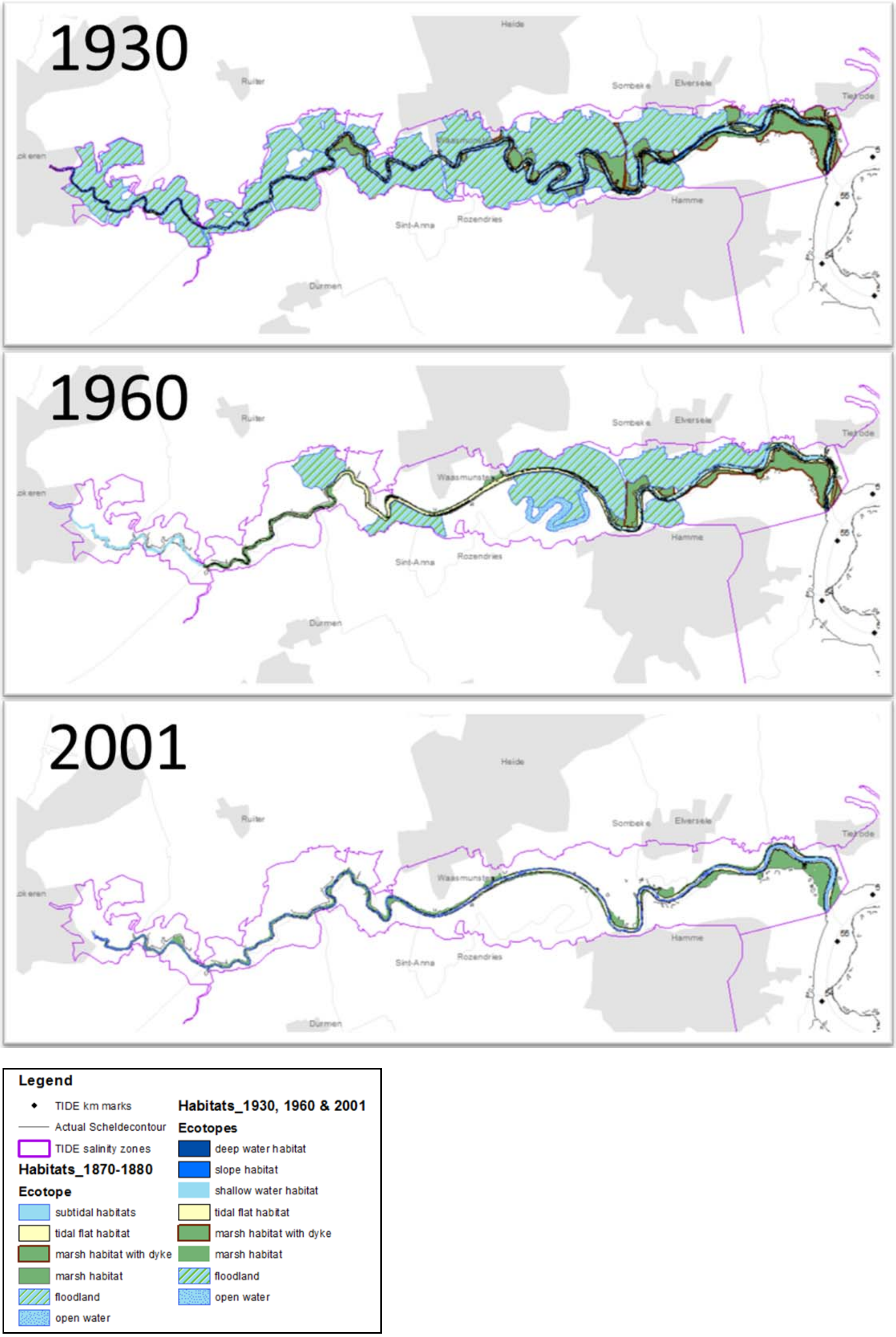

Figure 2.9. Development of the Durme tributary

In general, the isolation of tributaries from the main estuary can be considered as the primary reason for the losses although dyke (bank) construction, either for land-claim or for flood protection, has also reduced tidally influenced marsh area (Figures 2.8 and 2.9). Straightening and deepening of the channel led to higher current velocities and tidal penetration further into the river catchment and in order to protect the catchment from those changes, higher dykes and weirs were subsequently required in order to counter this increased tidal intrusion. These management measures further changed the hydrological characteristics, leading to further increases in current velocities and associated changes in sedimentation and erosion patterns. Subsequently, new measures were required such as the stabilisation of the estuary bed with shoreline structures such as groynes and training walls and intensified maintenance dredging (Herrling and Niemeyer 2008).

Although this study does not present data on the patterns of organisms and functions distributed within the mapped habitats, a reduction in overall habitat area and no notable increase of any specific habitat combined with higher tidal velocities influencing turbidity will lead to substantial alteration to the boundary conditions for many of the biotopes present. In particular, the elimination of shallow water areas and secondary channels which can deliver the most productive estuarine biotopes will influence the overall biological productivity of estuarine systems including associated benthic, bird and fish populations and can result in a decreasing biodiversity.

2.3 Summary

The equitable and sustainable exploitation of the diverse and extensive services provided by estuarine ecosystems provides a considerable management challenge. The TIDE project has developed the ecosystem service approach within estuarine management and since the services of an ecosystem are dependent on habitat area and quality (and associated faunal assemblages), the analysis of temporal and spatial change of key habitats within the case study areas is considered of value, providing an indication of trends in ecosystem service provision.

The evolution of the habitats of the four estuaries was analysed in three time steps: (1) at the end of 19th Century/early 20th Century, (2) at the middle of the 20th century and (3) in recent times. This approach has allowed a characterisation of the changes to overall ecosystem area, areas related to a certain salinity zones and different habitats within these zones, as well as a comparison of these changes between estuaries featuring differing development and management priorities. In order to undertake this analysis, navigation charts, a range of maps and aerial images were digitised and the data from this process analysed using GIS to identify the extent of the respective habitat types within different salinity zones as well as temporal changes. Additionally, estuary specific inventories of human activities with the potential to influence estuarine morphology were identified. Estuaries have historically been subject to modification by Man, including the draining of systems for agriculture and settlement, related needs for flood protection and to allow and maintain navigation along the fairways. In some estuaries, the growth of settlements some distance inland to exploit a range of resources have entailed the establishment of inland port facilities and necessitated the development and maintenance of navigation routes to support these, whilst in other systems, the growth of population centres, industry and other infrastructure along the estuarine system has entailed the construction of an extensive network of hard flood defences, the maintenance of these entailing ongoing management against a background of coastal squeeze and Natura 2000 habitat delivery. Over the analysis period of the last 100 years, the highest loss of habitat area has been generally identified from the inner freshwater and oligohaline zones of the case study estuaries, whilst in the mesohaline zone less area has been lost, and within polyhaline areas there was more or less stability. Across all salinity zones, the Elbe, Weser and Sea Scheldt showed a decrease in their overall area of between 5->30% in the last 100 years, whilst the overall size of the Humber reduced greatly in the preceding 18th and 19th Centuries through land-claim for agriculture, industrial and port developments, but with little further losses from the 20th Century.

The loss of estuarine habitat and constituent habitat types can be related to several anthropogenic impacts such as building dykes (banks) and land claim, straightening and deepening of channels, shoreline protection and the dislocation of tributaries or side channels from the system. These measures have partly led to higher current velocities, a further upstream tidal penetration and tidal amplification. These changes in hydromorphological features have led to alterations to the size and location of key habitats, decreased the overall area of the estuaries and, in turn, affected the ecological functioning of the estuarine environment.

The following Chapters 3 and 4 explore the importance of these functions, as well techniques that can be used to describe, value, quantify and better integrate the management of their use.

Acknowledgements

The authors would like to thank Prof. Enrico Dinelli, University of Bologna for critical discussion of the results and conclusion; the Bundesamt für Seeschifffahrt und Hydrographie (BSH), Hamburg and the Niedersächsischer Landesbetrieb für Wasserwirtschaft, Küsten- und Naturschutz (NLWKN), and Oldenburg for handing out maps and GIS data for scientific purposes; the Flemish Research Institute for Nature and Forest (INBO) for preparing the habitat maps of the Sea Scheldt; Frederik Roose, Maritime Access division of the Flemish Ministry of Mobility and Public Works for recalculating the habitat areas following the TIDE approach; and Dr. Wouter Vandenbruwaene, Flemish Government, Department Mobility and Public Works, Flanders Hydraulics Research, Research Group Coast and Maritime Access, Antwerp for critical review of result and discussion.

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3 Hydroecological Functioning

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3.1 Hydro-geomorphology

Hydro-geomorphology is of crucial importance for both the estuarine functioning and accessibility of ports. Management measures such as dredging, sediment disposal, managed realignment and others (Adriaensen et al. 2005; Kerner 2007) directly affect the hydro-geomorphology and all processes that are strongly related to hydro-geomorphology such as the ecological functioning. To assure a good functioning estuary as itself as well as for all users, a better understanding of the hydro-geomorphology of the system is required.
In this study, we collected several parameters which we considered as crucial to study the hydro-geomorphology of an estuary. Some of them were directly measured in the estuary, e.g. riverine discharge, bathymetry, tidal range etc., others were derived indirectly using specific techniques. The cubage technique for example (Smets 1996; Plancke et al. 2011) calculates flow velocities based on topo-bathymetric data and water levels. The Dalrymple energy concept calculates tidal and fluvial energy based on water levels and flow velocities (Dalrymple et al. 1992). The derived flow velocities (cubage technique) and energy terms (Dalrymple) are important parameters to explain suspended particulate matter (SPM) behavior in an estuary. There are differences between the four TIDE case estuaries in both measured and calculated parameters, with a 1.9 m difference in the tidal range between the estuaries, and a difference in mean freshwater discharge between the four estuaries of 615 m^3s^{-1} in the temporal period under consideration (Table 3.1). A full explanation of the methodology deployed in the investigation can be found in Vandenbruwaene et al. (2013, at www.tide-toolbox.eu).

It was not possible within the scope of the TIDE project to examine all physical processes, and analysis was limited by existing data availability and timescales. A collaborative decision was taken to focus on the following aspects within the project.

- To consider the relationship between tidal conditions (high and low water and tidal amplification) with the geometrical shape of the estuaries
- To consider the relationship between habitat distribution with flow patterns (velocity and discharge) and tidal range
- To consider the interrelationships between salinity, the turbidity maxima and distribution of tidal energy

- To consider the relationship between residence time and the interaction of fresh and tidal water characteristics
- To consider interrelationships between salt marsh, hydrodynamics and sediment characteristics of the four estuaries, with particular reference to changes in mean high water level (MHWL) and changes in marsh platform elevation.

Table 3.1. Values and ranking of the 4 TIDE estuaries for a selection of hydro-geomorphological parameters (red = lowest, green = highest value) (Vandenbruwaene et al. 2013)

	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 to 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	1.9	1.9	1.5
Tidal asymmetry at the upstream border	1.6	1.4	-	1.7
Total freshwater discharge (mean) (m^3/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 m^3)	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

3.1.1 Geometrical characteristics

Each of the TIDE estuaries has a distinctive morphology although all four estuaries have a typical funnel shape. The Humber is the most convergent, followed by the Scheldt (intermediate convergence), with the Elbe and Weser being the least convergent (Figure 3.1). In the past the width of the estuaries has been reduced by land claim. A large proportion of the land claim has taken place over a long time period, commencing in the Middle Ages, morphological changes in the estuaries can still be influenced by these historical activities.

The mean estuary depth is very comparable for the Scheldt, Weser and Elbe and ranges from 7 - 7.5 m (i.e. the cross-section averaged depth at low water, Figure 3.1 and 3.2). The

Humber on the other hand is much shallower with a mean depth of about 3.3 m. Mean values for estuary depth were derived by averaging the estuary depths at individual cross-sections. Cross-sections were hereby defined about every 500-1000 m along the estuary (see Figure 3 in Vandenbruwaene et al. 2013 at www.tide-toolbox.eu).

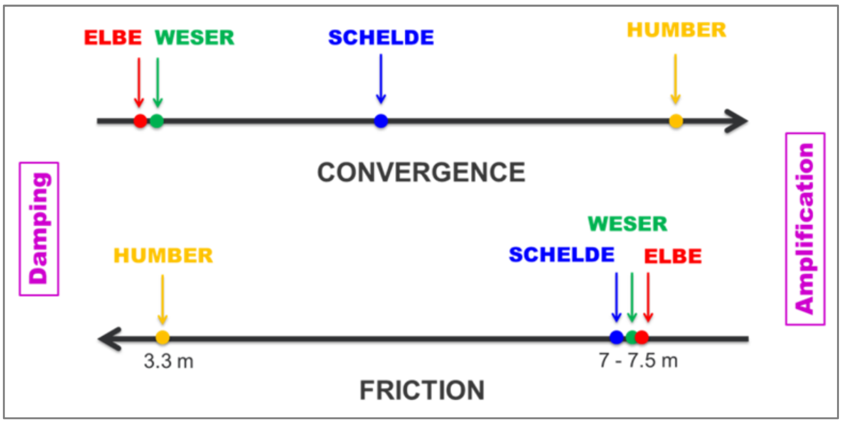

Figure 3.1. Convergence (based on 1/b value, see estuary convergence in Section 3.1.2) and friction (based on the cross-section averaged depth at low water) for the four TIDE estuaries.

The larger depths of the Scheldt, Elbe and Weser are (partly) a consequence of intense dredging activities. As the most important ports are located deep inland, large parts of these 3 estuaries need to be dredged to maintain and occasionally also deepen the fairway in order to enable large ships to reach the ports of Antwerp, Hamburg and Bremen respectively Figure 3.2). In the Humber, the most important ports (Immingham, Hull and Grimsby) are located in the middle and outer estuary (i.e. between Hull and Spurn Head, see map in Chapter 1) and hence dredging activities are restricted to that area. Moreover, the dredged volumes are limited in size (locally in Sunk Dredge Channel, dock entrances or estuary berths) and are small compared to the other TIDE estuaries.

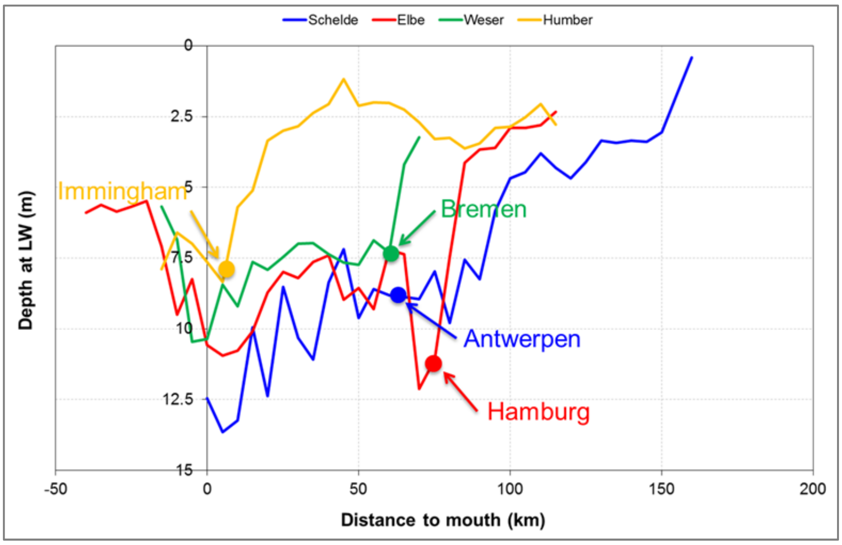

Figure 3.2. Cross-section averaged depth at low water along the four TIDE estuaries, with indication of the major ports

Deepening of the fairway not only affects the depth, but also the shape of a cross section. Deepened, dredged channels have a typical wide and deep trapezoidal shape, while naturally formed channels (no artificial dredging) have a more rounded profile and generally shallower average depths. These differences in shape are found in the distribution of the subtidal habitats (deep, moderately deep and shallow, see Figure 3.3 and Vandenbruwaene et al. 2013). The Scheldt, Elbe and Weser are dominated by the deep subtidal habitat, whereas the deep, moderately deep and shallow subtidal habitats of the Humber are equally distributed (Figure 3.3).

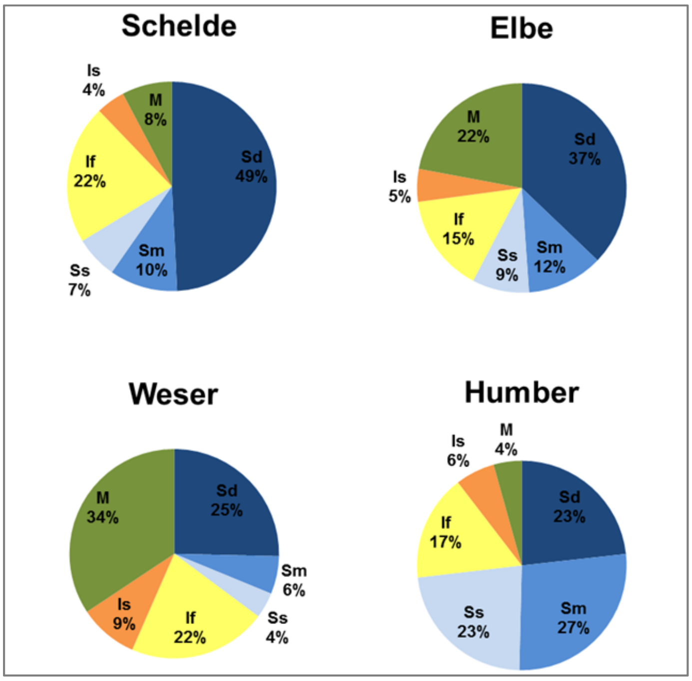

Figure 3.3. Relative presentation of the habitat areas (percentages) for the 4 estuaries from mouth$_{geo}$ to up-estuary boundary. Mouth$_{geo}$ is defined based on the change in estuary width (see Vandenbruwaene et al. 2013). Abbreviations in figure: Sd = subtidal deep; Sm = subtidal moderately deep; Ss = subtidal shallow; If = intertidal flat; Is = intertidal steep; M = marsh

3.1.2 The role of morphology on tidal amplification/damping

The two most important factors that influence tidal amplification and tidal damping in an estuary are: (1) the funnelling of the estuary either laterally or with depth, or both (i.e. estuary convergence, meaning that the estuary size is squeezed both across the sides (the funnel shape) and with depth (shallowing with distance upstream) leading to tidal amplification (the more convergent, the more tidal amplification), and (2) the friction in the estuary (controlled by the estuary depth) which leads to tidal damping. So, if an estuary is strongly convergent and it has a large estuary depth (thus a limited friction), it makes the estuary more vulnerable to tidal amplification (Figure 3.1). Based on the geometric and morphological features of the TIDE estuaries (Figure 3.1), we may infer that the Scheldt estuary is most vulnerable to tidal amplification since it has an intermediate convergence and a large estuary depth. Indeed, we observe that the tidal range (TR, at the mouth ´0´ = TR0; defined as once the width change at MHWL is below a certain threshold value, at that location the mouth area stops and the estuary starts; TR at a given distance in the estuary ´x´ = TRx) increases up to a maximum TRx/TR0 value of 1.4 (the highest of the 4 estuaries, see Figure 3.4), and that increased tidal range (TRx/TR0 > 1) occurs over a distance of 130 km, which is 85% of the estuary length.

The Elbe also reaches large TRx/TR0 values (up to 1.3), but here tidal amplification starts further into the estuary (about 10 km from the estuary mouth). Although the focus of the work was not the estuary mouth, the shallow character of the Elbe in the region of the estuary mouth (which is friction dominated) may possibly play an important role in the damping of the tidal wave as it enters the estuary ($1/\beta < 0$, see Vandenbruwaene et al. (2013) where $1/ \beta <0$ means Tidal Damping Scale is less than 0). Moreover, between km 0 at the mouth and 40km from the mouth, the Elbe can be considered as a more or less prismatic channel. It is known that in an ideal prismatic channel no tidal amplification occurs (Savenije 2001). The Weser has only a limited maximum TRx/TR0 value of 1.1, but here an increased tidal range (TRx/TR0 > 1) occurs over the entire estuary length.

The Weser, which is the shortest estuary (65 km), is not sufficiently long to reduce the tidal range (TRx/TR0 < 1). The fact that the maximum tidal range only reaches a value of TRx/TR0 = 1.1 is due to absence of tidal amplification between km 15 and 40 from the geographical mouth (Figure 3.4). In this area the subtidal width is relatively small compared to the intertidal width and thus the volume of water stored above the intertidal area (which is affected by friction) is probably relatively large compared to the volume of water which is transported through the deep subtidal channel with limited friction ($1/\beta < 0$, see Vandenbruwaene et al. (2013)). A second explanation for the absence of tidal amplification is the fact that the Weser estuary in that area is not a converging channel but a prismatic channel.

The Humber is the most convergent estuary, but has a limited maximum TRx/TR0 of 1.15, and the tidal range becomes already damped at 25 km from the mouth. At this point friction becomes strongly dominant in the Humber (no deepened channels), especially in the area between Hull and Trent falls ($1/\beta << 0$, see Vandenbruwaene et al. (2013). TIDE has used Mean Low Water (MLW) and Mean High Water (MHW) to calculate the tidal range (i.e. the difference between the two). In the UK most analysis is undertaken using Mean Spring and Neap conditions. In the Humber when it comes to sediment movement and changes to the morphology at many locations very different things happen on springs and neaps tides, which would not necessarily result for a mean tide. If this work to be considered further and lead to management decisions, this varying technique needs to be borne in mind with respect to management implications for each estuary. One inference that can be drawn is that if the Humber were to be deepened, particularly in the shallow areas then the tidal amplification that would result would be considerably larger than has been seen to occur from the deepening of the other TIDE estuaries (Figure 3.2). This could potentially give rise to larger effects such as increased water levels which appears to be related to the general shape of the estuary (Figure 3.2 and 3.4).

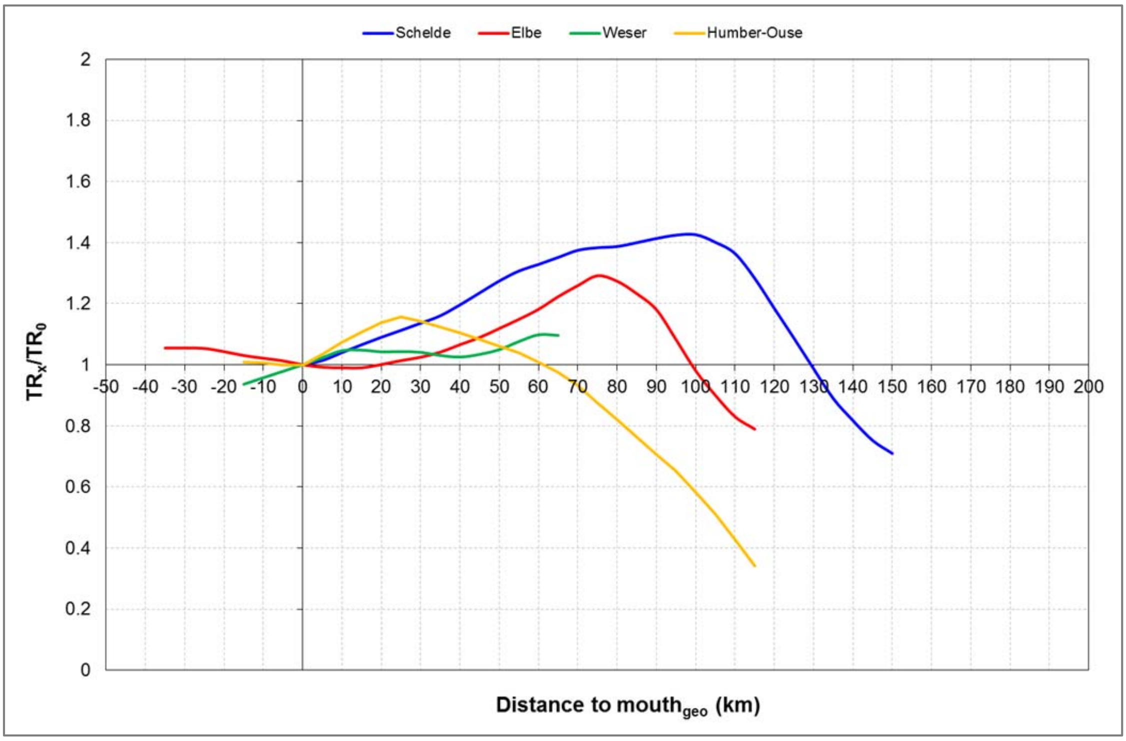

Figure 3.4. Dimensionless presentation of the tidal range defined by TR_x/TR_0 (with TR_x = tidal range at distance x in the estuary; TR_0 = tidal range at $mouth_{geo}$

Each of the TIDE estuaries has thus an area which can be considered as very important in the protection against flooding, since these areas induce tidal damping or they reduce the tidal amplification. In the Elbe, the mouth area and the area in the most downstream part of the estuary between the cities of Brunsbüttel and Glückstadt (see map in Chapter 1) prevent an increase in tidal range due to respectively the limited estuary depth (induces important friction) and the prismatic nature of the channel (limited convergence). For the Weser, no increase in tidal range is observed between the cities of Bremen and Elsfleth, i.e. between TIDE km 30 and 60, due to prismatic nature of the Weser channel in combination with an increase in friction. In the Humber, important tidal damping occurs between Hull and Trent Falls due to high friction in that area. The high friction is induced by the shallow character of the subtidal channels (there is no dredging required or carried out in that zone). This area is very important component to safeguard against flooding along the Humber, especially since the Humber is the most convergent (more vulnerable to tidal amplification) of all TIDE estuaries. In the Scheldt estuary we do not observe directly an area which could be considered as important for tidal damping or reduction of the tidal amplification. However, in this study we only looked at mean tidal conditions and consequently the effect of tidal marshes was not evaluated. For the Scheldt, it is known that the Saeftinghe marsh (3000 ha) stores a large volume of water during spring tides and in this way protects more upstream parts along the estuary. One recommendation would be to investigate the effect of tidal damping and amplification when Mean High Water Springs (MHWS) and Mean Low Water Neaps (MLWN) are used in the analysis.

Despite the above findings in relation to reducing or stopping tidal amplification, this is insufficient in isolation to provide robust protection against flooding, especially along the Scheldt and Elbe where the strongest tidal amplification is observed. Based on the analysis of all 4 estuaries, tidal damping in an estuary becomes important once the estuary depth (i.e. cross-section averaged depth at low water) is smaller than 4.2 - 7.7 m (see Figure 3.5 and Figure 3.6). As analyses were performed over 5 km blocks, this critical estuary depth should be present for at least 5 km along the estuary. The range in critical estuary depth (4.2 – 7.7 m) is a consequence of the estuary convergence: the more convergent the estuary, the smaller the critical estuary depth. However, to provide a more robust case it is necessary to include more estuaries in the analysis to improve the accuracy of the estuary depth threshold values. The effects of habitat occurrence on tidal damping/amplification (i.e. vertical tide) and on flow velocities (i.e. horizontal tide) were investigated. The results showed that tidal damping and tidal amplification in estuaries are to a large extent determined by the subtidal habitats (Vandenbruwaene et al. 2013). Tidal amplification occurs when the relative width in deep subtidal habitat (Sd) (> 5 m below LW) is larger than 30% (Sd > 30%) and the sum of the moderately deep (Sm) and shallow subtidal (Ss) habitats (5 - 0 m below LW = SmSs) is smaller than 25%. Tidal damping occurs when Sd < 20% and SmSs > 35%. To induce tidal damping in an estuary we recommend having over a distance of 5 km (data were averaged over 5 km blocks), no excessive width in deep subtidal habitat (< 20%) and sufficient width in moderately deep and shallow subtidal habitat (> 35%). However, other studies also report on the important role of intertidal areas and tidal marshes in damping of the tidal wave, see Winterwerp (2012). Tidal marshes are able to store large volumes of water during spring tides, whilst our analyses were only performed for mean tidal conditions, this aligns with the recommendation in section 3.1.2 of Vandenbruwaene et al. (2013) to undertake analysis using MHWS and MLWN prior to implementation and management measures. Concerning the horizontal tide no relationship was found between the habitat occurrences and the flow velocity. An overview of the main hydro-geomorphological features for each estuary is already given in Table 3.1.

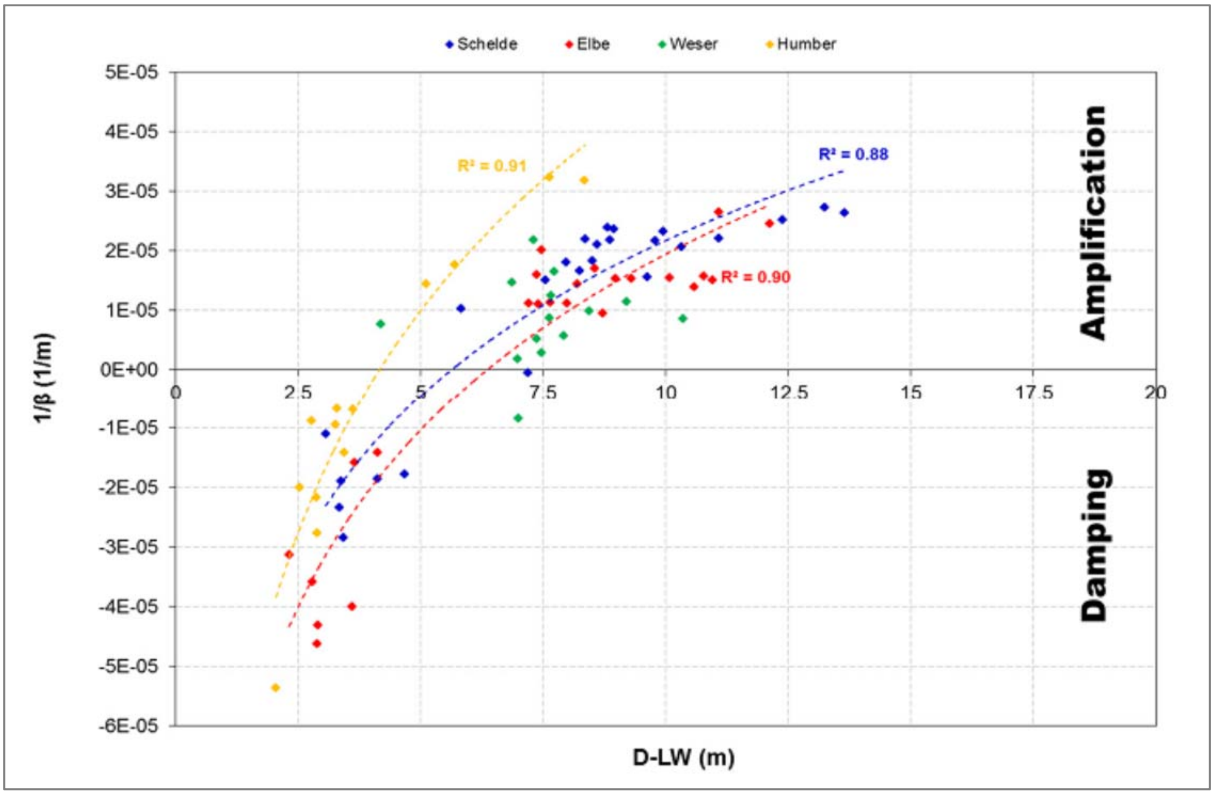

Figure 3.5. The cross-section averaged depth at MLWL versus tidal damping (1/β). For 1/β< 0 tidal damping, for 1/β> 0 amplification (Vandenbruwaene et al. 2013).

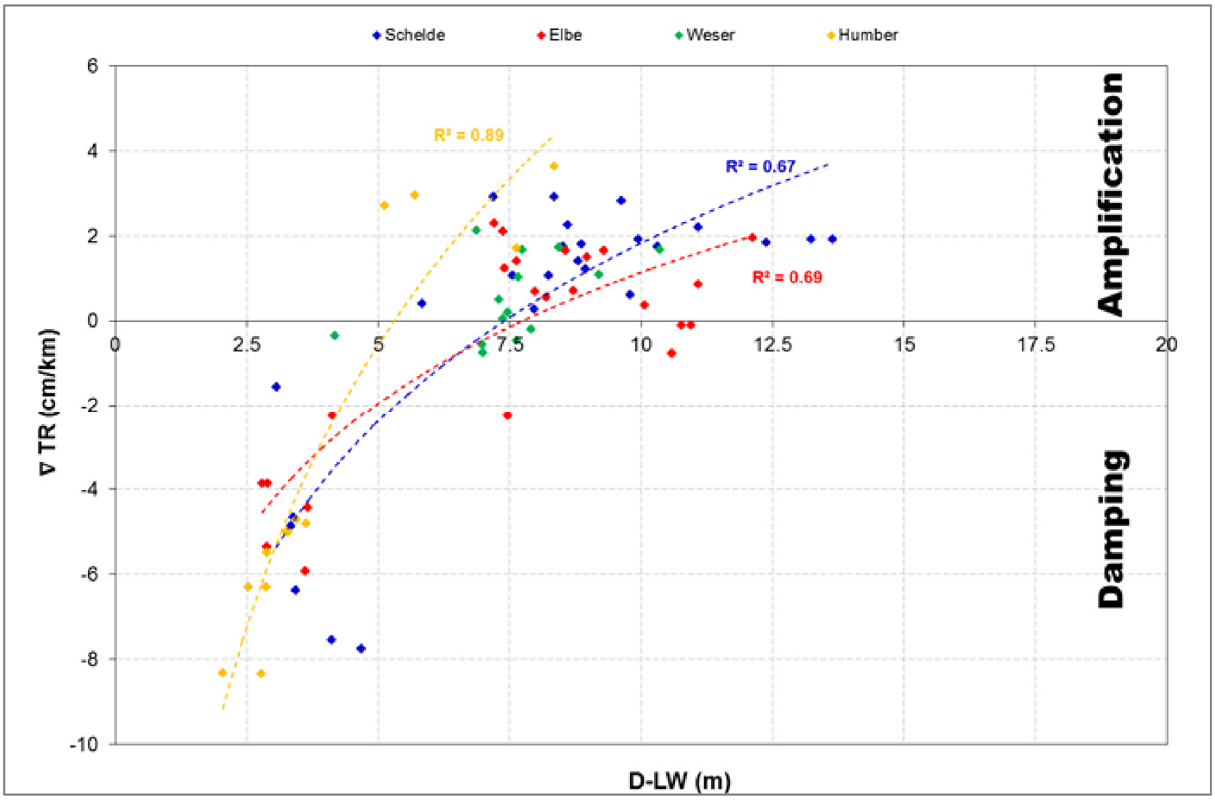

Figure 3.6. The cross-section averaged depth at MLWL versus the observed gradient in tidal range (∆TR). For ∆TR < 0 tidal damping, for ∆TR > 0 amplification (Vandenbruwaene et al. 2013).

3.1.3 Indirect effects of morphology on SPM and tidal marsh evolution

Tidal amplification along estuaries not only affects the risk of flooding, but also indirectly effects both sediment management and ecology. The results showed that the turbidity maxima in these four estuaries occur at locations where the tidal energy (i.e. common effect of vertical and horizontal tide) is high (see Vandenbruwaene et al. 2013). For the Scheldt and Elbe deflocculation/flocculation processes may also lead to higher Suspended Particulate Matter (SPM) values. Higher amounts of SPM have an important influence on the ecology, for example on primary production or tidal marsh ecology. With regard to tidal marshes, higher SPM values lead to a faster evolution towards a climax vegetation state. However, biodiversity should not be considered as just the number of species, because estuaries are less diverse taxonomically but more diverse in other ways like functionality. On the other hand are sufficient high SPM values wanted because it enables tidal marshes to follow up the increase in MHWL which can be considered as favourable for coastal protection.

3.2 Water quality and primary production

A good ecological status and well-functioning of the estuary is a first prerequisite for sustainable estuarine management. To ensure the robustness of an estuarine system, it is important to take all biotic and abiotic interactions into consideration and not only the elements of which it is constituted (del Monte-Luna et al. 2004; Muller 2005). As an example when discussing the source or sink function for nutrients of an estuary, it is important to not only take into account the biogeochemical processes, but also to consider the differences in residence time between estuaries, the difference in tributary input etc. In order to better understand differences and similarities in ecological functioning between the four case estuaries their filter function for nutrients, primary production and the occurrence of oxygen deficiencies were examined. A good nutrient composition is the first prerequisite for the well-functioning of estuaries (Thieu et al. 2010), oxygen is an important integrator of many biological and physical processes in estuarine systems (Testa and Kemp 2011) and primary production forms the first link to higher trophic levels (Underwood and Kromkamp 1999). Furthermore, the distribution of birds and habitats were studied as an example of a higher trophic level. Unfortunately zooplankton dynamics, another important intermediate link between primary production and higher trophic levels such as birds, could not be studied due to limited availability of comparable data for the four case estuaries.

3.2.1 Filtering function

Estuaries can be considered as a large biogeochemical reactor and are the last possible barrier before nutrients, pollutants and suspended solids reach the coastal zone. The biogeochemical removal of nutrients within the estuary, the sink function of estuaries is considered as one of the most valuable ecosystem services and can be regarded as a natural complementary waste water treatment service (Dähnke et al. 2008; Dähnke et al. 2012). Due to increased water treatment in the Elbe catchment in the 1990's after the reunion of the two German states as well as in the Scheldt, where among others, a new sewage treatment plant with a capacity of more than one million inhabitant equivalents came into use in 2008, water quality of these estuaries improved. Oxygen conditions in the water column improved and the dominant form of nitrogen changed from ammonia towards nitrate. In general, a decrease in concentrations of both nitrogen and phosphorus occurred although, phosphorus was controlled more efficiently than nitrogen (point versus diffuse source related).

For each estuary nutrient concentrations corrected for dilution effects were calculated according to the conservative mixing theory (Eyre et al. 2002) as adapted in Geerts et al. (2013) When the measured nutrient concentrations exceeded the calculated concentrations corrected for dilution effects, it was suggested the estuary is a source for that particular nutrient. If the measured nutrient concentrations were lower than the calculated concentrations, it was suggested the estuary is a sink for that nutrient. In this way, gain (production in the estuary) or loss (removal in the estuary) along the longitudinal gradient could be detected. Here beneath, an example for nitrate and ammonium is elaborated.

The Scheldt was characterised by alternately nitrate gain and loss dynamics; however on average nitrate seemed to behave conservatively. Ammonium was mostly removed in the freshwater and mesohaline zone and particularly in the oligohaline zone. The Elbe showed a notable gain in nitrate in the oligohaline and freshwater zone, a gain of ammonium in the oligohaline zone and losses of each downstream. The Humber demonstrated loss of both nitrate and ammonium in the fresh and polyhaline zone and ammonium and nitrate were both gained in the oligo and mesohaline zone (Figures 3.7 and 3.8). Although local dynamics of gain and loss in mg/(l*km) could be higher in the Scheldt, when taking into account the freshwater discharge the Elbe has shown to be the most nitrogen exporting estuary in ton/(yr*km).

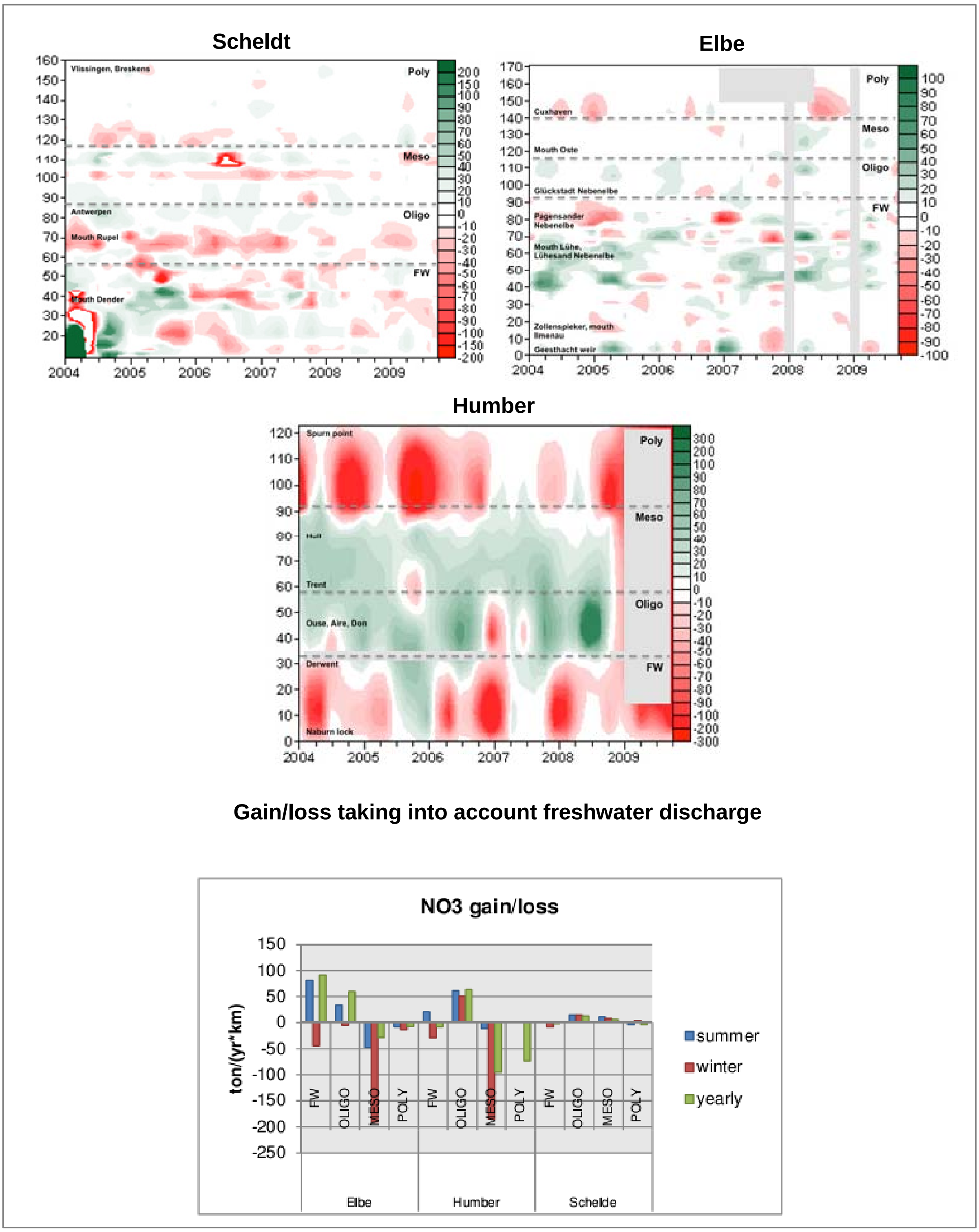

*Figure 3.7. Gain loss dynamics of nitrate (NO_3^-) for the different salinity zones in the Scheldt, Elbe and Humber estuaries calculated according to the conservative mixing theory (Eyre et al. 2002) for 2004-2009. The y-axis in the three SURFER graphs represents the TIDE-kilometres, while the dashed lines indicate the freshwater (FW), the oligohaline (OLIGO), the mesohaline (MESO) and the polyhaline (POLY) zones. The x-axis shows the years, with each minor axis tick representing the winter, spring, summer and autumn season consecutively. In the gain/loss graph, gain and loss are given on the y-axis in ton/(year*km), per zone as presented on the x-axis (FW: freshwater, OLIGO: oligohaline zone, MESO: mesohaline zone, POLY: polyhaline zone. The Weser gain and loss dynamics could not be calculated, because not enough data points were available. Missing data in the time-distance plots are represented as solid filled rectangles.*

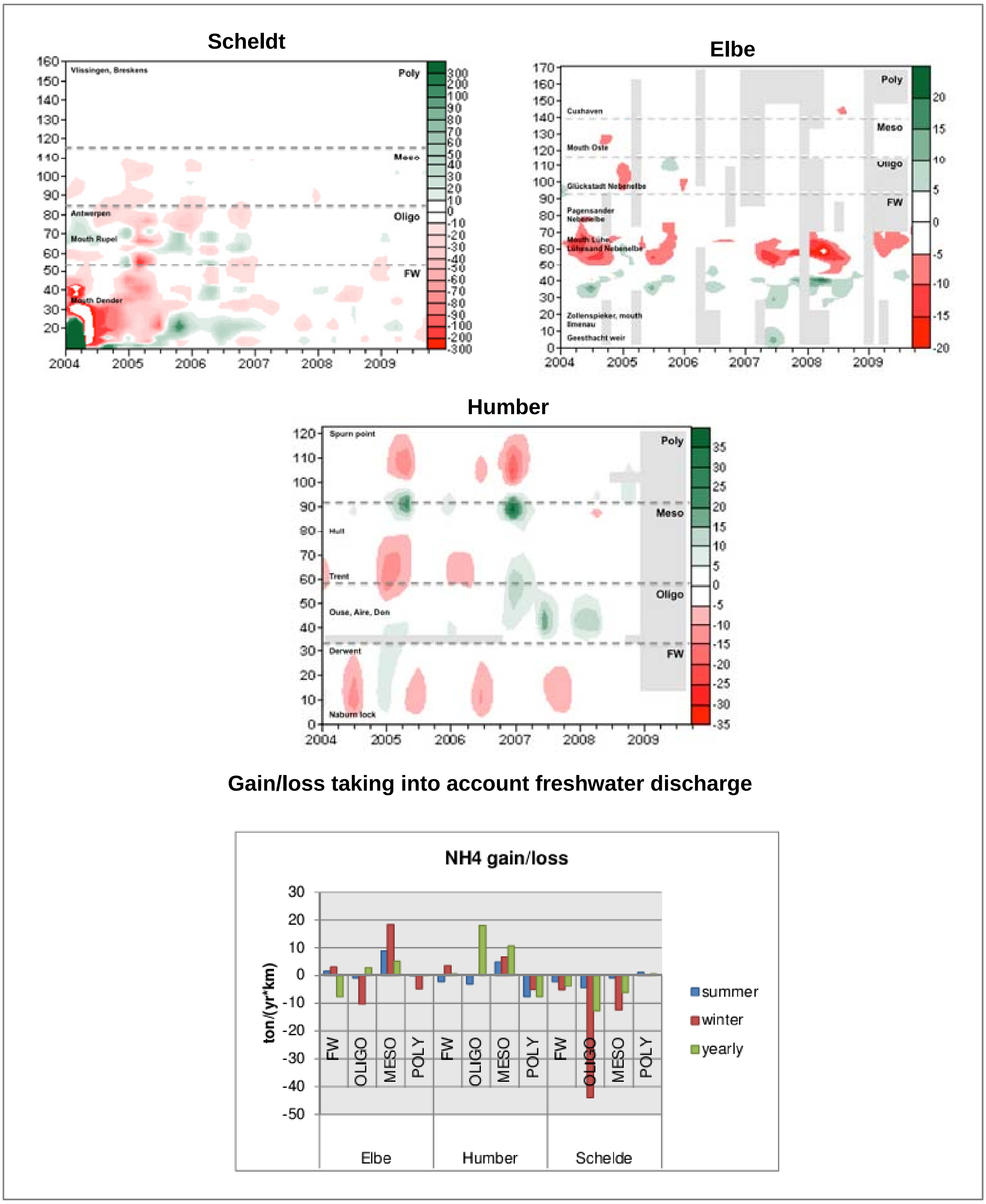

*Figure 3.8. Gain loss dynamics of ammonium (NH4+) for the Scheldt, Elbe and Humber estuaries calculated according to the conservative mixing theory (Eyre et al. 2002) for 2004-2009. The y-axis in the three SURFER graphs represents the TIDE-km, while the dashed lines indicate the freshwater (FW), the oligohaline (OLIGO), the mesohaline (MESO) and the polyhaline (POLY) zones. The x-axis shows the years, with each minor axis tick representing the winter, spring, summer and autumn season consecutively. In the gain/loss graph, gain and loss are given on the y-axis in ton/(year*km), per zone as presented on the x-axis (FW: freshwater, OLIGO: oligohaline zone, MESO: mesohaline zone, POLY: polyhaline zone. The Weser gain and loss dynamics could not be calculated, because not enough data points were available. Missing data in the time-distance plots are represented as solid filled rectangles.*

The morphological conditions of the Hamburg port area, i.e. a sudden increase of the water depth at TIDE km 34 from 7.4 m to -18.3 m at TIDE km 41 creates a detrimental light climate (Figure 3.9) for the algae coming from upstream (euphotic depth, mixing depth ratio is larger than 1/6 ~ 0.17). When this ratio is exceeded, algal blooms can be expected (Underwood and Kromkamp 1999).

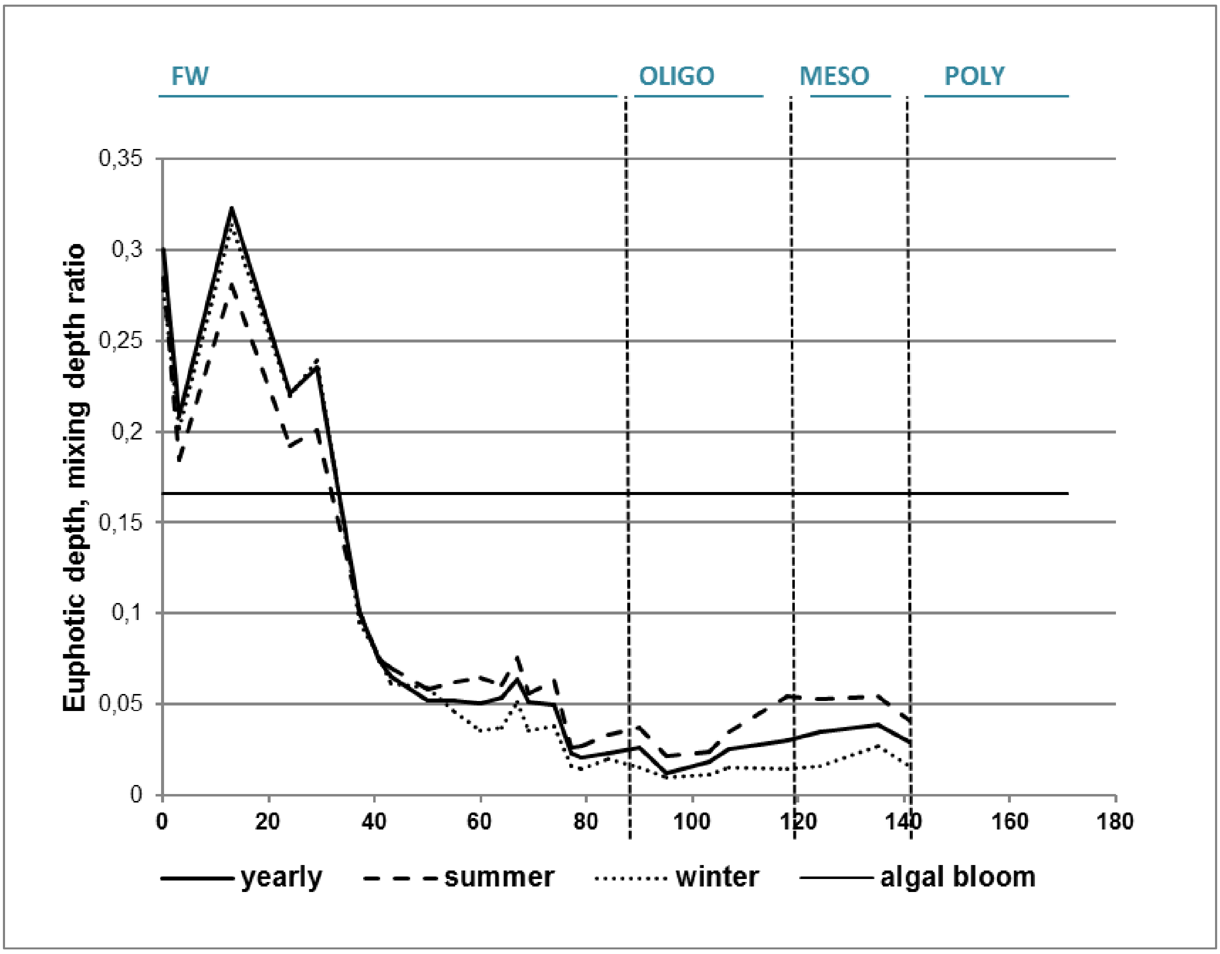

Figure 3.9. Euphotic depth, mixing depth ratios in the Elbe estuary. The algal bloom line represents a euphotic depth, mixing depth ratio of 1/6 ~ 0.17.

By consequence, it is most likely that nitrification (Figure 3.10) is observed within the estuary (freshwater and oligohaline zone) and it seems to be driven by ammonium coming from degradation of autochthonous organic matter (algal die-off, see decrease in chlorophyll a, Figure 3.13). Nevertheless, it is mostly the high riverine input that causes the Elbe to be a major source for dissolved inorganic nitrogen and this can be attributed to a very high freshwater discharge (the nitrogen concentrations are low, but the discharges are very high in the Elbe when compared to the Scheldt estuary – 645.6 m^3/s versus 101.2 m^3/s for a six-yearly average (2004-2009), respectively – giving a high nitrogen load for the estuary to process).

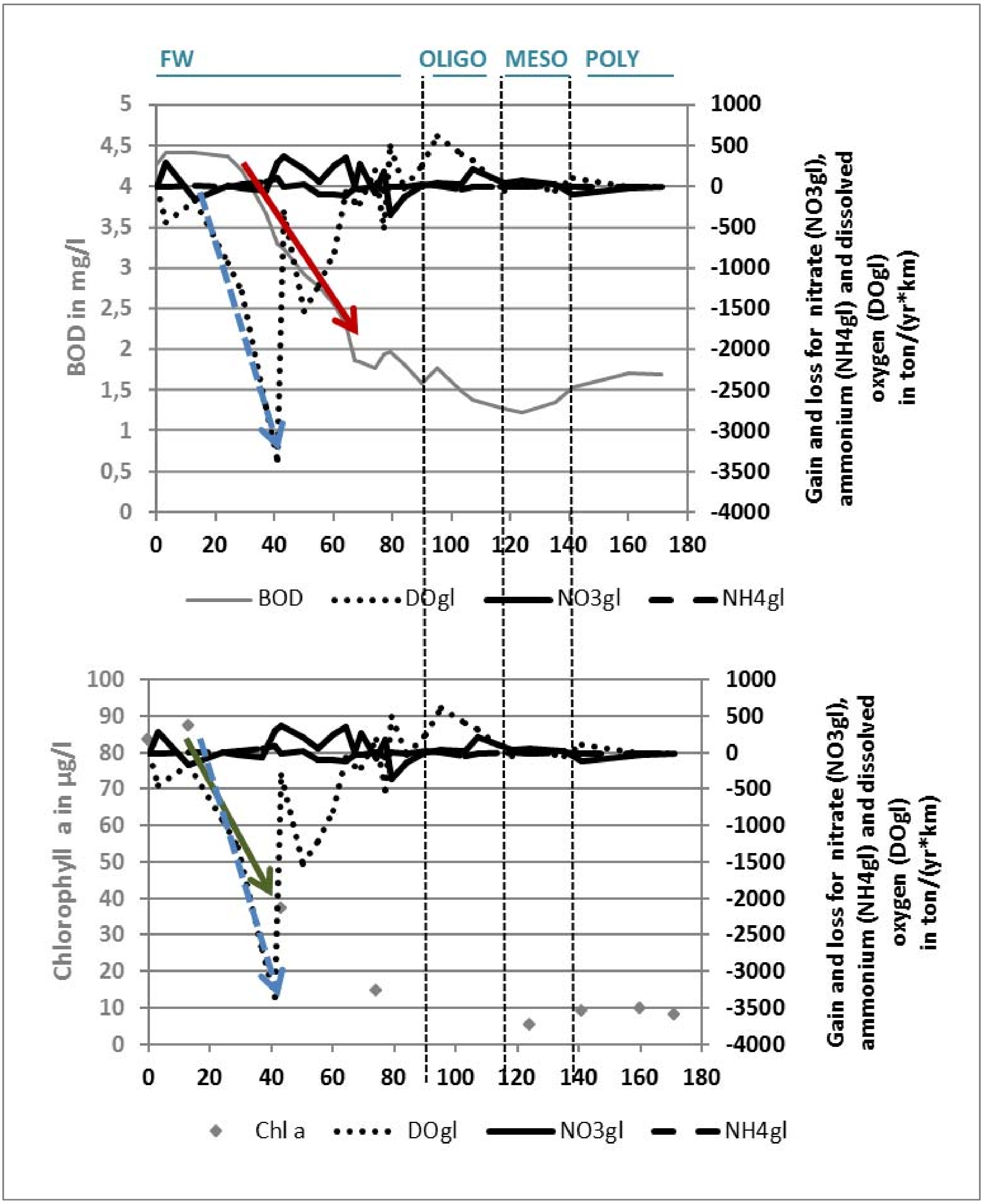

*Figure 3.10 There seems to be a nitrification peak nearby the zone of steep deepening of the Elbe. The x-axis shows the TIDE-kilometres and dashed vertical lines show the different zones (FW: freshwater zone, OLIGO: oligohaline zone, MESO: mesohaline zone, POLY: polyhaline zone). The y-axis at the left side shows the mean annual values of biochemical oxygen demand (mg/l) in the upper, and chlorophyll a values (µg/l) in the lower graph. The y-axis at the right side shows in both upper and lower graph the gain and loss of nitrate (NO3 g/l), ammonium (NH4 g/l) and dissolved oxygen (DO g/l) in ton/(year*km). The blue dashed arrows indicate the loss in dissolved oxygen, the red arrow indicates the decrease in biochemical oxygen demand and the green arrow indicates the decrease in chlorophyll a.*

The Humber and Scheldt are a source for dissolved inorganic nitrogen, with data for the Humber showing a much larger source than the Scheldt estuary. Since freshwater discharge and nitrogen input in the Scheldt and Humber are similar, differences in gain or loss are solely the result of differences in estuarine processing. In the Humber gain of ammonium in the oligo and mesohaline zone seems to coincide with the turbidity maximum zone, which is in agreement with earlier observations (Sanders et al. 1997). This is most likely due to increased mineralisation of particulate nitrogen in the turbidity maximum zone. Suspended matter seemed to be of main importance in the Humber for the sink source functions (Figures 3.8 and 3.11), with greater prominence for phosphorus than for nitrogen (Geerts et al. 2013 at www.tide-toolbox.eu). Furthermore, nitrate removal in the Humber can most likely be linked to the increase in intertidal mudflat towards the polyhaline zone of the Humber. This finding corresponds well to the results of Mortimer et al. (1998). The effect of nitrogen gain in the turbidity maximum zone seems to be larger than the effect of nitrogen removal by denitrification or burial further downstream (Figure 3.11). This corresponds to findings of Jickells et al. (2000) who stated the role of intertidal habitat decreased and the role of the interaction with the reactive surface of suspended matter increased.

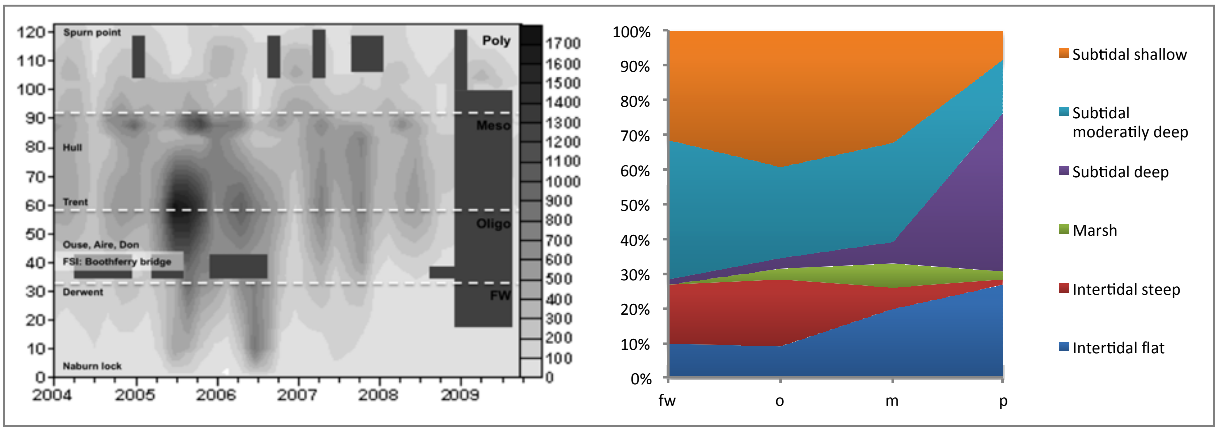

Figure 3.11. Suspended particulate matter (mg/l) distribution along the Humber estuary for 2004-2009 and relative intertidal habitat distribution (%) along the estuarine width.

In the Scheldt the ammonium removal could probably be attributed to denitrification near the tributary mouth, the Rupel. This peak in denitrification in the water column corresponds well to a sag in dissolved oxygen concentration (Figure 3.12). With the oxygen conditions further improving and organic matter inputs decreasing in recent decades, it is expected that the ammonium removal will become limited and hence, also the Scheldt will turn to a nitrification dominated estuary (at least in the water column) (Soetaert et al. 2006).

For the Weser estuary there was insufficient data to identify the sink or source function for nitrogen (or phosphorus). Only limited studies were performed in the Weser and most of them rather focus on sediment dynamics, e.g. (Müller et al. 1990). However, some studies report high nitrification (50 – 70 % of the oxygen consumption) in the upper reaches of the estuary (Schuchardt et al. 1993 in Cox et al. 2009).

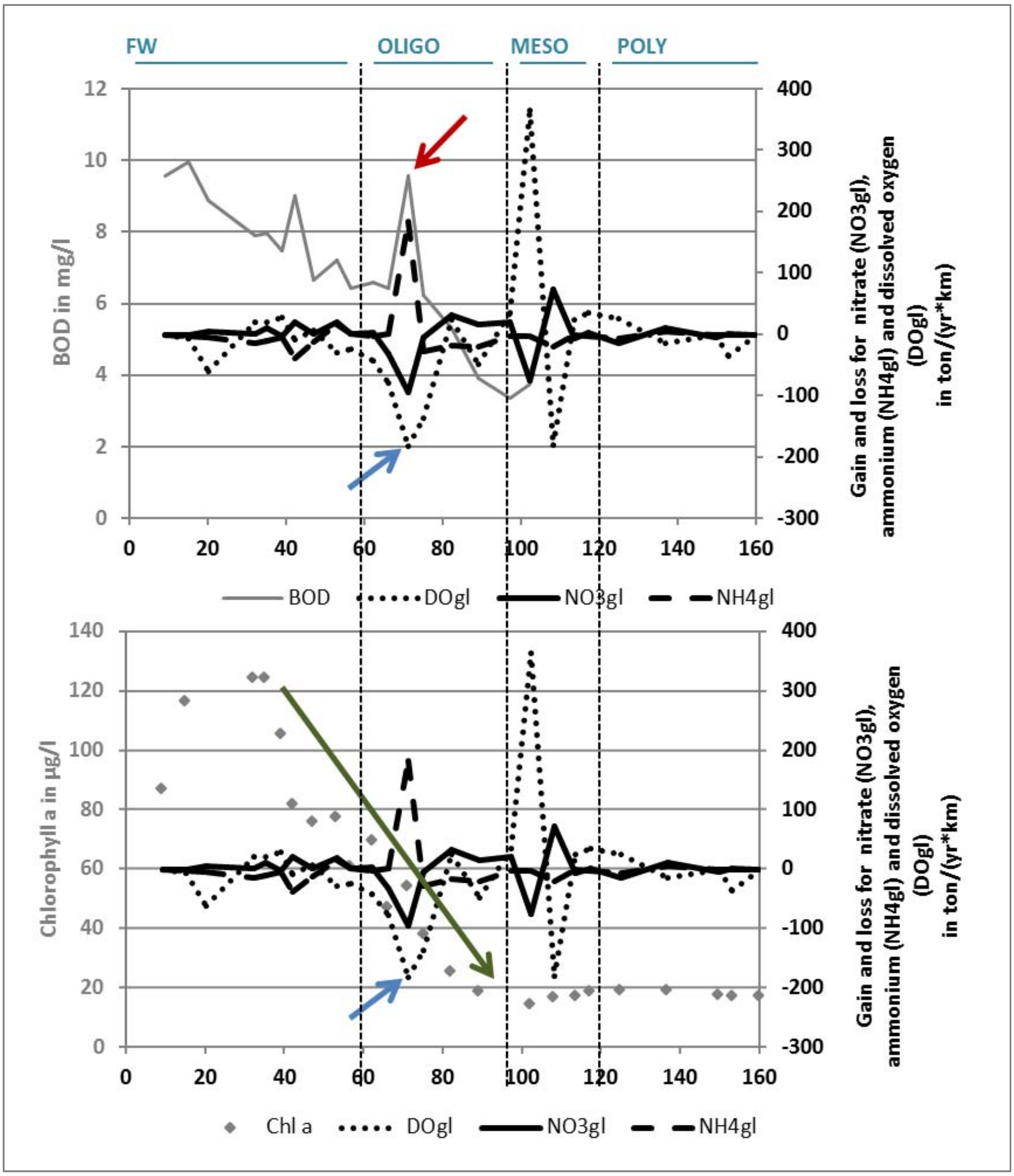

*Figure 3.12. Denitrification peak near the Rupel mouth. The x-axis shows the TIDE-km and dashed vertical lines show the different zones (FW: freshwater zone, OLIGO: oligohaline zone, MESO: mesohaline zone, POLY: polyhaline zone). The y-axis at the left side shows the mean annual values of biochemical oxygen demand (mg/l) in the upper, and chlorophyll a values (µg/l) in the lower graph. The y-axis at the right side shows in both upper and lower graph the gain and loss of nitrate (NO3 g/l), ammonium (NH4 g/l) and dissolved oxygen (DO g/l) in ton/(year*km). The blue arrows indicate the loss in dissolved oxygen near the Rupel, the red arrow indicates the increase in biochemical oxygen demand near the Rupel and the green arrow indicates the decrease in chlorophyll a along the estuarine gradient. It seems denitrification follows mineralization and subsequent nitrification of ammonium to nitrate, with decreasing oxygen values and increased availability of nitrate creating the ideal circumstances for denitrification, explaining the net loss in nitrate near the Rupel mouth.*

In summary, the Scheldt has the highest capacity to improve the water quality for nitrogen, while the Elbe the lowest. It seems that the difference in sink and source function between the Elbe and Scheldt estuary is mostly related to the difference in freshwater discharge. The six-yearly averaged freshwater discharge (2004-2009) in the Elbe estuary is about six times higher than in the Scheldt estuary. Hence, although dissolved inorganic nitrogen concentrations in the Elbe are much lower than in the Scheldt estuary, most nitrogen in the Elbe will be flushed out to the sea. By consequence, future changes in water quality in the Elbe will rather be coupled to changes in freshwater flow related to the effects of climate change (Whitehead et al. 2009). The current ammonium removal is expected to disappear in the Scheldt estuary when the water quality will further improve in the future. The source function for nitrogen in the Humber is mostly controlled by suspended matter dynamics, which increased strongly, over the last 300 years many estuarine habitats (sedimentation potential) were lost (Jickells et al. 2000; Elliott and Cutts 2004) and this is not likely to change dramatically in the near future. For the Weser estuary the sink or source function for inorganic nitrogen species could not be indicated in this study.

3.2.2 Primary production

Estuaries are characterised by a high production of organic matter within the system (autochthonous production), and a large import from outside the estuary both upstream from the catchment and downstream from the sea (allochthonous production) (Elliott and Whitfield 2011). In some areas, the in-situ primary production determines the carrying capacity of the food web, hence of the food provisioning ecosystem services. Chlorophyll *a* concentrations and gross primary production estimates were both used as a proxy for primary production (Figure 3.13). However, only the role of water column phytoplankton as a primary producer was studied; the potential contribution of microphytobenthos (Underwood and Kromkamp 1999) and higher plants has not been considered.

When comparing the chlorophyll *a* values between the Elbe and Scheldt estuary, chlorophyll a values are clearly higher in the Scheldt estuary. Therefore, it is expected that gross primary production in the Elbe will be lower. However, when the gross primary production estimates (calculated based on continuous dissolved oxygen series) were compared, effective production appeared to be higher in the Elbe estuary (Figure 3.14). Chlorophyll *a* values are a proxy for algal biomass and do not necessarily represent actual production. Biomass can be high, while primary production might be low (Underwood and Kromkamp 1999). Nevertheless, the latter result could also be the result of limitations of the method that estimates gross primary production (Cox et al. in prep.). E.g. this method does not work very well when the estuary is not fully mixed, and this is known to be the case for the Elbe

(Goosen et al. 1999). Goosen et al. (1999) also found the primary production to be higher in the Scheldt oligohaline and mesohaline zone then in the Elbe freshwater and oligohaline zone (using the zonation approach as adopted in Geerts et al. 2012 at www.tide-toolbox.eu). Hence the chlorophyll a values seem not only to reflect a difference in algal biomass, but also a difference in primary production between the Scheldt and Elbe estuaries in this study.

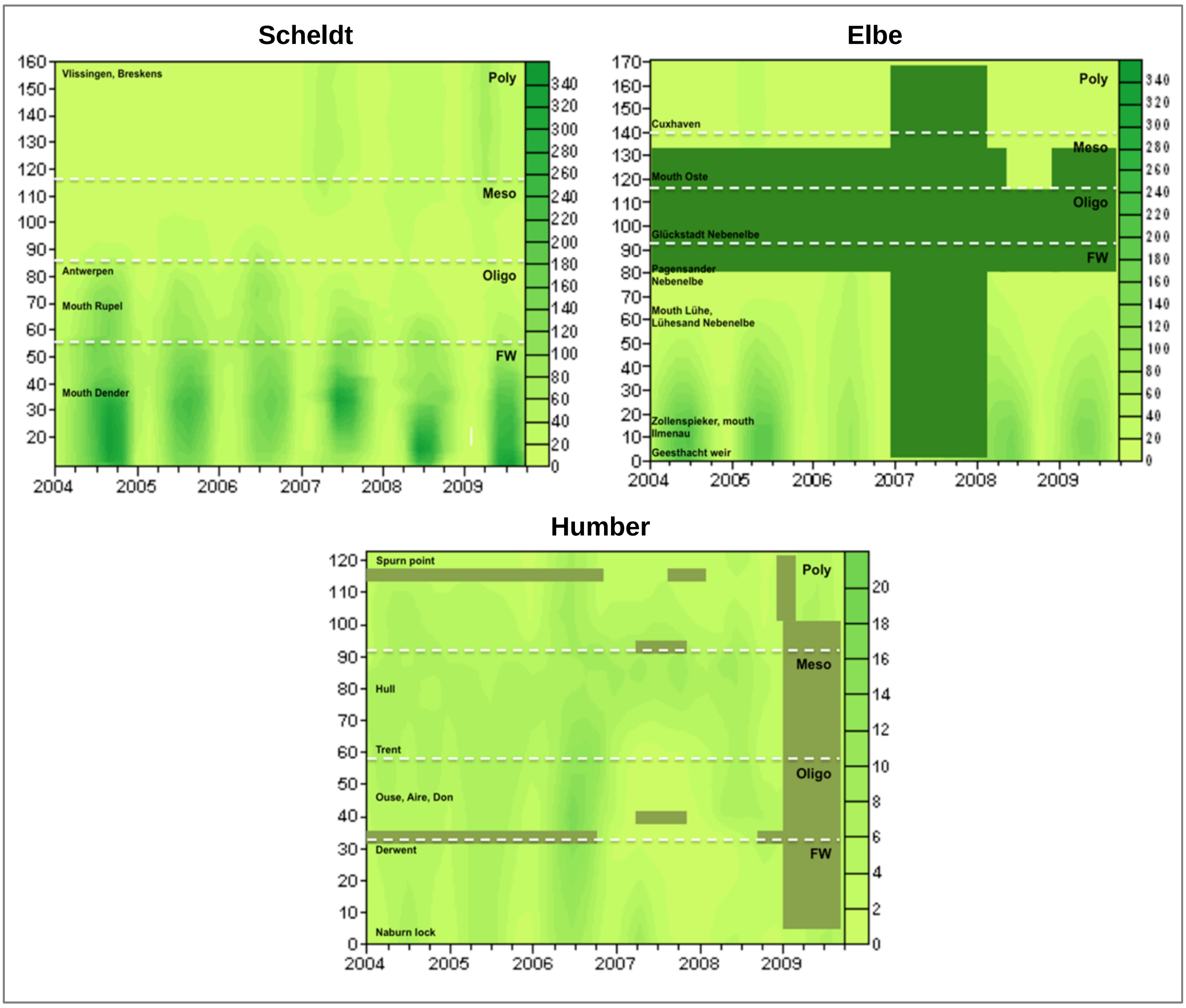

Figure 3.13. Spatial (TIDE km at the y-axis) temporal (years at the x-axis, minor tick marks indicating winter, spring, summer and autumn consecutively) distribution of chlorophyll a concentrations in the Elbe and Scheldt estuary; and for chlorophyll extract values in the Humber estuary (in µg/l). Main tributaries and recognizing sampling points are shown in the surfer plots. Missing data in the time-distance plots are represented as solid filled rectangles. Within the Weser chlorophyll pigments are only measured 6 times within the polyhaline zone of the estuary and therefore not be represented here.

In the Humber, as chlorophyll values measured were very low and based on estimates from continuous dissolved oxygen series no primary production could in fact be detected. Both findings correspond to the results from the multivariate analyses, in which the Humber was distinguished by its absence of seasonal chlorophyll dynamics. In addition the Humber could be distinguished from the other estuaries by its high suspended matter concentrations (based on a six-yearly average for 2004-2009 along the entire estuarine gradient 268 mg/l).

This is much higher than in any of the other case estuaries examined (six-yearly averages for Elbe, Scheldt and Weser are 85 mg/l, 65 mg/l and 94 mg/l resp.). Primary production in the pelagic of the Humber estuary is impeded by light limitation, and any chlorophyll measured is likely to be the result of re-suspended microphytobenthos (Boyes and Elliott 2006).

In the Weser no chlorophyll a measurements were done. However, based on estimates for gross primary production from continuous oxygen series, it appears that production in the Weser could be highest of all estuaries studied.

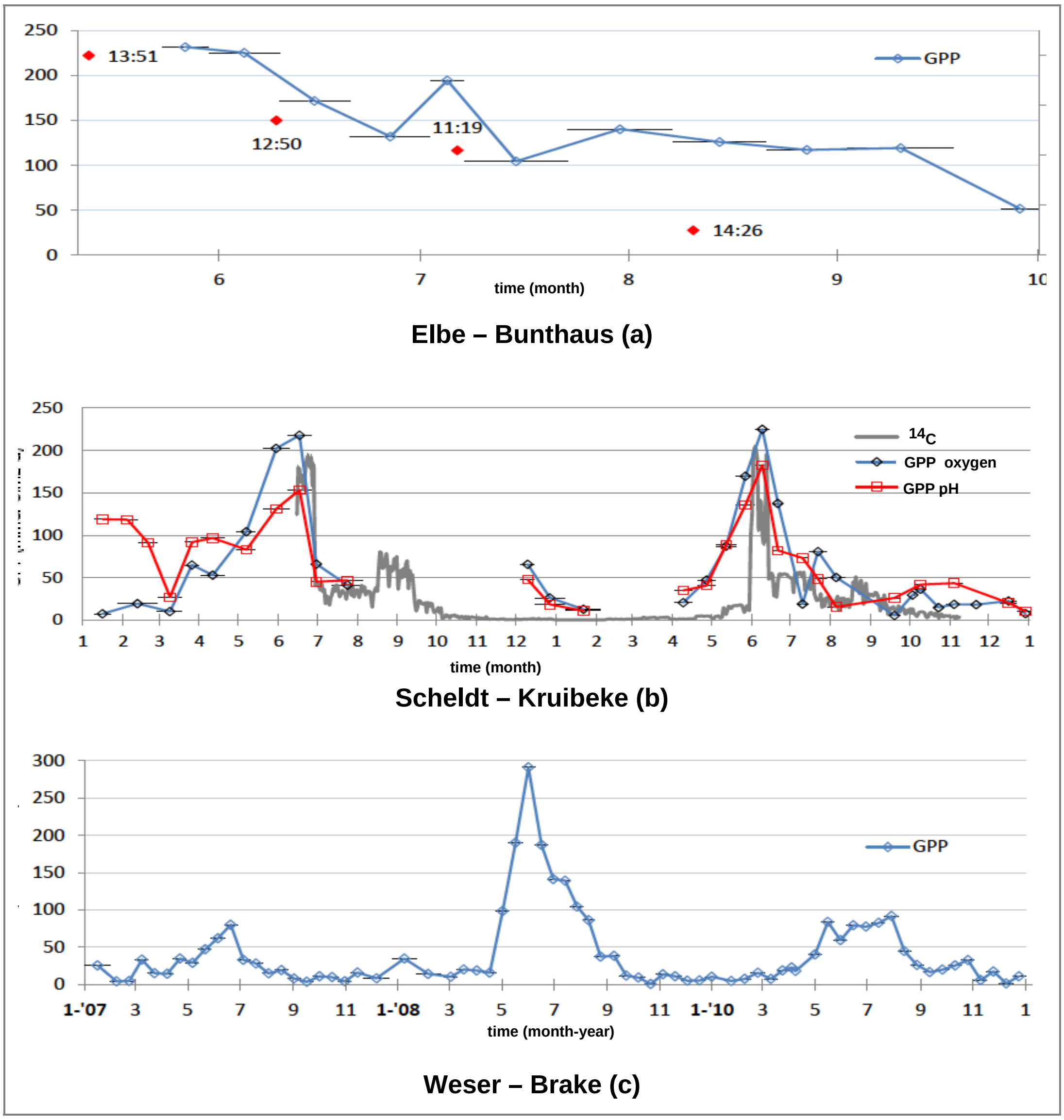

Figure 3.14. GPP estimates from continuous oxygen data series in Elbe, Scheldt and Weser for the locations Bunthaus, Kruibeke and Brake resp.; (a) in the Elbe, GPP is represented for the time period of 23-5-2009 to 1-10-2009; the horizontal bar displays length of the time interval considered; oxygen saturation values based on a 14day average are added in red; (b) in the Scheldt, GPP for the time period 2009 to 2010 is displayed; also GPP estimates based on pH continuous profiles and GPP calculation from 14C in situ methods are added to the graph; (c) in the Weser, the GPP estimates based continuous oxygen profiles for 2007 to 2008 are represented; horizontal bars represent time interval.

For both the Scheldt and Elbe estuary, highest chlorophyll concentrations are observed in the freshwater zone (Figure 3.14). Concentrations in the Scheldt freshwater zone are twice as high as those in the Elbe freshwater zone, despite the fact that in the most upstream part of the Elbe freshwater zone most dissolved oxygen oversaturation events occurred when compared to the other estuaries. Further downstream the algae appear to promote oxygen deficiencies (see Section 3.2.3 for further discussion). To understand firstly the mechanisms controlling primary production, the following possible limiting factors were studied: light climate, nutrients and residence time.

From the most upstream part to the more downstream part in the freshwater zone, the euphotic depth in the Scheldt decreases from approximate 0.8 m to 0.4 m, while in the Elbe it decreases from approximate 1.1 m to 0.25 m. Despite euphotic depth decreasing more in the Elbe, these differences do not seem large enough to explain differences in chlorophyll *a* values. However, when bathymetrical depth (as a proxy for mixing depth in macro-tidal estuaries) is also considered, it is clear that in the Elbe from TIDE km 34 the increase in depth causes a decrease in the euphotic depth-mixing depth ratio, detrimental to algal growth. Hence, light climate does seem to be an important factor contributing to a lower algal growth in the Elbe estuary.

Residence time in the summer when summed over the length for each zone appears to be higher in the freshwater zone of the Elbe than in the freshwater zone of the Scheldt (Figure 3.15). Even when corrected for distance per zone (in days/km), residence times is higher in the Elbe than in the Scheldt estuary. Hence, differences in residence times do not provide any clear explanation.

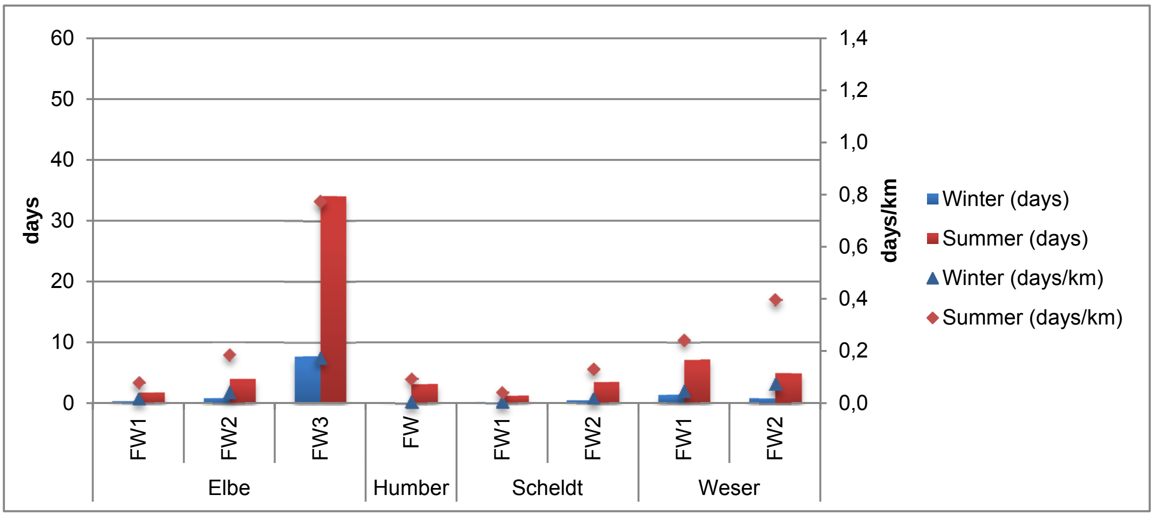

Figure 3.15. Winter and summer residence time per freshwater zone (days) and normalized for the length of each freshwater zone (days/km) of the Elbe, Humber, Scheldt and Weser estuaries calculated according to the fractal freshwater method as calculated in (Vandenbruwaene et al. 2013). The freshwater zone was further divided according to the zonation as decided in (Geerts et al. 2012).

The Redfield ratio represents the composition of phytoplankton as found in sea. Hence deviations from this 'ideal Redfield ratio' (C/N/P/Si: 106/16/1/20) indicate nutrient limitations and the potential to sustain new production of non-silicious algae (Billen and Garnier 2007). Nitrogen is clearly not limiting in any of the estuaries studied within this report. When nitrogen:silica and phosphorus:silica ratios are considered, it is clear that most limitation for silica occurs in the freshwater zone of both Scheldt and Elbe estuaries. However, in the Elbe estuary this is most pronounced in the most downstream part of the freshwater zone and in summer (but also on a yearly basis), after the area of increased depth observed in this estuary. Although relative ratios might be limiting according to the Redfield ratio, it is the absolute concentrations that will effectively prevent algal growth. Most dissolved silica concentrations lower than 0.3 mg/l, are clearly observed in the freshwater zone of the Elbe estuary. This might be attributed to sinking of diatoms to the deeper layers within the freshwater part of the Elbe estuary and more limited recycling to the upper layers of the water column. In the Scheldt, no absolute dissolved silica limitations are observed.

Since chlorophyll *a* is regarded here as a proxy for algal biomass, grazing (by zooplankton) is another factor that might explain the discrepancy of the lower chlorophyll *a* values in the shallower, most upstream part of the Elbe and the regular observed oversaturation events in the most upstream part of the Elbe estuary indicating primary production. Unfortunately no data were available on this. However, grazing is also reported to be an important controlling factor in the upstream river part of the Elbe by Quiel et al. (2011).

In summary, it can be concluded that primary production is limited by light climate in the Humber estuary. The Humber is naturally so turbid that the food chain depends mostly upon detritus from the catchment, the adjacent wetlands and human-derived inputs, re-suspended microphytobenthos (the sediment microalgae), and local benthic production on tidal flats, the light-exposed sites, thus emphasizing the importance of intertidal habitats in this estuary. Despite this, the Humber has in total the lowest relative area of intertidal habitats of the estuaries studied. In the Humber mudflats and marshes combined cover approximately a quarter of the total system surface, an example where the inter-estuarine comparison revealed a case of high demand versus low offer of an estuarine function (see Section 4.2). In the Scheldt and Elbe estuary primary production is limited by a combined effect of dissolved silica limitation, light climate and possibly grazing within the Elbe estuary. Compared to the Scheldt, the Elbe estuary is in general deeper, more turbid and has a shorter residence time, which together explains its relatively low primary production. Consequently, the filter function of the Elbe estuary is reduced, thus explaining the important release of dissolved silica in the oligohaline zone, a crucial element in the food web. The Weser potentially has a high primary production capacity. Primary production in the Scheldt has been considered to be limited by light. However, recently chlorophyll *a* values seem to increase again in the freshwater zone, indicating another limitation must have played previously. Hypotheses suggest ammonium and oxygen could have had inhibitory effects upon algal growth, when oxygen deficits were more prevalent in the Scheldt estuary (Cox et al. 2009).

3.2.3 Oxygen deficiencies

Many estuaries naturally have low dissolved oxygen levels (termed a spatio-temporal DO sag) often in the turbidity maximum zone, because of high oxygen demand by detritus and suspended sediment there. Part of that spatio-temporal DO sag can be attributed to freshwater and marine micro-algae dying once they reach brackish conditions. Historically in many estuaries, this natural DO sag has been exacerbated by human organic inputs either from the catchment or surrounding cities and industries (Testa and Kemp 2011).

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 (Kerner and Edelkraut 1995; Bergemann et al. 1996). In the 1990's water quality of the Elbe greatly improved due to the closure of several former East German industries after the German reunion. The improved water quality led to regular algal blooms in the middle stretches - the riverine part - of the Elbe. Since summer 1991 the improvement in the water quality has resulted in regular algal blooms in of the Elbe river and ammonium concentrations less than 0.1 mg/ l N (Bergemann et al.1996). Nevertheless, oxygen deficits regularly occur in the tidal regions of the Elbe during the summer months (Figure 3.17). In former years, the presence of toxic substances prevented both nitrification processes and the growth of algae in the middle Elbe. The development of an oxygen deficiency in the tidal Elbe was at that time mainly caused by the degree of nitrification (Bergemann et al. 1996). Also in the Scheldt estuary a DO sag can be observed. The zone of oxygen deficits in the Scheldt, extends over a large part of the freshwater zone and almost the entire oligohaline zone. Recently oxygen concentrations have improved in the Scheldt estuary and in 2009 oxygen concentrations did not drop below 5 mg/l anymore along the whole estuarine gradient. Although, overall averaged dissolved oxygen concentrations are still markedly higher in the Elbe compared to the Scheldt estuary, the Elbe estuary appears to persistently experience these oxygen drops below 5 mg/l (see also Kerner 2007 and Quiel et al. 2011).

Lower dissolved oxygen concentrations in the Scheldt (Figure 3.16) in general can be explained by the higher biological oxygen demand concentrations observed here compared to the Elbe estuary. Nevertheless, in the Scheldt biological oxygen demand concentrations have improved greatly, while in the Elbe biological oxygen demand concentrations did not change markedly. In the Scheldt input of ammonium strongly reduced. Furthermore, with an increasing water treatment effort since 2007 (Aquiris 2010) there is also less organic matter input in the Scheldt estuary coming from the Rupel tributary. Hence, in the Scheldt the improvement of water quality can be related to a decrease in oxygen consuming processes such as nitrification and mineralization.

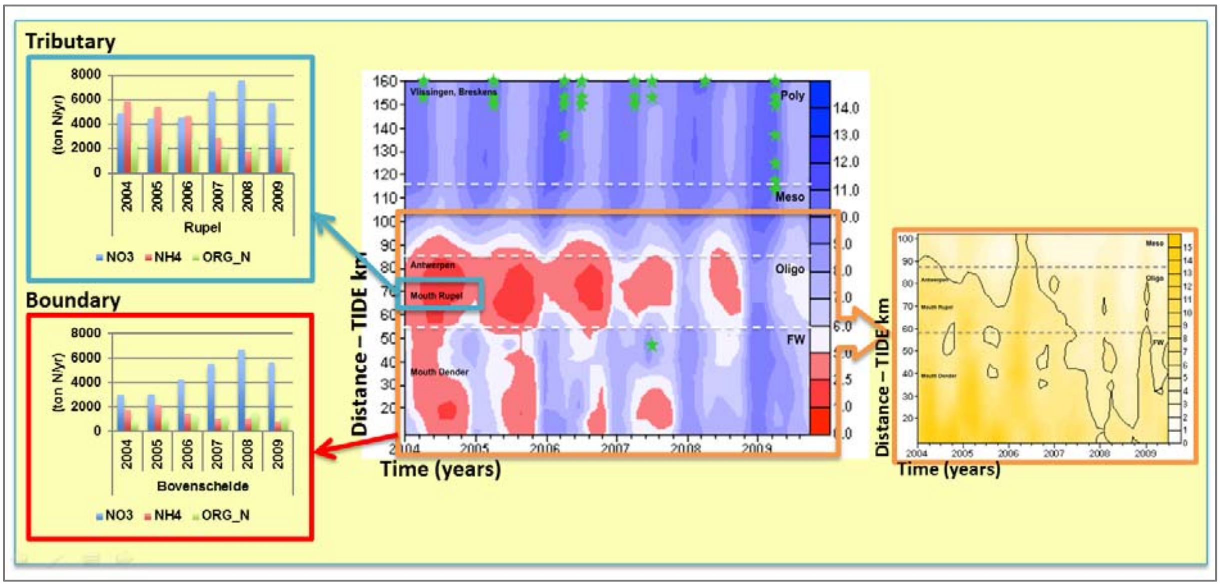

Figure 3.16. Oxygen deficiencies in the Scheldt estuary seem to coincide with a high biological oxygen demand (yellow surfer plot) and high nitrogen input from the tributaries.

In the Elbe, oxygen deficiencies are likely related to an intense peak of nitrification and mineralization. Although, biological oxygen demand concentrations are much lower in the Elbe estuary and they did not change very much. Contrary to the other estuaries, in the Elbe estuary average depth abruptly increases in the Hamburg port area, coinciding with a peak of oxygen loss and nitrate and ammonium gain. Increased depth also creates increased residence times (Figure 3.15) and a decreased euphotic depth-mixing depth ratio within this area (Figure 3.17). Also in the Scheldt euphotic depth-mixing depth ratio decreases rapidly towards the end of the freshwater zone, however this decrease seems to be slightly more gradual and the minimum euphotic depth-mixing depth ratio is rather situated in the oligohaline zone compared with the Elbe estuary.

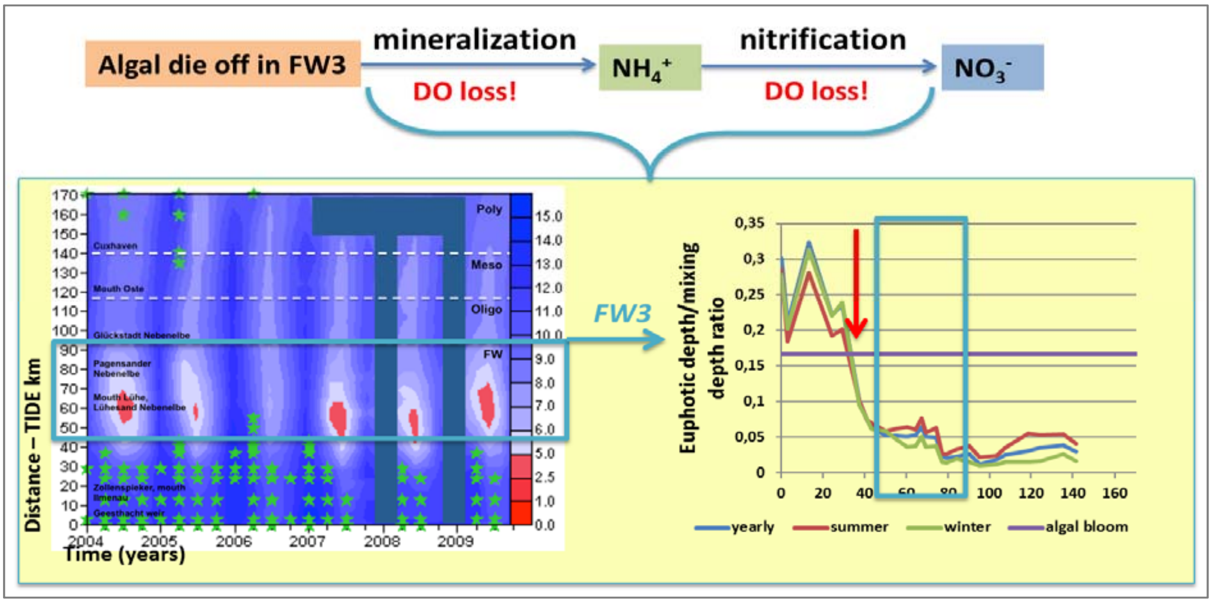

Figure 3.17. The DO sag in the Elbe estuary seems to coincide with an algal die-off due to a detrimental light climate. At the left a surfer graph of dissolved oxygen concentrations in the Elbe is presented. Stars (*) indicate oversaturation events (dissolved oxygen – DO – larger than 100%). The euphotic depth-mixing depth ratios are presented in the right graph. The purple algal bloom line represents a euphotic depth, mixing depth ratio of 1/6 ~ 0.17.

It is likely that allochthonous (input from upstream) and autochthonous (from algae dying off) organic matter is piling up in this transition zone of changing hydro-morphological characteristics characterized by a pronounced transition between river dominance and tidal dominance – read also the Dalrymple concept in Vandenbruwaene et al. (2013). A large zone of intense nitrification and mineralization likely gives rise to oxygen deficiencies more downstream (Quiel et al. 2011).Also in the Humber a dissolved oxygen sag can be noticed (Boyes and Elliott 2006). However, this oxygen sag is not of a degree that it impedes ecological functioning (Holzhauer et al. 2011) and therefore not further mentioned here.

In summary, in the Scheldt severe oxygen deficiencies (<5 mg/l) have recently disappeared because of general water quality improvement. In the Elbe these oxygen deficiencies seem to persist even after water quality improvement in the 90's, i.e. input reduction of nutrients as well as heavy metals and other pollutants. This could be linked to intensified mineralization and subsequent nitrification related to the particular morphometric characteristics of the freshwater zone, for example a negative light climate i.e. a very small euphotic zone compared to the overall water depth leading to the already mentioned algal die-off (Bergemann et al. 1996). In conclusion, if water quality in the Scheldt does not deteriorate or the Scheldt is not suddenly deepened over a large extent within the freshwater zone, it can be stated that problems of oxygen deficiencies are not expected in the nearby future. In the Elbe, biological oxygen demand concentrations are already much lower compared to the Scheldt estuary and much lower than what is considered as a healthy threshold (< 6 mg/l) for a good ecological functioning system according to (Holzhauer et al. 2011). Hence it might be unrealistic to further reduce organic matter input. However Bergemann et al. (1996) suggest that a further improvement in the oxygen content of the tidal Elbe in summer can only be achieved by reducing the concentration of algae in the middle Elbe. Therefore a model has been run to test the effect of a strong reduced algal input at the upper boundary (0.1 µg/l). Severe oxygen deficiencies (<5 mg/l) seem to disappear now in the Elbe freshwater zone. Nevertheless, concentrations still approach 5 mg/l, which is considered the minimum level needed for a good ecological status (Holzhauer et al. 2011). Model runs to test the oxygenation capacity from shallow water zones near the Hamburg port area, showed positive effects within these areas. However, positive effects from shallow water areas upon oxygen levels within the Elbe main stream were restricted (Schöl 2012 at www.tide-toolbox.eu). Possibly the positioning of these shallow water zones near the freshwater part of increased depth makes exchange of oxygen with the deeper waters of the partially mixed Elbe very difficult. Thus, at the moment it is not clear how to resolve this problem of a DO sag in the Elbe estuary.

It is clear that the combination of morphological factors (sudden increase in depth and smaller euphotic depth in relation to mixing depth) and high input of organic degradable matter cause intensified biogeochemical processing. One direction that could be investigated is to find a measure that distributes the organic matter input over a more elongated stretch of the estuary, hence not all oxygen is consumed in one area.

3.3 Habitat function, fish and waterbird habitat needs

Estuaries provide many marine, migratory, or estuarine species with basic requirements for their life cycle (Elliott and Hemingway 2002; McLusky and Elliott 2004; Mander et al. 2013).

A diverse fish fauna can be found in estuaries, with species showing a variety of ways of using the resources (e.g., space and food) that are available in estuarine habitats. Based on these differences, fish species have been grouped into guilds, or functional groups, describing fish adaptations to the estuarine environment in terms of habitat use, feeding and reproduction (Elliott et al 2007; Franco et al. 2008; Potter et al. 2013).

Only a small number of fish species are able to reside permanently in estuaries, due to the challenges that these highly variable environments pose to the physiology of aquatic organisms. For example, a recent study on the fish populations using the Humber Estuary (UK), has highlighted that, out of the 82 fish taxa recorded in this estuary over the last decade, only 19 (23%) of these species were estuarine residents (EA 2013). Fish belonging to this group (e.g., gobies) are often small sized, feed on the invertebrate populations living on the bottom or in close proximity and can be an important food source for larger predators (marine fish and piscivorous birds), hence constituting an important link in the energy transfer between the local estuarine benthic compartment and the estuarine and marine pelagic compartment (Franco et al. 2008; EA 2013).

The majority of fish species found in estuaries enter these systems from adjacent ecosystems (mostly from marine areas, but also from fresh waters), using estuarine habitats only temporarily. Marine species can use estuaries in an opportunistic way, occurring in estuaries occasionally or performing regular migrations to take advantage of the abundant food resources seasonally available in these systems. Several marine species also take advantage of the sheltered and productive conditions in the estuarine habitats during a vulnerable stage of their life cycle thus enhancing the survival and growth potential of juveniles to achieve the adult size faster before returning to the marine environment. As many of these migrant species have commercial value to coastal fisheries (e.g., flatfishes and whitefishes), this dependency on estuaries for their nursery function is particularly important in ensuring sustainability of marine fisheries. Being at the interface between the marine and freshwater realms, estuaries can also be used as pathways of spawning migration between these two ecosystems by anadromous and catadromous species (often identified together under the name of diadromous; e.g., eel and salmonids, respectively). Although only a few species belonging to this group are usually found in European estuaries (5 species on average, accounting for 9% of the fish diversity; Franco et al. 2008), they may be quantitatively important. In the Elbe Estuary (Germany), for example, diadromous fishes make up approximately 90% of the abundance of fish fauna, with European smelt, *Osmerus eperlanus* being their main representative (Thiel and Potter 2001; Thiel et al. 2003).

The morphological diversity of estuaries provides a variety of aquatic habitats distributed along the salinity gradient (e.g., mudflats, deeper areas, salt marshes) that can be used by the estuarine fauna depending on their specific ecological requirements. In the Humber Estuary, juvenile sole, *Solea solea* have been found to abound particularly in shallow areas covered with fine sediment, especially in the lower reaches of the estuary, whereas juvenile plaice, *Pleuronectes platessa* occurring in the estuary showed a preference for sandy substrata at the mouth of the estuary as nursery habitats (EA 2013). Other important marine migrant whitefish species that use the Humber as a nursery, (e.g. cod, *Gadus morhua* (Linnaeus 1758) and whiting, *Merlangius merlangus* (), occurred with higher frequency in deeper areas (>2m). Important food species for fish, birds and seals like sprats, *Sprattus sprattus* and herring, *Clupea harengus* were also found at juvenile stages within the Humber, mainly in the lower estuary (EA 2013). Estuarine marshes may provide significant refugia for life stages vulnerable to predation, hence functioning as important nursery habitats for several nekton species (e.g., Boesh and Turner 1984; Cattrijsse et al. 1994; Mathieson et al. 2000) as well feeding grounds for benthivorous fish, invertebrates and waterbirds. In the

Scheldt Estuary (The Netherlands and Belgium), a high carrying capacity has been identified in this habitat, as associated with the large excess of macrobenthic prey compared to the fish populations exploiting this food resource (Hampel et al. 2005). The salinity gradient has been indicated as the major determining factor also for macrobenthic fauna, as observed for example in both marsh and other intertidal habitats of the Scheldt Estuary (The Netherlands and Belgium) (Ysebaert et al. 1993, 1998; Hampel et al. 2009), thus affecting the distribution of fish and benthivorous waterbirds (Ysebaert et al. 2000; Hampel et al. 2005). Food availability (both in quantitative and qualitative terms) has been suggested as the major factor determining habitat quality (Gibson 1994), as recently demonstrated also by a study on the use of restored intertidal areas in the Humber Estuary as a foraging ground for Redshank, *Tringa totanus* (Mander et al. 2013).

Estuarine connectivity across the various scales has been highlighted as one of the main paradigms related to estuarine ecology and management (Elliott and Whitfield 2011). The connectivity of estuarine systems both with adjacent realms and with a network of habitats at a larger spatial scale is of major importance in ensuring that the estuarine functions highlighted above (e.g., as nursery ground for marine fishes, as feeding areas for migratory waterbirds) are fulfilled. This allows estuarine ecosystems not only to support local faunal populations but also to sustain biodiversity at a wider scale, e.g., via the net export of energy (as faunal biomass) gained from the estuarine resources to other ecosystems (e.g., Boesh and Turner 1984; Carleton Ray 2005).

At the widest scale, connectivity is ensured by the provision of suitable feeding as well as resting habitats during the great migrations between northern breeding grounds and southern wintering sites, thus determining the importance of estuarine systems for migratory waterbird populations, like in the case of the Humber, Scheldt, Weser (Germany) and Elbe (McLusky and Elliott 2004; van Roomen et al. 2012). These are essential staging areas and are part of a network of wetland sites that occur along the East Atlantic Flyway which stretches from the Arctic Circle, to southern Europe, west Africa and for some species as far as southern Africa. As a result, estuarine areas are often designated under European directives and other conventions, e.g., for their international importance for waterbird populations (e.g. the Birds Directive and Habitats Directive, Ramsar Convention) and contribute to the Natura 2000 Network. A series of Conservation Goals and associated Habitat Needs have been suggested for fishes and waterbirds to assist in the derivation of management objectives for estuaries, particularly Natura 2000 sites, and these are discussed in detail within the EU HARBASINS project reporting outputs (Elliott et al. 2008).

The protection of bird populations (and their associated habitats of importance) through EU directives and national legislation means that there is the potential for conflicts to arise with several other estuarine uses and users (see Chapter 5). Ultimately, sites designated under these directives are required to be managed so that the integrity of interest features identified within them, such as components of the waterbird assemblage, are maintained. Actions identified as having an effect on the integrity of a feature would require compensation measures to be applied in order to ensure no loss of integrity.

The understanding of the critical determinants of bird usage of such estuarine habitats is therefore an important element in the management of these systems both for compliance with EU directives, but also for wider estuarine health and function. In particular, they are of value in terms of both the identification of potential user conflict scenarios (and associated potential impacts), and also in the identification of suitable and effective mitigation and compensation measures.

High water bird count data and a series of potentially important environmental parameters (including natural habitat extent, water quality components, and indicators of anthropogenic disturbance) were therefore employed in both a multivariate analysis and in species-habitat regression models in order to identify a series of important habitat requirements for different bird species, with the Elbe, Weser and Humber used as case-studies.

3.3.1 Case study: bird assemblages in TIDE estuaries

High water bird count data obtained between 1984 and 2011 in the Elbe, 1984 to 2009 in the Weser and 1991 to 2011 in the Humber (with additional records available from 1975 in this estuary for wildfowl species only) were analysed. The wader and wildfowl assemblages from the estuaries studied within TIDE included a total of 19 and 21 species respectively (Table 3.2).

Whilst not an exhaustive list of all species encountered within estuarine habitats, they are considered to be broadly representative of those commonly occurring in north-west European estuary assemblages either directly, or as surrogates for allies.

Wader assemblages within an estuarine system are often numerically dominated by species primarily using the mudflat habitat for feeding, and this was seen from the data used in this analysis, with species such as Dunlin (*Calidris alpina*) (Figure 3.18), Oystercatcher (*Haematopus ostralegus*), Curlew (*Numenius arquata)* and Knot (*C. canutus*) present in large numbers, although species primarily roosting on mudflats, including Lapwing (*Vanellus vanellus*) and Golden Plover (*Pluvialis apricaria*) were also locally abundant (Figure 3.19). Wildfowl assemblages were also present within the datasets, dominated by duck species (Shelduck (*Tadorna tadorna*), Wigeon (*Anas penelope*), Mallard (*A. platyrhynchos*) and Teal

(*A. crecca*) being the most numerous), but with goose species also being locally highly abundant (e.g. Barnacle Goose (*Branta leucopsis*) in the Elbe).

Figure 3.18. Dunlin and Little stint (C. minuta). Dunlin is a commonly encountered wader on intertidal mudflats but the wintering population has declined in Europe in recent years.

In general, higher densities of wader and wildfowl species feeding on mudflat habitat were recorded from the outer part of the studied estuaries (polyhaline zone), this pattern being particularly marked when considering the contribution of the southern bank of the Elbe. However, in the Weser and especially in the Humber, the oligohaline zone also appears to be important in supporting dense populations of waders roosting on mudflats (Lapwing and Golden Plover) as well as high wildfowl numbers, including Teal, Wigeon and Mallard (Figure 3.19).

Table 3.2. Bird species included in the analysed datasets from the Humber, Weser and Elbe (NDS = southern bank, SH = northern bank). Max annual count (per counting unit/sector) in each estuarine dataset is reported (empty cells indicate species not included in the analysed dataset). Species allocation to guilds is also indicated for waders (Mud F, generalist feeder species predominantly feeding on mudflat; F specialist, specialist feeder species predominantly feeding on mudflat, preying on larger/specific prey; Mud R, species predominantly roosting on mudflat; Mud, species showing a loose association with mudflat) and wildfowl (Est F, estuarine feeder species, spending most of their life in estuaries; Marsh, species showing a loose association with marsh; Mud Grazer, species grazing on mudflats on Zostera/Enteromorpha; Mud R/ F inland, species roosting on mudflats but feeding mostly inland); Subtidal, fish eating duck/diver; FW duck, freshwater duck; Sea duck, sea duck, mostly marine).

BTO Species code	Species (EN)	Species (scientific)	Group	Guild	Max count in the dataset			
						Elbe		
					Humber	(NDS)	(SH)	Weser
WADERS:								
DN	Dunlin	*Calidris alpina*	Sandpipers and allies	Mud F	25000	85000	144442	55000
KN	Knot	*Calidris canutus*	Sandpipers and allies	Mud F	35004	20000	32180	42000
GV	Grey Plover	*Pluvialis squatarola*	Plovers and lapwings	Mud F	5000	25000	8735	11050
RK	Redshank	*Tringa totanus*	Sandpipers and allies	Mud F (1)	7500	1580	11778	1000
CV	Curlew Sandpiper	*Calidris ferruginea*	Sandpipers and allies	Mud F		45	10805	500
DR	Spotted Redshank	*Tringa erythropus*	Sandpipers and allies	Mud F		3850	5412	810
RP	Ringed Plover	*Charadrius hiaticula*	Plovers and lapwings	Mud F	1410	1530	7742	1323
TT	Turnstone	*Arenaria interpres*	Sandpipers and allies	Mud F (2)	480	2630	437	500
WM	Whimbrel	*Numenius phaeopus*	Sandpipers and allies	F specialist	150	831	87	580
OC	Oystercatcher	*Haematopus ostralegus*	Oystercatchers	F specialist	4000	26604	15990	40000
CU	Curlew	*Numenius arquata*	Sandpipers and allies	F specialist	3000	42000	8398	23000
BA	Bar-tailed Godwit	*Limosa lapponica*	Sandpipers and allies	F specialist	5900	12000	16700	8000
BW	Black-tailed Godwit	*Limosa limosa*	Sandpipers and allies	F specialist	696	3500	13	2000
GP	Golden Plover	*Pluvialis apricaria*	Plovers and lapwings	Mud R	26260	18000	5100	5842
L.	Lapwing	*Vanellus vanellus*	Plovers and lapwings	Mud R	14488	23000	3084	8000
SS	Sanderling	*Calidris alba*	Sandpipers and allies	Mud	701	2400	7105	2394
AV	Avocet	*Recurvirostra avosetta*	Stilts and avocets	Mud	270	2400	3234	5000
GK	Greenshank	*Tringa nebularia*	Sandpipers and allies	Mud		1050	3711	2370
RU	Ruff	*Philomachus pugnax*	Sandpipers and allies	Mud		872	360	
WILDFOWL:								
SU	Shelduck	*Tadorna tadorna*	Ducks (Swans, ducks and geese)	Est F	4111	31100	45000	10300
WN	Wigeon	*Anas penelope*	Ducks (Swans, ducks and geese)	Est F (3)	8000	9700	11930	15000
MA	Mallard	*Anas platyrhynchos*	Ducks (Swans, ducks and geese)	Est F	5000	9700	8950	8427
T.	Teal	*Anas crecca*	Ducks (Swans, ducks and geese)	Est F	3163	7640	5018	11323
BY	Barnacle Goose	*Branta leucopsis*	Geese (Swans, ducks and geese)	Marsh	348	40000	27500	6000
WG	White-fronted Goose (European)	*Anser albifrons albifrons*	Geese (Swans, ducks and geese)	Marsh	96	9400	421	10160
GJ	Greylag Goose	*Anser anser*	Geese (Swans, ducks and geese)	Marsh	901	6760	1703	5000
CG	Canada Goose	*Branta canadensis*	Geese (Swans, ducks and geese)	Marsh	420			
BG	Brent Goose	*Branta bernicla*	Geese (Swans, ducks and geese)	Mud Grazer	813	4686	2770	7052
PG	Pink-footed Goose	*Anser brachyrhynchus*	Geese (Swans, ducks and geese)	Mud R / F inland	1500			
BE	Bean Goose	*Anser fabalis*	Geese (Swans, ducks and geese)	Mud R / F inland		970	0	1600
BS	Bewick's Swan	*Cygnus columbianus*	Swans (Swans, ducks and geese)	Mud R / F inland		1742	1	624
WS	Whooper Swan	*Cygnus cygnus*	Swans (Swans, ducks and geese)	Mud R / F inland		580	54	167
PT	Pintail	*Anas acuta*	Ducks (Swans, ducks and geese)	FW duck	550	1047	3561	2210
SV	Shoveler	*Anas clypeata*	Ducks (Swans, ducks and geese)	FW duck		1998	216	400
TU	Tufted Duck	*Aythya fuligula*	Ducks (Swans, ducks and geese)	FW duck		1490	32	719
PO	Pochard	*Aythya ferina*	Ducks (Swans, ducks and geese)	FW duck	400			
GA	Gadwall	*Anas strepera*	Ducks (Swans, ducks and geese)	FW duck		217	54	137
SP	Scaup	*Aythya marila*	Ducks (Swans, ducks and geese)	Sea duck	550			
CX	Common Scoter	*Melanitta nigra*	Ducks (Swans, ducks and geese)	Sea duck	200			
EE	Eider	*Somateria mollissima*	Ducks (Swans, ducks and geese)	Sea duck	200			

(1) Generalist feeder on mudflat but likes *Corophium*, between generalist and specialist feeding

(2) Generalist feeder on mudflat but also feeds on hard substratum cobbles and weed on estuaries

(3) Estuarine feeder, mostly grazing on marsh/grass in the estuary (and roosting on mudflats)

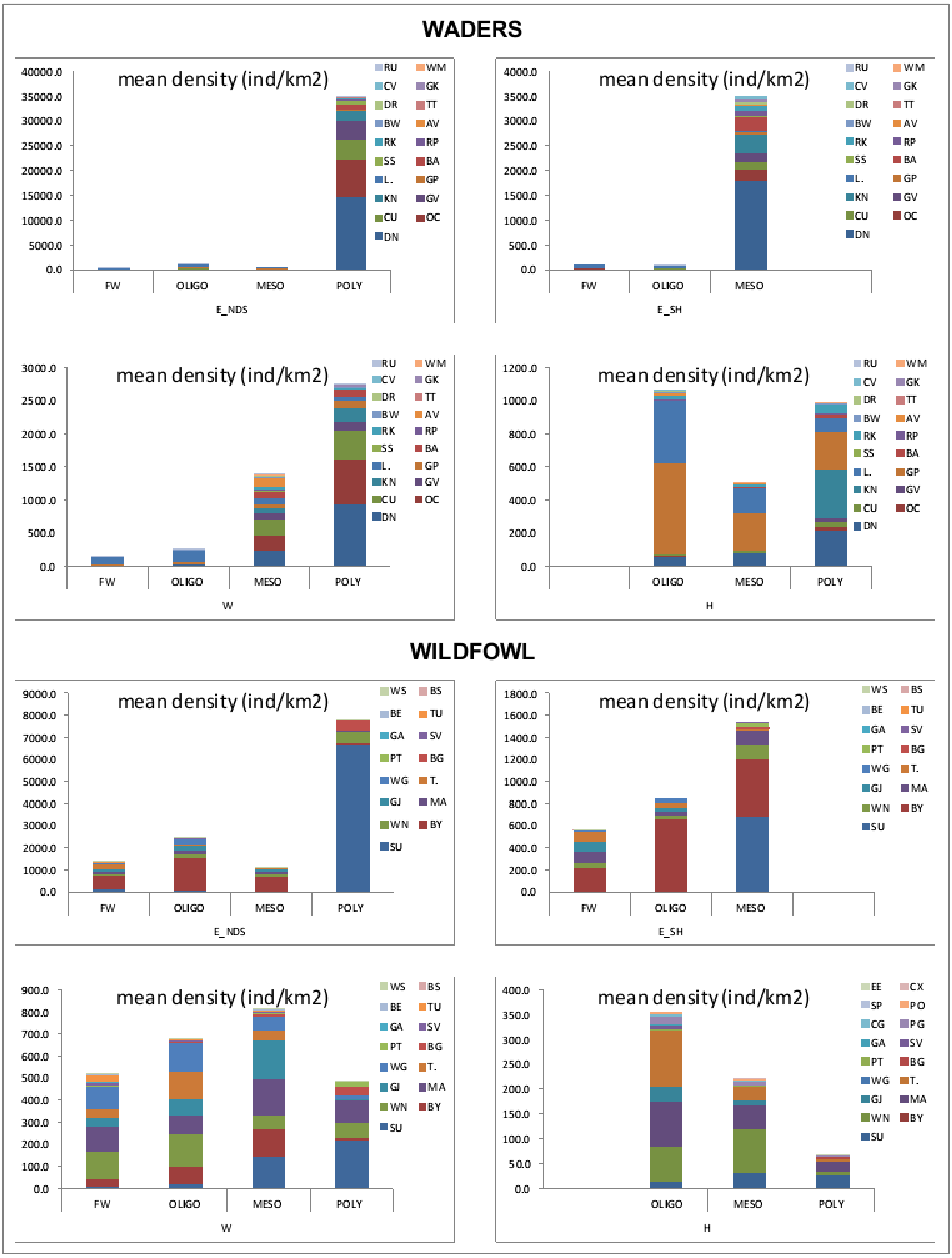

Figure 3.19. Mean density (ind.km-2) of waders and wildfowl in the salinity zones within the Elbe (E; NDS=southern bank, SH=northern bank), Weser (W) and Humber (H, northern bank) estuaries. Species codes are as in Table 3.2.

3.3.2 Relationship with environmental variables

Analysis of the case study datasets identified the structure of the estuarine waterbird assemblages to be more strongly correlated to spatial distribution (e.g. location within estuary) than temporal factors (e.g. inter-annual patterns). As such, the data indicate that, although subject to a degree of variation, there is a spatial pattern to waterbird assemblage composition in estuaries that is persistent over time.

However a higher temporal importance was observed in the Weser compared to the Elbe and Humber, mainly due to low species densities recorded during the period 1980-1984 in this estuary.

The availability of estuarine habitats (in terms of habitat area) (Table 3.3) is also identified as relevant in driving the density distribution of waders and wildfowl, especially in the Weser and Humber, with the analysis indicating that intertidal area is the most important variable influencing wader density distribution, e.g. with higher densities of species such as Dunlin, Knot and Oystercatcher associated with larger intertidal areas, mostly in the outer parts of these estuaries. This variable is also positively correlated to wildfowl density in the Weser, whereas the extent of marsh is more important to this group in the Humber.

Water quality parameters are also identified as relevant determinants of species distribution, their influence being particularly important in the Elbe. The regression models results highlighted that salinity gradient is the most important single predictor of wader and wildfowl species density, due to the general higher densities observed in the polyhaline and mesohaline zones. However, the salinity gradient is more likely to affect the distribution of waterbirds via the variability in geomorphology and habitat quality (e.g. availability of benthic food resources) along the estuarine gradient rather than through a direct effect of water quality on birds, as suggested also by Ysebaert et al. (2000) in their study in the Scheldt. In the Elbe, a differentiation in species density also occurs between the north and south banks, particularly in the oligohaline and mesohaline zones, broadly matching the distribution of human pressures in these areas. This would suggest that, perhaps unsurprisingly, human activity has a negative effect on bird abundance (possibly both through direct disturbance response (e.g. see Chapter 5) and as an indirect effect on the availability of high value habitat).

Table 3.3. Results of the multivariate multiple regression models. The percentage of variance in the wader and wildfowl density explained by the environmental variables included in the models (as combination of all variables, habitats or water quality (WQ) variables only, or as single variables) is reported, as well as the number of observations included in the full model. Although environmental variables used in the analyses for each estuary may differ, depending on the data availability, they were selected to represent similar estuarine characteristics, like coverage of natural habitats and water quality parameters. The variables included in the best model (after backward selection using AIC criterion) are indicated with Y.

HUMBER:	**Waders (18 species)**			**Wildfowl (22 species)**		
Type (and no.) of environmental variables	**% expl. Variance**	**no. obs modelled**	**Variables included in the Best model**	**% expl. Variance**	**no. obs modelled**	**Variables included in the Best model**
Single regression models:						
1- Intertidal area	40%	27	Y	24%	28	Y
2- Subtidal area	12%	27	Y	9%	28	Y
3- Marsh area	30%	27	N	26%	28	Y
4- Supralittoral area	6%	27	Y	13%	28	Y
5- % Hard - pebble	30%	27	Y	22%	28	Y
6- % Hard - man made	12%	27	Y	23%	28	Y
7- Salinity	30%	27	Y	18%	28	Y
8- Intert Benth Abundance	22%	27	Y	10%	28	N
9- Disturbance	12%	27	Y	9%	28	Y
Multiple regression models:						
All variables (1-9)	87%	27		83%	28	
Habitat (1-6)	72%	27		71%	28	
Habitat areas only (1-4)	57%	27		51%	28	
WQ and others (7-9)	45%	27		29%	28	
ELBE:	**Waders (19 species)**			**Wildfowl (15 species)**		
Type (and no.) of environmental variables	**% expl. Variance**	**no. obs modelled**	**Variables included in the Best model**	**% expl. Variance**	**no. obs modelled**	**Variables included in the Best model**
Single regression models:						
1- Intertidal area	7%	61	Y	3%	67	Y
2- Subt_shallow area	9%	61	Y	5%	67	Y
3- Subt_deep area	13%	61	Y	9%	67	Y
4- Foreland area	7%	61	Y	6%	67	Y
5- Chlorinity	24%	90	Y	18%	91	Y
6- BOD5	5%	90	Y	9%	91	Y
7- %DOsat	9%	90	Y	6%	91	Y
8- PO4	10%	90	Y	16%	91	Y
9- NH4(aut)	6%	90	Y	4%	91	Y
Multiple regression models:						
Habitat (1-4)	27%	61		20%	67	
WQ (5-9)	41%	90		37%	91	
WESER:	**Waders (19 species)**			**Wildfowl (15 species)**		
Type (and no.) of environmental variables	**% expl. Variance**	**no. obs modelled**	**Variables included in the Best model**	**% expl. Variance**	**no. obs modelled**	**Variables included in the Best model**
Single regression models:						
1- Intertidal area	19%	42	Y	12%	42	Y
2- Subt_shallow area	4%	42	Y	6%	42	Y
3- Subtidal area	14%	42	Y	11%	42	Y
4- Marsh area	4%	42	Y	6%	42	Y
5- Chlorinity*	4%	66	Y	3%	72	Y
6- BOD5*	6%	66	Y	2%	72	N
7- PO4*	3%	66	Y	13%	72	Y
8- NH4+NO2(aut)*	3%	66	N	2%	72	N
Multiple regression models:						
Habitat (1-4)	46%	42		32%	42	
WQ (5-8)*	14%	66		18%	72	
*this dataset covers only the freshwater and oligohaline zones of the Weser estuary						

3.3.3 Species distribution models

Seven waterbird species were selected for this component of the analysis, based on their representativeness of different guilds, their distribution in the case study estuaries, local importance, and also taking into account their frequency of occurrence in the estuary. These species were the waders Dunlin, Golden Plover, Redshank (*Tringa totanus*), Bar-tailed Godwit (*Limosa lapponica*); and the wildfowl (ducks and geese) Brent Goose (*B. bernicla*), Shelduck and Pochard (*Aythya ferina*). Multiple regression models applied to Dunlin (in the three studied estuaries) and to Golden Plover, Redshank, Bar-Tailed Godwit, Shelduck, Pochard and Brent-Goose (in the Humber) allowed the identification of the main environmental determinants of their habitat use within the studied TIDE estuaries.

In general, the outcomes of the analysis show no single environmental factor as responsible for species distribution, although some factors may show a higher importance than others in affecting it. Overall, although relevant to some species, temporal changes have a secondary effect on species distribution within the estuaries compared to spatial factors. However, temporal change as a management consideration is also important, as it can both provide wider context to estuary or zone variability e.g. national/international population trends, as well as providing an indication of a potential management problem e.g. a longer term reduction in a species or assemblage within a management zone or wider system. In such instances care is however required in the establishment of a representative baseline dataset against which a temporal trend may be assessed e.g. the use of a 5 year mean rather than single year baseline may be appropriate, but long-term analysis is of value to establish any broader population trends.

The analysis indicates that the extent of intertidal and shallow subtidal habitats (but also marsh) is particularly important in affecting Dunlin density distribution (Table 3.4). A higher density of the species is predicted where more extensive habitats occur for the Weser and Humber estuaries, although this effect is mostly related to the higher density of the species in the larger counting units (including larger aquatic habitat areas) occurring in the outer zones of these estuaries. In turn, in the Elbe a contrary relationship is observed, with a negative association with salinity also shown (see Figure 6 in Franco et al. 2013) . Although the importance of salinity in predicting the distribution of Dunlin is possibly related to changes in benthic invertebrate communities (and hence preferred prey availability) along the estuarine gradient, the results for the Elbe were also likely to have been influenced by the high species abundance observed in the smaller counting units found in the polyhaline zone of this estuary, in the outer sands and remote islands in the Wadden Sea. The Elbe analysis also indicates that the presence of Dunlin is affected by nutrient levels, with a lower occurrence of the species where high phosphate and intermediate ammonium concentrations are present.

The more extensive intertidal habitats were also identified as the most important determinant of higher occurrence density for two other wader species in the Elbe. These are Redshank and Bar-tailed Godwit, which predominantly feed on a range of intertidal soft sediment habitats, with the data showing a correlation with the presence of littoral sands and benthic invertebrate abundance. This preference for littoral sands by Bar-tailed Godwit accords with other observations (Prater 1981). Interestingly however, whilst there is an expected correlation between increased Redshank usage and high invertebrate abundance, for Bar-tailed Godwit the linkage is with a lower abundance figure. This may reflect a preference by the species for relatively large prey items such as *Arenicola* and *Hediste* (Cramp 1998).

Table 3.4. Summary of the habitat distribution models applied to Dunlin in the Humber, Weser and Elbe estuaries. Single predictor models are also reported as a means to rank the importance of the single variables in affecting the species distribution. The variables highlighted in grey are those variables that were excluded from the analysis because of co-llinearity (their relationship with the other variables included in the analysis is indicated in parenthesis). The variables in bold (and with the asterisk) are those variables that were selected as relevant predictors of the species distribution in the final (best) model. Codes for variables shown in the Table are the following: Int, intertidal area; Mar/For, marsh/foreland area; Sub, subtidal areas (also distinguished in shallow, Subs, and deep, Subd); Sup, supralittoral area; Eun, dominant intertidal habitat (Eunis); Sal, salinity, Salz, salinity zone; Cl, chlorinity; BOD, biochemical oxygen demand; DO, dissolved oxygen saturation; P, total phosphate concentration; N, concentration of NH_4 and NO_2; Y, year; DN.GB/DNpop, wider species population trend (GB population size for the Humber, Niedersachsen area for the Weser, Schleswig-Holstein area for the Elbe); Dis, disturbance; jurisd, jurisdictions (Elbe only: Niedersachsen (NDS) for the southern bank, Schleswig-Holstein (SH) for the northern bank).

	Humber (all)		**Weser (habitat + Salz)**		**Elbe (habitat + Salz)**		**Elbe (habitat + Salz)**		**Elbe (water quality)**	
Variable modelled	density (Sqrt2)		density (Sqrt2)		density (Log)		probab. of presence		probab. of presence	
Best model:										
n	146		140		169		171		247	
dev. expl.	85.5%		77.0%		79.2%		43.8%		32.6%	
no. covariates incl.(*)	4		5		5		5		5	
Covariates (single predictor models - % deviance explained and rank of predictor importance based on AIC)										
Habitat	**Int**	**56.1 (3) ***	**Int**	**48.8 (4) ***	**Int**	**65.5 (1) ***	Int (+For)	13.2 (4)		
	Eun	57.2 (2)								
	Sub	**77.7 (1) ***	**Subs**	**50.3 (3) ***	**Subs**	**34.9 (4) ***	**Subs**	**19.1 (3) ***		
			Sub (+Subs)	27.6 (5)	Subd (+Subs)	19.8 (5)	Subd (+Subs)	5.4 (6)		
	Mar (+Int)	45.9 (5)	**Mar**	**52.7 (2) ***	For (+Int)	46.7 (2)	**For**	**28.2 (1) ***		
	Sup (-Sub, -Sal)	53.0 (4)								
Water Quality	Sal (+Int, +Sub)	35.6 (7)	Salz	61.9 (1)	**Salz**	**45.4 (3) ***	**Salz**	**15.6 (2) ***	**Cl**	**20.9 (1) ***
									BOD (-P)	6.5 (6)
									DO (+Cl)	17.9 (2)
									P	**12.5 (3) ***
									N	**13.8 (3) ***
Other (temporal)	**Y**	**0.5 (8) ***	**Y**	**8.4 (6) ***	**Y**	**2.4 (7) ***	**Y**	**3.3 (7) ***	**Y**	**3.1 (5) ***
	DN.GB (-Y)	0.2 (9)	**DNpop**	**1.1 (7) ***	**DNpop**	**0.03 (8) ***	DNpop	0.3 (8)	DNpop	0.5 (8)
Other (spatial)	**Dis**	**38.9 (6) ***			jurisd	9.42 (6)	**jurisd**	**6.5 (5) ***	**jurisd**	**0.7 (7) ***

The analysis also indicates that Golden Plover density in the Humber is increased by the presence of smaller subtidal areas and greater marsh and intertidal habitat, combined with sandy substrata in the intertidal. This might be expected as the species tends to use the intertidal zone to roost, with a preference for large, dense flocks of the species to congregate in more extensive open intertidal areas which provide better sight and flight lines and thus allow a more effective response to potential predator interactions.

The extent of the intertidal and marsh habitats is also seen to be generally important in affecting the distribution of the wildfowl species analysed in the Humber, although different relationships have been observed between species. A higher density of Shelduck (a species that primarily feeds on mudflats) is predicted in larger sectors where wider subtidal, intertidal and supralittoral habitats occur, in combination with a more muddy substratum in the intertidal and, interestingly, relatively higher disturbance. As Shelduck often choose to feed in areas of dense aggregations of *Hydrobia* and small polychaetes and oligochaetes and use a foraging technique whereby the bill is pushed through the top layer of soft sediment, the soft substratum association might be expected. However, the association with higher disturbance is somewhat unexpected, and whilst it may simply be an artefact of analysis, it may relate to an often greater tolerance of several duck species to anthropogenic activity when compared to most wader species and a likely increased habituation level associated with such an association. Brent Goose (a species that commonly grazes *Zostera* and *Enteromorpha*/*Ulva* beds on mudflats) is also shown from the data to be more likely to occur where larger intertidal habitats are present in the estuary, in association with smaller marsh areas and intermediate areas of the supralittoral habitat. This may relate to the presence of *Zostera* often towards the mouths of estuarine systems where larger mudflat areas can occur. However, for Pochard, a duck often associated with freshwater estuarine margins but also intertidal and subtidal habitats, the analysis indicates that it is more likely to occur where wider marsh areas are present together with smaller intertidal habitat extent.

3.3.4 Summary and management recommendations

In general, an overall positive relationship has been observed between bird species densities and the habitat area, in particular the intertidal extent, suggesting that larger mudflats might have a greater carrying capacity per unit of area than smaller zones.

The size of any productive area in an estuary is generally positively associated to its carrying capacity in supporting wading birds, in terms of maximum number of individuals (or biomass) that can be sustained (Meire 1993; Elliott et al. 1998). However, when the density of individuals in the estuarine area is considered (i.e., the number of individuals per unit area), a lower wader density has been reported in larger estuarine areas, this negative relationship possibly ascribed to the inclusion of many unsuitable feeding areas (e.g. deeper subtidal areas) in these cases (Prater 1981). Although this explanation may be valid at the larger inter-estuarine scale, a different one might support the opposite pattern at the smaller intra-estuarine scale as observed in the present study, particularly when considering the area of suitable feeding habitats such as intertidal mudflats.

Given that preferred prey availability is considered to be the major determinant of shorebird distribution, the relationship with the intertidal habitat area may be linked to the availability of food resources in it (Prater 1981; McLusky and Elliott 2004). In particular, more extensive habitat areas are likely to have a higher diversity of microhabitats (hence a possible higher diversity in the food resources) and this might lead to a higher probability for bird species of accessing different food resources, possibly resulting also in a reduction in the possible intra- and inter-specific competition, thus allowing a higher concentration of individuals in larger habitat areas. However, it is acknowledged that habitat size alone will not necessarily determine bird distribution, with other site specific factors also influencing this.

Analyses of bird count data and environmental variables lead us to the following management recommendations:

- The positive relationship between intertidal habitat area and waterbird density is a potentially important conclusion for estuarine management, as it suggests that the loss of intertidal habitat from a range of anthropogenic activities, as well as the effective reduction in the width of mudflat from coastal squeeze or even saltmarsh colonisation may result in a reduction of waterbird usage density (both foraging and roosting).
- Although not examined in the analysis, if factors such as edge effect (e.g. reduction in the viable functional area for waterbirds (due to disturbance and/or constraint to flight and sightlines) are taken into account, then the fragmentation of an intertidal mudflat habitat is also important, as the effective functional loss will be greater.
- Furthermore, based on the above, the application of compensatory measures such as managed realignment which are employed to compensate for development-derived intertidal habitat losses may need to consider the delivery of sufficient (additional) habitat area to accommodate any fragmentation effects of the land-claim in addition to the obvious direct losses e.g. may require an increase in the offset area compensation ratio.
- Habitat re-creation in estuaries is not always successful, and carrying capacity can be lower than in more natural areas. As such, the management priority should be to minimise habitat loss from development (ideally avoid loss), and in particular, avoid fragmentation with an ‘over compensation’ principle applied in offsetting areas.
- Although not identified as a key determinant from this analysis (probably due to the nature of the data used), disturbance has been identified as a significant influence on habitat utilisation by waterfowl species, and as such, management needs to ensure

disturbance stimuli are restricted and where possible provide refugia where disturbance is at a low/background level.

- In particular the provision of undisturbed high tide roost areas, both on the upper shore of the estuary and the immediate hinterland is considered very important, these should be located in close proximity to preferred foraging areas and where possible integrated under the Natura 2000 designation, and, in the case of agricultural land, managed in conjunction with the land owner to maximise the conservation potential (e.g. crop types, fallow periods, cropping timing etc.).
- In setting management aims for waterbird communities in estuarine systems, consideration of the main Conservation Goals (CG) is required, these linked to, where possible, Habitat Needs (HN). These principles are discussed in Elliott et al. 2008, with information derived from the case studies described above providing additional information allowing a start to the empirical population of some of these principles.

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4 Structure and Functioning to Deliver Ecosystem Services

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The analysis of historical data and the integration of system knowledge of the TIDE estuaries have resulted in a better understanding of the functioning of each estuary. In this chapter, the aim is to translate this improved knowledge of estuarine functioning into society oriented points of interest. The Ecosystem Services (ES) Concept provides a useful method to illustrate the benefits and opportunities provided by estuarine functions and allows the combining of different, often interdisciplinary, aspects of ecology in order to achieve win-win management situations. The field of ecosystem services aims to classify, describe and assess the natural assets, their supply functions, quantification, valuation and management. Ecosystem services are now generally categorised as provisioning (e.g. food and water), regulating (e.g. flood control and air purification), and cultural (e.g. recreation and aesthetic experiences) services. All of these are eventually generated, supported and ensured by ecosystems in all their diversity (supporting services or broadly defined biodiversity).

This chapter initially presents information about the demand for services, identified by a panel of experts from the case study estuaries, and representing a range of perceptions of the estuarine system. Following on from this, the supply of services has been derived from the functioning, with progress in the quantification of the supply subsequently presented. Matching the demand with the supply of these services reveals management opportunities for the maximisation of benefits.

Within the TIDE project, an approach was therefore developed to address a number of key questions concerning ecosystem services in estuaries:

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

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

4.1 The TIDE importance score of ecosystem services

The principles of the Ecosystem Service Approach have been described earlier in this summary report. Within this section, ecosystem services and estuarine functioning are linked in order to obtain an indication of the benefits and values associated with them. This is done in a qualitative way, however, scientific progress has been made to also allow progress in the quantitative estimates by relating quantifications of processes and structures (functioning) and derived services.

Ecosystem services are valued by the balance between:

1. A societal demand, i.e. the benefits which are obtained
2. A supply, i.e. the functioning of the system structures and processes

The ecosystem service demand is the formulation of human needs, expressing what is expected from the ecosystem functioning to eventually implement societal benefits. The supply of services on the other hand, is calculated from the structures and processes of the system itself. Both demand and supply may vary along the estuarine gradients and in time, and therefore a spatial and temporal distribution of service demand and supply exists.

4.2 Identification of estuarine ecosystem service demands

Initially, a “long list” of services was identified (Table 4.1), based on literature and estuarine expert involvement. The “TIDE long list”, comprises 46 services, of which 15 are provisioning, 25 regulating and 5 cultural services plus the habitat service ´biodiversity´. The category “supporting service” (benefit: insurance of all services; see Section 1.3) was defined as the *total amount of abiotic and biotic diversity at all levels (gene-landscape), regardless of rarity or vulnerability.* All services were briefly defined and main benefits mentioned (Table 4.1)

The concept of ecosystem services is a recent and developing scientific discipline and the identification and classification of services is still evolving. At the start of the TIDE project, the most recent list of ecosystem services resulted from the TEEB (The Economics of Ecosystems and Biodiversity) project (TEEB 2010) (Table 4.1). This approach was therefore used by the four TIDE Regional estuary specific Working Groups (RWG´s) in the identification of the ES demand for each of the TIDE estuaries. This survey led to a list of 20 ES which were considered to be the most important in the four estuaries (Figure 4.1).

Table 4.1. Longlist of estuarine ecosystem services for the four TIDE estuaries. Category (TEEB 2010), benefits and short definition is added.

#	Services	Benefits	Short description
Provisioning services			
1.1	Food: plants	Food	Presence and use of edible plants, including agricultural production for direct food consumption
1.2	Food: animals	Food	Presence and use of edible animals, including livestock growth and fodder production
1.3	Water for household use	Drinking water	Provision and use of water for household use meeting the quality standards for drinking water
1.4	Water for industrial use	Improved industrial production	Provision and use of water for e.g. cooling water, rinsing water, water for chemical reactions
1.5	Water for agricultural use	Improved agricultural production	Provision and use of water for e.g. irrigation water, freezing prevention for fruit trees, drinking water for cattle, etc.
1.6	Water for energy use	Renewable energy production	Provision and use of water for tidal or dam water turbines
1.7	Water for navigation	Shipping	Presence and use of water for shipping purposes
1.8	Raw materials: renewable soil Materials: sand	Building material	Provision and use of sand from dynamic environments which are renewed within a few generations (100 y)
1.9	Raw materials: Renewable soil Materials: clay	Building material	Provision and use of clay from dynamic environments which are renewed within a few generations (100 y)
1.10	Raw materials: platform	Building platform for housing, roads, infrastructure,…	Presence and use of stable and safe environments for building of infrastructure: housing, roads, etc.
1.11	Raw materials: plants	Building material, fibre, fuel	Presence and use of forests, energy and fibre crops
1.12	Raw materials: animals	Building material, fibre, fuel	Presence and use of animals for fur, leather, gelatine, etc.
1.13	Genetic resources	Various improved provisioning services	Presence and use of typical varieties and cultivars of species, adapted to a specific environment
1.14	Medicinal resources	Human health	Presence and use of plants/organisms used in herbal medicine, medicinal tea, etc.
1.15	Ornamental resources	Well-being	Presence and use of organisms for decorative purposes
Regulating services			
2.1	Air quality regulation: removing harmful particles	Human health	Adsorption of fine dust and pollutants on leaf surfaces of forests, etc.
2.2	Air quality regulation: Air-water exchange	Human health	Influence of evaporation and evapotranspiration, condensation on air quality

2.3	Air quality regulation: biogeochemical reactions due to activity of organisms	Human health	Respiration and photosynthesis, exudation of chemicals by degradation reactions, etc.
2.4	Climate regulation: carbon sequestration and burial	Human health, avoided costs caused by extreme events or disturbance, ensured provisioning services	Buffering carbon stock in living vegetation, burial of organic matter in soils
2.5	Climate regulation: water thermodynamic regulation	Human health, avoided costs caused by extreme events or disturbance, ensured provisioning services	Cooling effect of vegetation, uptake of solar energy for photosynthesis and evapotranspiration,
2.6	Climate regulation: heat exchange regulation	Human health, avoided costs caused by extreme events or disturbance, ensured provisioning services	Effect of direct reflection, storage, transport, radiation of solar heat by various soil and water bodies
2.7	Regulation extreme events or disturbance: flood water storage	Human health, avoided costs caused by extreme events or disturbance, ensured provisioning services	Storage of storm or extreme spring tides in natural or flood control habitats
2.8	Regulation extreme events or disturbance: peak discharge buffering	Human health, avoided costs caused by extreme events or disturbance, ensured provisioning services	Storage of peak discharge floods in natural or flood control habitats
2.9	Regulation extreme events or disturbance: water current reduction	Human health, avoided costs caused by extreme events or disturbance, ensured provisioning services	Reduction of water current by physical features or vegetation
2.10	Regulation extreme events or disturbance: wave reduction	Human health, avoided costs caused by extreme events or disturbance, ensured provisioning services	Reduction of wave height by physical features or vegetation
2.11	Regulation extreme events or disturbance: sound buffering	Human health	Reduction of noise disturbance by presence of natural buffers
2.12	Water quantity regulation: drainage of river water	Ensured platform, food, water other provisioning services	Drainage of the catchment by the river
2.13	Water quantity regulation: prevention of saline intrusion	Various ensured provisioning services	Countering of saline tidal wave by freshwater discharge
2.14	Water quantity regulation: dissipation of tidal and river energy	Various ensured provisioning services, avoided maintenance costs	Buffering of average flood and discharge variations in the river bed
2.15	Water quantity regulation: landscape maintenance	Various ensured services	Formation and maintenance of typical landscapes and hydrology

2.16	Water quantity regulation: transportation	Shipping	Discharge and tidal input for shipping, including water use for canals and docks
2.17	Water quality regulation: transport of pollutants and excess nutrients	Improved water quality, various ensured services	Transport of pollutants from source, dilution
2.18	Water quality regulation: reduction of excess loads coming from the catchment	Improved water quality, various ensured services	Binding of N, P in sediments and pelagic food web
2.19	Erosion and sedimentation regulation by water bodies	Avoided damage or maintenance costs, various ensured provisioning services	Sediment trapping and gully erosion by variable water currents and topography
2.20	Erosion and sedimentation regulation by biological mediation	Avoided damage or maintenance costs, various ensured provisioning services	Sediment trapping and erosion prevention by vegetation, effects of bioturbation
2.21	Biological regulation of soil processes and soil formation	Various ensured provisioning services	Soil microbial activities important for agriculture or water quality regulation processes, bioturbation
2.22	Prevention of establishment of harmful invasive species	Various ensured provisioning services	Presence of resilient natural populations able to withstand invasion
2.23	Reduced spread of diseases	Various ensured provisioning services, human health	Presence of resilient and equilibrated natural populations avoiding excessive population growth of disease-carrying vector species, importance for human health or agriculture
2.24	Pollination	Various ensured provisioning services	Presence of pollinators and importance for agricultural production
2.25	Pest control	Various ensured provisioning services	Presence of predators for problematic pest species impacting agricultural production
Habitat services			
3.1	"Biodiversity"	Insurance of all services	Total amount of abiotic and biotic diversity at all levels (gene-landscape), regardless of rarity or vulnerability
Cultural and amenity services			
4.1	Aesthetic information	Well-being	Appreciation of beauty of organisms, landscapes, etc.
4.2	Opportunities for recreation and tourism	Well-being	Opportunities and exploitation for recreation and tourism
4.3	Inspiration for culture, art and design	Well-being	Appreciation of organisms, landscapes, etc. as inspiration for culture, art and design
4.4	Spiritual experience	Well-being	Appreciation of organisms, landscapes, etc. on a spiritual level
4.5	Information for cognitive development	Well-being	Use of organisms, landscapes for (self-) educational purposes

However, during the TIDE project, an important update of ecosystem service classification was provided by CICES (Towards a Common International Classification of Ecosystem Services), a working group of the European Environmental Agency. The TIDE list has therefore been compared with the latest CICES list of services for highly populated countries, by identifying the TIDE services in the CICES classification. This comparison shows a high degree of accordance between the two lists, although some services are formulated in a slightly different way. One major difference however is apparent: Ecosystem services that were selected in TIDE but are not present in the CICES list are the provisioning services concerning abiotic solid materials, such as building materials, sand and clay. As estuaries constantly build up stocks of these materials which are eroded from the catchment or transported upstream by tidal currents from the sea, these materials can be considered as eternally renewable, although the rate of exploitation is limited by the transport processes. Hence, it is advised that they should be included in the CICES list if applied to estuaries. This point of difference indicates the peculiar estuarine benefits concerning mineral richness.

A survey, utilising the expertise of 28 estuarine users (e.g. managers and scientists) and stakeholders from the regional working groups of all four estuaries, was used to determine the demand of ecosystem services and trends in these services.

Looking at the ranking of the demand results, of the top 10 services with the highest demand, seven were regulating for hydro-geomorphologic aspects, one was ´biodiversity´ and two were directly linked with navigational or industrial use of water (Figure 4.1). Except for water, there was a relatively lower demand for provisioning services (e.g. food and 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 considered more important, whereas provisioning services achieved a lower ranking. The relatively low ranking of food provisioning may be an artefact of the questionaire categories or it reflects market economics as transport allows import/export of goods which probably are more interesting and important for people. With increasing urbanisation and industrialisation, regulating services have become more important probably because of increased flooding and pollution.

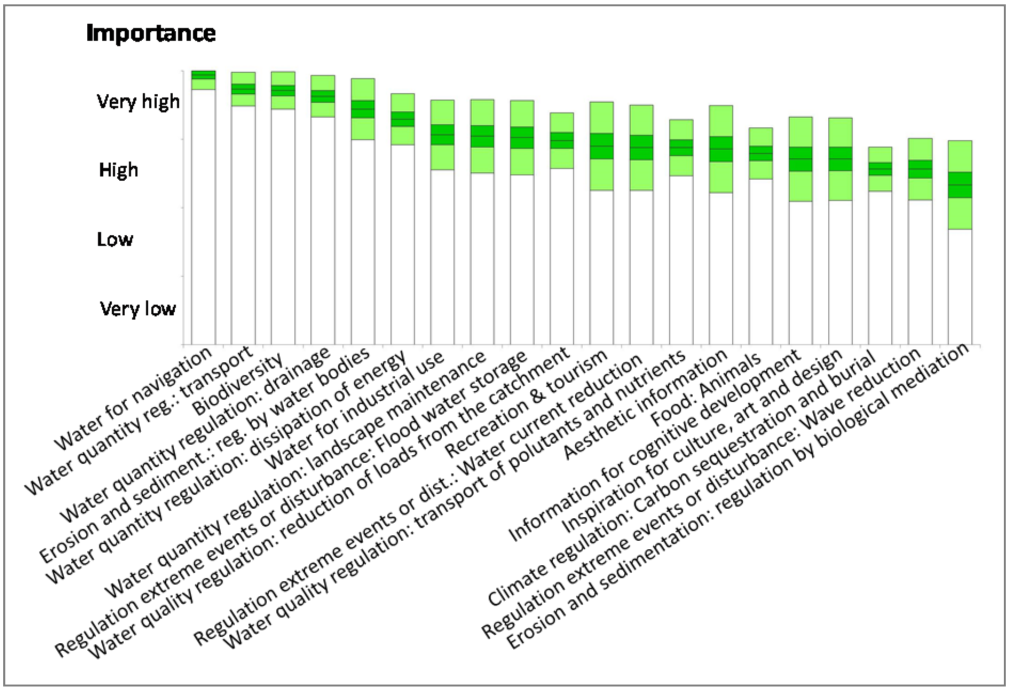

Figure 4.1. Demand of ecosystem services (mean of the four case estuaries), ranked according to experienced importance. Dark green bars represent standard error over all estuaries and zones, light green bars standard deviation.

ES demand in the four estuaries is very similar, possibly due to the composition of the regional expert groups. However, a remarkable difference between estuaries was seen with the lower demand for sedimentation-erosion regulation by biological mediation, extreme water current reduction and landscape maintenance services in the Humber Estuary, these differences probably due to the naturally very high turbidity and fluid mud conditions present in the Humber, combined with much lower maintenance dredging requirements compared to the other case study estuaries.

4.3 Service supply

The supply of ecosystem services has been determined in two ways. Firstly, in addition to the enquiry questionnaire concerning the ES demand, an additional enquiry was performed on the supply of the services. Provisioning and regulating services provide more quantified estimates than cultural services, whereas results derived from functioning are more readily quantifiable, and hence dominate the enquiry results. The enquiry questionnaire also had the advantage that the supply of cultural and amenity services could be estimated, services for which the functional approach did not prove satisfactory.

The service supplies, as derived from the underlying estuarine functioning, have been ranked for all estuaries (Table 4.2). These results show that each estuary is very specific in the delivery importance of various ecosystem services. A more detailed synthesis of results is provided in the Section ‘The Ecosystem Services in Detail’.

Table 4.2. 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 spatial or other factors determining the occurrence of the service.

CATEGORY	SERVICES	BENEFITS	Short description	Elbe	Weser	Humber	Schelde	Location or factor of prime importance
PROVISIONING SERVICES	Food: Animals	Nutrition	presence and use of edible animals, including livestock growth and fodder production	3	1	4	2	Saline zone
	Water for industrial use	Improved industrial production	provision and use of water for e.g. cooling water, rinsing water, water for chemical reactions	Depends on application				
	Water for navigation	Shipping	presence and use of water for shipping purposes	1	2	4	2	Subtidal deep, thalweg depth
REGULATING SERVICES	Climate regulation: Carbon sequestration and burial	Human health, avoided costs caused by extreme events or disturbance, ensured provisioning services	buffering carbon stock in living vegetation, burial of organic matter in soils	2	1	4	3	Tidal marshes
	Regulation extreme events or disturbance: Flood water storage	Human health, avoided costs caused by extreme events or disturbance, ensured provisioning	storage of storm or extreme spring tides in natural or flood control habitats	Depends on available space for flooding areas				
	Regulation extreme events or disturbance: Water current reduction	Human health, avoided costs caused by extreme events or disturbance, ensured provisioning services	reduction of water current by physical features or vegetation	2	4	1	3	Location of maximal hydraulic friction
	Regulation extreme events or disturbance: Wave reduction	Human health, avoided costs caused by extreme events or disturbance, ensured provisioning services	reduction of wave height by physical features or vegetation	Depends on marsh spatial distribution				Tidal marshes
	Water quantity regulation: drainage of river water	Ensured platform, food, water	drainage of the catchment by the river	2	1	3	4	Tidal range at upstream border, residence time
	Water quantity regulation: dissipation of tidal and river energy	Various ensured provisioning services, avoided maintenance costs	buffering of average flood and discharge variations in the river bed	4	3	1	2	Downstream location of maximal tidal amplitude
	Water quantity regulation: landscape maintenance	Various ensured benefits	formation and maintenance of typical landscapes and hydrology	Depends on local factors				
	Water quantity regulation: transportation	Shipping	discharge and tidal input for shipping, including water use for canals and docks	1	2	4	2	Subtidal deep, thalweg depth
	Water quality regulation: transport of pollutants and excess nutrients	Improved water quality, various ensured services	transport of pollutants from source, dilution	2	1	3	4	Residence time, tidal asymmetry
	Water quality regulation: reduction of excess loads coming from the catchment	Improved water quality, various ensured services	binding of N, P in sediments and pelagic food web	3	?	1	2	
	Erosion and sedimentation regulation by water bodies	Avoided damage or maintenance costs, various ensured provisioning services	sediment trapping and gully erosion by variable water currents and topography	?	?	?	?	
	Erosion and sedimentation regulation by biological mediation	Avoided damage or maintenance costs, various ensured provisioning services	sediment trapping and erosion prevention by vegetation, effects of bioturbation	Depends on marsh spatial distribution				Marshes, meanders
HABITAT SERVICES	"Biodiversity"	Insurance of all services	total amount of abiotic and biotic diversity at all levels (gene-landscape), regardless of rarity or vulnerability	?	?	?	?	All habitats
CULTURAL & AMENITY SERVICES	Aesthetic information	Wellbeing	appreciation of beauty of organisms, landscapes,...	Depends on individual preferences				
	Opportunities for recreation & tourism	Wellbeing	opportunities and exploitation for recreation & tourism	Depends on market mechanisms				
	Inspiration for culture, art and design	Wellbeing	appreciation of organisms, landscapes,... as inspiration for culture, art and design	Depends on individual preferences				
	Information for cognitive development	Wellbeing	use of organisms, landscapes for (self-) educational purposes	Depends on individual preferences				

4.4 Important habitats and zones for the delivery of ecosystem services

Ecosystem services are supplied by ecosystem functions. These functions are the collection of structures (e.g. species, water bodies and soil entities) and processes (e.g. primary production and sedimentation), and many are linked to the supply of the service. Some services also consist of several functionally separated 'intermediate' services, such as 'water purification' which consists of 'denitrification', 'immobilisation of pollutants' etc.

A common unit however is 'the habitat', which is a well described part of the ecosystem and which is distinguished by its physical and/or ecological properties.

The role of different habitats was scoped in TIDE as the delivery of ecosystem services is spatially variable – among habitats and between different systems, and in time showing large seasonal variability.

The service supply was ranked according to the delivery by the main habitat types (Table 4.3). These results are applicable for all TIDE estuaries. 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 a lower amount of direct provisioning service supplies, such as marshes, mudflats, and shallow water habitats. However, steep intertidal habitats (results not shown), where ecological functioning is hampered, provide the least ecosystem services.

A more detailed synthesis of results is provided in the section 4.5 'Some ecosystem services in detail'.

Table 4.3. Ecosystem service supply scores for different habitat types (in both the freshwater and saline zone). Scores, ascending from 0 to 5, provide rankings of the importance of habitats for an individual service. The scores do not allow a comparison between services.

Ecosystem service	Habitat							
	Freshwater				Saline			
	Tidal marsh	Mudflat	Shallow subtidal	Deep subtidal	Tidal marsh	Mudflat	Shallow subtidal	Deep subtidal
Erosion and sedimentation regulation by biological mediation	5	3	0	0	4	3	0	0
Climate regulation: Carbon sequestration and burial	5	3	1	1	5	3	1	1
Regulation extreme events or disturbance: Wave reduction	5	4	2	0	5	4	2	0
Information for cognitive development	3	3	3	3	3	3	3	3
Inspiration for culture, art and design	4	4	4	4	4	4	4	4
Food: Animals	0	1	2	2	2	3	5	5
Aesthetic information	4	3	3	3	4	4	3	3
Regulation extreme events or disturbance: Water current reduction	2	3	1	0	3	4	2	0
Water quality regulation: transport of pollutants and excess nutrients	3	2	2	4	3	2	3	3
Opportunities for recreation & tourism	3	2	3	3	3	2	4	4
Water quality regulation: reduction of excess loads coming from the catchment	3	4	5	5	1	2	2	2
Regulation extreme events or disturbance: Flood water storage	4	2	1	0	4	2	1	0
Water quantity regulation: landscape maintenance	3	3	2	1	3	2	2	1
Water for industrial use	0	0	5	5	0	0	4	4
Water quantity regulation: dissipation of tidal and river energy	1	4	3	0	1	4	4	0
Erosion and sedimentation regulation by water bodies	3	3	3	1	3	3	3	3
Water quantity regulation: drainage of river water	0	1	3	5	0	0	1	3
"Biodiversity"	3	2	1	1	3	2	1	1
Water quantity regulation: transportation	0	0	1	4	0	0	1	5
Water for navigation	0	0	1	4	0	0	1	5

4.5 Some ecosystem services in detail

Comparing the demand and supply of the various ecosystem services provides an indication on their value. For most services described here, also a description in quantitative terms is given (summary in Table 4.4). This is based on the best available knowledge. Quantitative data could be used to calculate the magnitude of each service supplied by the estuary. This could also be used in economic analysis as basic for monetary valuation (see section 4.6 ‚Ecosystem Service valuation and application approach‘). Although most of the data used in this analysis have been gathered from the Scheldt estuary, given the large amount of monitoring and research that has been undertaken there, the presented data are considered to be applicable to similar estuaries within north-western Europe. However, it is advised that use should be made of local estuary-specific data where possible for more accurate results. Indeed, local characteristics such as salinity, tidal range, and suspended matter concentration influence the supply of ecosystem services.

4.5.1 Biodiversity

In contrast to services related to water and air quality regulation, the demand for biodiversity was ranked very highly, although estuaries host few endemic species. Quantification of this service is difficult and it involves a risk of double-counting for the same benefit since biodiversity is typically considered as an underlying service, supporting many other services (e.g. fish provisioning and water purification etc.). However, many units and indices are used to quantify biodiversity, including number of species, number of targeted species (e.g. red list species from the Water Framework Directive), and relative species abundance, and this for example could be used to verify the current situation with legislative targets.

4.5.2 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.

The filter function of estuaries is considered as one of the most valuable ecosystem services and can be regarded as a natural complementary waste water treatment service (Costanza 1997; Dähnke et al. 2008).

Important parameters for water quality are the concentrations of nitrogen, phosphorous and oxygen. Nitrogen and phosphorous removal from the water reduces the risk for eutrophication (see also estuarine filter function in Chapter 3.2).

4.5.2.1 Nitrogen (N)

In an intertidal area, nitrogen is mainly removed by two processes: N-burial and N removal by denitrification. The role of the pelagic in removing nitrogen strongly depends on the aeration content of the water. As the TIDE case estuaries nowadays feature a water quality that has improved considerably, nitrogen is removed less than in the past.

<u>Quantification (Table 4.4):</u>

- N burial: Values presented here are based on data from the Scheldt estuary: between 150 and 250 kg N/ha/y (Middelburg et al. 1995b; Broekx et al. 2011). For a more detailed impact assessment for a specific case study, the following calculation could be used: sedimentation rate (in m/y) × surface (in m²) × bulk density (in kg/m³) × organic N content in the sediment (in mg N/g dry weight × % dry weight). Data bulk density on average is 1.6 g/cm³ (Middelburg et al. 1995b; Parkes 2003; Shepherd et al. 2007), with the organic N content estimated for the Scheldt estuary (location at Doel) at 0.18 wt% (Middelburg et al. 1995b).
- N removal by denitrification: Values presented here are based on data from the Scheldt estuary: estimation of between 11 and 347 kg N/ha/y (Van Damme et al.

2010), with higher rates in unvegetated sediment (mudflats) compared to marshes (Gribsholt et al. 2005; Van Damme et al. 2010) and with higher rates in freshwater zones compared to saline zones (Cox et al. 2005; Broekx et al. 2011). Besides N-removal, some N-emissions (NH_4 and N_2O) are also generated during the N cycling in intertidal areas. The values are small compared to N-burial and N removal by denitrification.

- N_2O emission: Values presented here are based on data from the Scheldt estuary: between 0 and 1.4 kg N/ha/y (Middelburg et al. 1995b). Note: N_2O emission is highest in the freshwater zone and almost zero in the polyhaline zone, in the brackish zone about 0.9 kg N/ha/y (Middelburg et al. 1995a). N_2O-emission is also considered as a greenhouse gas (GHG) and hence is a negative for the climate regulation service.
- NH_4 emission: Values presented here are based on data from the Scheldt estuary: on average 60 kg N/ha/y (Middelburg et al. 1995b).

4.5.2.2 Phosphorous (P)

In intertidal areas, phosphorous is removed from the water by burial.

Quantification (Table 4.4)

- P-burial: Values presented here are based on a literature study: estimation of between 1 and 167 kg(P)/ha/y. For a more detailed impact assessment for a specific case study, the following calculation could be used: sedimentation rate (in m/y) × surface (in m²) × bulk density (in kg/m³) × organic P content in the sediment (in mg P/g dry weight × % dry weight). Data bulk density on average 1.6 g/cm³ (Middelburg et al. 1995b; Parkes 2003; Shepherd et al. 2007).

4.5.2.3 Silica (Si)

The supply of dissolved silica by tidal marshes is an underestimated service (see chapter 3.2.2.) and was only documented for the Scheldt. Dissolved silica is a pivotal component ameliorating the negative effects of eutrophication (harmful algal blooms) and assisting positive processes for animal food production. It is released mainly by marshes during the summer, when the uptake by primary producers in the water column is highest, whilst it is released at a maximal rate by the marshes when the pelagic need is highest.

4.5.2.4 Aeration

Tidal marshes and anabranches (e.g. near the oxygen depletion zone of the Elbe) are important for the provision of sufficient oxygen to restore fish migration routes. Managed realignment projects could improve the oxygen concentration of the estuary. However, this is only a benefit if the oxygen concentration in the river is *too* low. Hence, this benefit depends on the oxygen profile of the river in the area of the managed realignment project. With improving oxygen concentrations, this benefit reduces.

Quantification (Table 4.4)

- Aeration: Values for the aeration function for brackish intertidal areas are based on data from the Scheldt estuary: 8.6 – 12 mol O_2/ha/y (De Nocker et al. 2004; Ruijgrok 2004; Broekx et al. 2011).

4.5.2.5 Climate regulation: carbon

Estuarine ecosystems are biologically extremely productive (Bianchi 2007), with net primary production rates among the highest in the world. Consequently, these systems play an important global role as carbon sinks in terms of carbon burial (Chmura et al. 2003). Most of the studies on carbon sequestration only account for carbon burial, and not for greenhouse gas emissions such as carbon dioxide, methane and nitrous oxide emissions. However, these emissions may decrease the potential benefits of CO_2-sequestration through gross organic burial by at least 50%. Carbon sequestration consists of carbon burial and a correction for greenhouse gas emissions (CO_2, CH_4 and N_2O). The N_2O-flux is already accounted for in the net N-flux.

Quantification (Table 4.4):

- C burial: Values presented here are based on data from the Scheldt estuary: range of between 5.5 to 8.1 ton CO_2-eq./ha/y. For more a detailed impact assessment for a specific case study, the following calculation could be used: sedimentation rate (in m/y) × surface (in m²) × bulk density (in kg/m³) × organic C content in the sediment (in mg C/g dry weight × % dry weight). Data bulk density on average 1.6 g/cm³ (Middelburg et al. 1995b; Parkes 2003; Shepherd et al. 2007). The organic C content is for the Scheldt estuary estimated at 2.2 to 3.5 wt% (Billen et al. 1985; Middelburg et al. 1995b).
- CO_2 emission: Values presented here are based on data from the Scheldt estuary: estimation of between 7.3 and 11 ton CO_2-eq./ha/y (Middelburg et al. 1995b).
- CH_4 emission: Values presented here are based on data from the Scheldt estuary: estimation of between 0.5 – 1.8 ton CO_2-eq./ha/y (Middelburg et al. 1995b). This corresponds to the order of magnitude identified from the literature study (Andrews et al. 2006). The air regulating service related to global warming may be less important as the effect of enhanced methane emissions – a more severe greenhouse gas than CO_2 – counters the carbon burial through sedimentation.

4.5.3 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 TIDE project working group process identified that the demand of different water or sediment quantity regulating services was very high. This can be explained by the importance of the estuarine hydro-geomorphology, which determines the potential for navigation, the flood risk and the habitat quality. These services are important for safety, navigation and ecology at the same time.

4.5.3.1 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 exposure, and habitat deterioration. Therefore it is important for managers to understand where opportunities to restore these dynamics are, for example by the dissipation of energy and the reduction of water levels and velocity. As shown in TIDE using the Dalrymple approach (see Section 3.2.1 for the Dalrymple concept), river energy was most dissipated in the Elbe, and tidal energy dissipation was greatest in the Humber and the Scheldt due to specific morphological characteristics (as shown in Chapter 3.1). This was a new analysis approach as the literature review had shown that no general quantitative data were available for this metric.

<u>Quantification flood prevention by intertidal areas:</u>

- Europe has suffered over 100 major damaging floods in recent years, and since 1998 floods have resulted in about 700 fatalities, the displacement of about half a million people and at least € 25 billion in insured economic losses. In addition, floods can also have negative impacts on human health. For example, substantial health implications can occur when floodwaters carry pollutants, or are mixed with contaminated water from drains and agricultural land. It is also widely acknowledged that the flooding risk in Europe is increasing as a result of climate change, i.e. due to higher intensity of rainfall as well as rising sea levels (IPCC 2001).
- Different hydrological models are developed to estimate the flood risk and create flood maps indicating potential flood-prone areas (e.g. FHRC 2010 or the LATIS-method). In the first example, the FHRC 2010 (which is a handbook of assessment techniques for a stepwise approach to assess the benefits of flood prevention) identifies the benefits of flood and Coastal Risk management whilst the second

example (the LATIS-method (Deckers et al. 2010)) can be used to quantify and value flood risk avoidance.

- Illustration Scheldt estuary: The tides from the Scheldt river create significant flood risks in both the Flemish region in Belgium and the Netherlands. Due to sea level rise and economic development, flood risk will increase during this century. In the context of the flood risk management plan from the Flemish government (Sigmaplan), an optimal scenario of flood protection measures was developed. This scenario combines 24 km of dyke heightening with the construction of 1325 ha of additional floodplains and generates a potential reduction of flood risk of approx. 78% (Broekx et al. 2011). The safety benefits of this plan were estimated to total € 737 million or approximately € 30 million a year.

4.5.3.2 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 for a given ship size.

<u>Quantification (Table 4.4)</u>

- Transportation: The indicator to quantify navigation is typically the amount of ton-km per year transported in the estuary.
- Water for navigation: Navigation is another service that is dependent on the flow regulation in an estuary. In shallow estuary channels and above natural sills, navigation might only be possible at high water. Similarly, ships with a large draught can only access certain channels during high water, when the water depth is sufficient. High water levels may in turn limit the possibilities for navigation under bridges. The magnitude and direction of flow in estuarine channels also influence the possibilities and costs for shipping through an estuary. Flow regulation can be used to improve possibilities for safe navigation in estuaries, and an example of this is the provision of longer time frames when vessels may safely pass obstacles such as sills or bridges, as a result of the dredging of shipping lanes or alteration to the estuarine hydrodynamics.

4.5.3.3 Water quantity regulation: drainage of river water

High tides will restrict catchment drainage and increase upstream water retention. The Dalrymple approach showed the comparison between the kinetic energy of the river flows and the potential energy of the tidal level. The ratio of these factors determines the drainage characteristics. For example, the results indicated that the Weser was the only system where river dominance could extend far downstream, almost to the estuary mouth (e.g. as far as

Bremerhaven) (see Section 3.1). The Weser therefore offers the best drainage service of the four TIDE estuaries. No general quantitative data are available in published literature, although this is an underlying service supporting many other services.

4.5.4 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. For instance, the loss of tidal marshes in front of a dyke due to erosion may exacerbate the erosion and increase maintenance costs.

<u>Quantification (Table 4.4):</u>

- Sedimentation: The sedimentation rate in intertidal areas depends on many factors such as elevation of the area relative to the tidal range, hydrodynamics in the area, flood duration and frequency and suspended particulate matter (SPM). The range presented here is based on data from the Scheldt estuary, with a sedimentation rate of between 0.4 and 10 cm/y for mudflat habitat and between 0.4 and 1.8 cm/y for marshes. This ecosystem service is limited in time in newly created intertidal areas. After a certain time, sedimentation and erosion will be in equilibrium.
- Erosion (creek formation): No general quantitative data are available. Erosion by creek formation will take place in intertidal areas but the intensity depends on many factors such as hydrodynamics, flood intensity, and water flow. The formation of an extensive creek system is important for good drainage of the area, but counteracts sedimentation in the area until an equilibrium of sedimentation and erosion is reached.
- For management purposes, the main interest is in the net sedimentation and/or erosion over a longer period of time (years, decades). It is common practice to express the net erosion or deposition of sediment as volumes of solid grains (m^3). Similarly, sediment transport is defined in transport rates (m^3/s or m^3/yr). Sedimentation and erosion can also be expressed in bed level changes (m).
- Hydrodynamic and morphological models can be used to obtain a better insight in the erosion and sedimentation processes in estuarine environments. Given the large spatial variability and complexity of these processes, the use of such models for the quantification of sediment accumulation and erosion is highly recommended. Examples of hydrodynamic models that can resolve water flow and sediment

transport equations are DELFT3D, TELEMAC-MASCARET and MIKE21. All these models are validated for estuarine environments. Another option for determining sediment accumulation on marshlands is to use the zero-dimensional physically based MARSED model, which computes vertical accretion of particular marshes based on the environmental conditions (Temmerman et al. 2004).

4.5.5 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 within the estuarine environment, with the recognition of estuaries as essential for the quality of (human) life and wealth creation.

<u>Quantification (Table 4.4):</u>

- Recreation: Estimate of annual visits to an area: 25 visits per day per km walking trail (with dyke length as proxy) (Broekx et al. 2011). Relevant recreation and tourism related activities include, for example, hiking, biking, fishing, swimming, camping, horse riding, hunting, bird- and nature-watching. Alternatively, nature related tourism can also include visits to sites of cultural heritage. The number of visits depends on several factors such as population density, characteristics of the area (e.g. accessibility, uniqueness etc.), distance to the area (how far away, how less likely are people going to undertake recreational activities at the site), the availability of substitutes (other natural areas that are closer to the population).
- Cultural heritage, identity and amenity values: No general quantitative data are available. The benefit could be expressed as the welfare gains for living close to and having a view from the home onto the natural area. Natural environments have been responsible for shaping cultural identity and values throughout human history. Ecosystems and landscapes also inspire cultural and artistic expression. People all over the world derive aesthetic pleasure from natural environments. However, the perception of aesthetic qualities is very subjective and does not necessarily fully match with the ecological quality and integrity of an area (see also Section 1.3.2).
- Cognitive development (education): No general quantitative data are available. Ecosystems and landscapes are an invaluable resource for science, scientific research and education. The total amount of / trends in the number of visits to the sites, specifically related to educational or cultural activities could be used as a metric.

Table 4.4. Quantitative data for ES assessment in estuaries

Sub-category	Detail	Unit	Habitat			References
			Flat habitat	Marsh	Water body	
ES: Biodiversity						
			[1]	[1]	[1]	
ES: Water and Air Quality Regulation Services						
Nitrogen (N)	Burial	kg(N)/ha/y	150 - 320[2]	150 - 320[2]		(Billen et al. 1985; Middelburg et al. 1995b; Dettmann 2001; Ruijgrok et al. 2006; Liekens et al. 2009; Böhnke-Henrichs and de Groot 2010; Broekx et al. 2011)
	Denitrification	kg(N)/ha/y	70 - 107[3]	0 - 70[3]		(Middelburg et al. 1995a,b; Cox et al. 2005; Van Damme et al. 2010; Broekx et al. 2011)
	N_2O-emission	kg(N)/ha/y	0.53 - 1.3[4]	0.53 - 1.3[4]		(Middelburg et al. 1995a,b)
	NH_4-emission	kg(N)/ha/y	60[5]	60[5]		(Middelburg et al. 1995a,b)
Phosphorous (P)	Burial	kg(P)/ha/y	1 - 167[6]	1 - 167[6]		(Billen et al. 1991; Nixon et al. 1996; Dehnhardt and Meyerhoff 2002; De Nocker et al. 2004; Ruijgrok 2004; Andrews et al. 2006; Ruijgrok et al. 2006; Liekens et al. 2009; Böhnke-Henrichs and de Groot 2010; Sousa et al. 2010; Broekx et al. 2011; Grossmann 2012)
Aeration		mol(O_2)/ha/y	8.6 - 12[7]	8.6 - 12[7]		(De Nocker et al. 2004; Ruijgrok 2004; Broekx et al. 2011)
Carbon (C)	Burial	ton(CO_2-eq.)/ha/y	5.5 - 8.1[8]	5.5 - 8.1[8]		(Middelburg et al. 1995b; Ruijgrok et al. 2006; Soresma et al. 2007; Böhnke-Henrichs and de Groot 2010)
	CO2-emission	ton(CO_2-eq.)/ha/y	7.3 - 11[9]	7.3 - 11[9]		(Middelburg et al. 1995b)
	CH4-emission	ton(CO_2-eq.)/ha/y	0.5 - 1.8[10]	0.5 - 1.8[10]		(Middelburg et al. 1995b)
ES: Water quantity regulation						
Dissipation of tidal and river energy	Flood prevention		[11]	[11]	[11]	
Transportation		ton/km	0	0	[12]	
Drainage of river water			[13]	[13]	[13]	
ES: Erosion and sedimentation: regulation by water bodies						
Sedimentation		m³/ha/y	40 - 1000[14]	40 - 180[14]		(Middelburg et al. 1995b; Temmerman et al. 2006)
Erosion	Creek formation	m³/ha/y	[15]	[15]		
ES: Cultural services						
Recreation and tourism	Dyke recreation	visit/day/km	25[16]	25[16]	25[16]	(Broekx et al. 2011)
Cultural heritage, identity and amenity values			[17]	[17]	[17]	

Cognitive development (education)			(18)	(18)	(18)	
Cultural heritage, identity and amenity values			(17)	(17)	(17)	
ES: Food provisioning						
Fish, shellfish		kg	(19)	(19)	(19)	
Livestock	e.g. cows	kg/ha	0[20]	200[20]	0[20]	(De Nocker et al. 2004; Veemarkt 2011)
Saline vegetables	e.g. Sea Aster (*Aster tripolium*)	ton/ha/y	0[21]	4 - 35[21]	0[21]	(Goosen 1999; De Nocker et al. 2004; van der Hiele et al. 2008; Böhnke-Henrichs and de Groot 2010)

Notes:

[**Biodiversity**] No general quantitative data available. Impact of specific case studies: check contribution to Conservation Objectives.
[**N-burial**] Data presented is based on data from the Scheldt estuary. For more detailed impact assessment for a specific case study, following calculation could be used: sedimentation rate (in m/y) × surface (in m^2) × bulk density (in kg/m^3) × organic N content in the sediment (in mg N/g dry weight × % dry weight). Data bulk density on average 1.6 g/cm^3 (Goosen 1999; De Nocker et al. 2004; van der Hiele et al. 2008; Böhnke-Henrichs and de Groot 2010). Data organic N content in Doel, Scheldt estuary: 0.18 wt% (Middelburg et al. 1995b).
[**Denitrification**] Data presented is based on data from the Scheldt estuary. Note: higher rates in unvegetated sediment (mudflats) compared to marshes (Gribsholt et al. 2005; Van Damme et al. 2010) and higher rates in freshwater zones compared to saline zones (Cox et al. 2005; Broekx et al. 2011).
[**N_2O-flux**] Data presented is based on data from the Scheldt estuary. Note: N2O emission is highest in freshwater zone and almost zero in polyhaline zone (saline), in the brackish zone about 0.9 kg N/ha/y (Middelburg et al. 1995a).
[**NH_4-flux**] Data presented is based on data from the Scheldt estuary.
[**P-burial**] Data presented is based on a literature study. For more detailed impact assessment for a specific case study, following calculation could be used: sedimentation rate (in m/y) × surface (in m^2) × bulk density (in kg/m^3) × organic P content in the sediment (in mg P/g dry weight × % dry weight). Data bulk density on average 1.6 g/cm^3 (Middelburg et al. 1995; Parkes 2003; Shepherd et al. 2007).
[**Aeration**] Data for aeration function for brackish intertidal areas, based on data from the Scheldt estuary.
[**C-burial**] Data presented is based on data from the Scheldt estuary. For more detailed impact assessment for a specific case study, following calculation could be used: sedimentation rate (in m/y) × surface (in m^2) × bulk density (in kg/m^3) × organic C content in the sediment (in mg C/g dry weight × % dry weight). Data bulk density on average 1.6 g/cm^3 (Middelburg et al. 1995; Parkes 2003; Shepherd et al. 2007). Data organic C content 2.2% - 3.5 wt% (Middelburg et al. 1995; Parkes 2003; Shepherd et al. 2007).
[**CO_2-emission**] Data presented is based on data from the Scheldt estuary.
[**CH_4-emission**] Data presented is based on data from the Scheldt estuary. Corresponds to order of magnitude from literature study (Andrews et al. 2006).
[**Tidal energy**] No general quantitative data available. Different hydrological models are developed to estimate the flood risk and create flood maps indicating potential floods (e.g. FHRC 2010 or LATIS-method).
[**Transport**] No general quantitative data available. The indicator to quantify navigation is typically the amount of tonne-km per year transported in the estuary.
[**Drainage**] No general quantitative data available. This is an underlying service supporting many other services, by not quantifying this service separately we avoid double-counting.
[**Sedimentation**] Sedimentation rate depends on many factors (location in the estuary, connection with the river, suspended matter concentration, etc.). The presented range is based on data from the Scheldt estuary, with a sedimentation rate between 0.4 and 10 cm/y for flat habitat and between 0.4 and 1.8 cm/y for marshes. This ecosystem service is limited in time in newly created intertidal areas. After a certain time, sedimentation and erosion will be in equilibrium.
[**Erosion**] No general quantitative data available. Erosion by creek formation will take place in intertidal areas but the intensity depends on many factors (hydrodynamics, water flow, etc). The formation of an extensive creek system is important for a good drainage of the area, but counteracts sedimentation in the area until an equilibrium of sedimentation and erosion in the area is reached.
[**Recreation and tourism**] Estimate of annual visits for area: 25 visits/day/km walking trail (with dyke length as proxy).
[**Cultural heritage, identity and amenity values**] No general quantitative data available. The benefit could be expressed as the welfare gains for living close to and having a view from the home on the natural area.
[**Cognitive development**] No general quantitative data available. Total amount of / trends in the number of visits to the sites, specifically related to educational or cultural activities.
[**Fish**] No general quantitative data available. Information or model that attributes the production of juveniles to the adult stock could be used.
[**Livestock**] Marshland could be used for grazing livestock such as cows or sheep. The potential capacity for livestock is estimated at 0.5 cows/ha or 3 sheep/ha (De Nocker et al. 2004). The slaughter weight of adult cows is around 400 kg (Veemarkt 2011), meaning on average 200 kg/ha for cows.
[**Saline vegetation**] Data presented is the potential production of saline vegetation in salt marshes. However, in most managed realignment projects the focus is on nature development and not on saline agriculture. Extensive production, e.g. for folkloric purposes, is feasible with rates of 1.5 kg/ha/y (data Land van Saeftinghe, Scheldt estuary) (De Nocker et al. 2004).

4.6 Ecosystem service valuation and application approach

There is clearly a need for the process of ecosystem service valuation to make the concept of ES operational to assist in communication of management measures as well as for its integration into decision support tools. A 10-step approach has been developed within the TIDE project for the evaluation of management measures in the estuarine environment (Figure 4.2 valuation approach), this approach having the potential to be employed as guidance on how to evaluate the impact of a particular management measure on the human society, and how to integrate the results into the decision making process. The approach consists of three main stages: preparation, valuation, and policy application and reporting. (Figure 4.2).

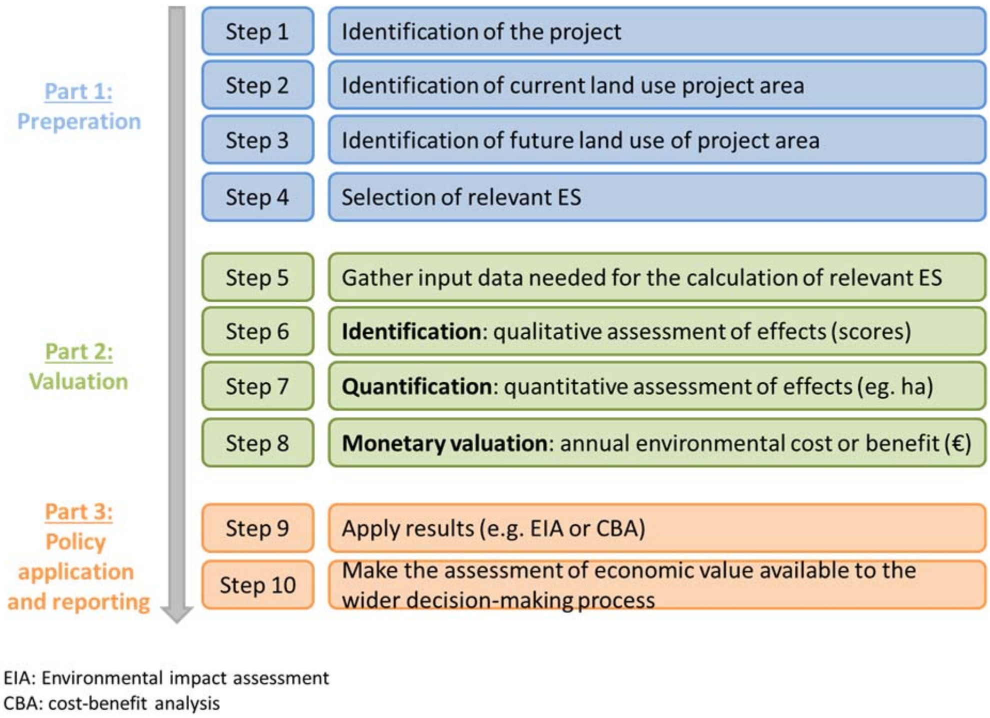

Figure 4.2. Stepwise approach for the evaluation of a management measures

4.6.1 Part 1: Preparation

In the preparation stage, the aim is to describe the management measures, mainly in terms of the uses that are present in the current situation (before the implementation of a measure), and in the future (after the implementation of a measure) (steps 2 and 3). Knowledge of the importance of the different estuarine habitats for the supply of ecosystem services (see Table 4.3) together with specific habitats involved in the provision of a measure, allow the ecosystem services which might be affected by a specific project to be identified. This includes both the services that are lost by converting the current ecosystem land use and the services which are gained by the new land uses after the implementation of the project.

4.6.2 Part 2: Valuation

4.6.2.1 Qualitative assessment

A simple qualitative screening approach was developed to assess the expected impact of the studied management measure on the supply of ES (Saathoff et al. 2013 sections 3.2.1.2 and 5.2.1.2). The expected impact of the studied management measure per ES is calculated by multiplying the creation or loss of the different habitats with the importance of those habitats for the supply of the ES (see Table 4.3). The result is a dimensionless score per ES which is transformed to a scale consisting of seven steps ranging from a very positive (+3) to a very negative impact (-3). The higher the change in the scores for a certain ES, the more important the impact will be. A subsequent more detailed investigation into the value of these services using more sophisticated ecological and economic models instead of using benefit transfer will subsequently be required. This approach is applied on the TIDE management measures and the results are described and discussed in chapter 6 (6.1.4). Furthermore, the beneficiaries of the management measure can be identified (Saathoff et al 2013, at www.tide-toolbox.eu). Two types of beneficiaries are identified reflecting different value categories (direct, indirect and future use), and spatial scales (local, regional and global scale). For each ES, an estimation was made of its contribution to the different beneficiaries, for instance the ES climate regulation is expected to have a large contribution for indirect and future use and at a global scale, whilst in another example, the food provisioning ES is expected to have a large contribution for direct use and at a local scale. To assess the expected impact of the studied measure on the beneficiaries, the expected impact per ES is multiplied with the contribution of each ES on the beneficiaries. The results for the TIDE management measures are described and discussed in Chapter 6 (6.1.4).

4.6.2.2 Monetary valuation

For most ecosystem services, the impact of the management measure could be calculated as surface per habitat type gained or lost (ha) × quantitative value of ES per habitat (e.g. kg nitrogen removal per hectare (see Table 4.4) × monetary value of ES (e.g. € per kg nitrogen removed) (see Table 4.4), summed over the involved habitats. For the calculation of cultural services, metrics such as the number of visits or number of houses in the surrounding area are needed. The presented biophysical and monetary data for estuarine ecosystem services (see Table 4.4 and 4.5), is provided on the basis of a literature review and could be used to calculate the impact of an estuarine management measure. Although most of the data used in this analysis have been gathered from the Scheldt estuary, given the large amount of monitoring and research that has been undertaken there, the presented data are considered to be applicable to similar estuaries within north-western Europe. However, it is advised that use should be made of local estuary-specific data where possible for more accurate results. Indeed, local characteristics such as salinity, tidal range, and suspended matter concentration influence the supply of ecosystem services.

Table 4.5. Monetary data for ES assessment in estuaries

Sub-category	Detail	Monetary value		Unit	Comment	References
		Lowest estimate	Highest estimate			
ES: Biodiversity						
					No general data presented.	
ES: Water and Air Quality Regulation Services						
N	Burial	53	53	€/kg(N)	Show price for N- and P-removal. This is the avoided costs for different measures that can be taken to improve the water quality by decreasing the N- or P-input.	(Broekx et al. 2006; Cools et al. 2011)
	Denitrification	53	53	€/kg(N)		
	N_2O-emission	53	53	€/kg(N)		
	NH_4-emission	53	53	€/kg(N)		
P	Burial	800	800	€/kg(P)		
Aeration		0.14	0.14	€/mol(O_2)	Based on costs of waste water treatment	(Broekx et al. 2011)
Carbon	Burial	32	32	€$_{2013}$/ton CO_2-eq	Avoided damage cost. Increases over time: 100 €/ton CO2-eq. in 2030 and 220 €/ton CO2-eq in 2050	(De Nocker et al. 2010)
	CO2-emission	32	32	€$_{2013}$/ton CO_2-eq		
	CH4-emission	32	32	€$_{2013}$/ton CO_2-eq		
ES: Water quantity regulation						
Dissipation of tidal and river energy	Flood prevention				No general data presented. Potential safety benefit depends to much on the local situation (presence of valuable properties, flood frequency and duration, etc).	
Transportation	Shipping			€/ton-km	Efficiency gains or losses if more less goods could be transported by ships. No general data presented.	
Drainage of river water					No general data presented.	
ES: Erosion and sedimentation: regulation by water bodies						
Sedimentation		5	10	€/m^3	Avoided cost for maintenance dredging. Net sedimentation in the intertidal area means less sediment flowing to the navigation channel and hence the need for maintenance dredging is reduced.	(Broekx et al. 2008)
Erosion	Creek formation	5	10	€/m^3		

ES: Cultural services						
Recreation and tourism	Dyke recreation	3	9	€/visit	willingness-to-pay of people to visit an estuary or estuarine nature	(Sen et al. 2012; Liekens et al. 2013)
Cultural heritage, identity and amenity values		-447	-447	€/house	Annual loss from visual intrusion, based on added value open space on housing prices between 6 and 12%	(Luttik 2000; Broekx et al. 2011)
Cognitive development (education)		6	6	€/visit	Fee per person for excursion in Land van Saeftinghe, Scheldt estuary	(Het zeeuwse landschap 2013)
ES: Food provisioning						
Fish, shellfish					No general data presented. The market price method could be used.	
Livestock	e.g. cows	2	5	€/kg	Market price. Added value "pré-salé" meet not included.	(Veemarkt 2011)
Saline vegetables	e.g. Sea Aster (*Aster tripolium*)	4	18	€/kg	Market value. Highest value (18 €/kg) is the sales price in Land van Saeftinghe with only extensive production for folkloric purposes	(Goosen 1999; De Nocker et al. 2004; van der Hiele et al. 2008; Böhnke-Henrichs and de Groot 2010)

4.6.3 Part 3: Policy application and reporting

Cost-benefit analysis (CBA) is an applied economics tool often used to guide economic agents in resource allocation or investment decisions. It is a technique that is used to sum up (in present value terms) and compare the future flows of benefits and costs of different alternatives to establish the worthiness of undertaking the stipulated activity or alternative, and inform the decision maker about economic efficiency (Balana et al. 2011). The inclusion of the identification of differing ecosystem service impacts is considered a particularly important assessment tool for multi-purpose development projects which have the potential to simultaneously impact on many different environmental and other components. By quantifying and valuing the different services these projects deliver, a better view can be obtained of their total impact instead of focusing on a single environmental issue.

Data presented here are yearly benefits (price level 2010). More information on how to move from yearly benefits to a cost-benefit analysis can be found in a wide range of manuals (Eijgenraam et al. 2000; Boardman 2006; Brent 2006; Mishan and Quah 2007; European Commission 2008; MOW 2013). Usually the Net Present Value (NPV) is calculated for a pre-defined time horizon (depending on the project lifespan) using a specific discounting procedure (Figure 4.3). A discount rate (e.g. 4%) is used to discount future cash flows to the present value. Different views exist on what an appropriate discount rate for nature restoration or nature loss should be. We advise a discount rate between 2.5% and 5% with

4% as the central value. Specific sources in the ecosystem services literature argue that it should be lower, e.g. (TEEB 2010). For the ecosystem service climate regulation the monetary value (€/ton CO_2-eq.) will increase over time, hence the value of the project (R_t in Figure 4.3) will change over time.

$$\mathrm{NPV}(i,N) = \sum_{t=0}^{N} \frac{R_t}{(1+i)^t}$$

Figure 4.3. Formula for calculation of the Net Present Value (NPV), with i the discount rate, N the total number of periods, t the time, and R_t the net value at time t.

The methodologies described here allow a rough estimation of the benefits of estuarine management measures to be undertaken. Quantifying the different effects in detail depends on site-specific circumstances and requires tailor-made research and calculations. It is therefore important to report the constraints of the valuation exercise. Attention should be paid to: (i) the uncertainty concerning estimates of environmental effects (e.g. timing, magnitude and significance); (ii) the assumptions embodied in estimates of the relevant number of households, visitors etc.; (iii) the assumptions entailed in the transfer of economic values or functions; (iv) the potential significance of any incomplete information or non-monetised impacts, and (v) the caveats associated with the resulting value estimates.

Illustration: Valuation of ES for the creation new intertidal area

- Part 1: In the case of the creation of intertidal areas, the estuary is affected in many direct and indirect ways. Examples are the creation of valuable habitat, and changing sedimentation and erosion processes. We assume a hypothetical project area of 100 hectares in the mesohaline zone consisting of 50 ha mudflat and 50 ha marshland. Prior to the development project, we assume that this area was agricultural land. In the case of this type of management measure, almost all considered services are relevant (see Table 4.2).
- Part 2:
    - o Qualitative assessment: This measure generates only positive or no effects on estuarine ecosystem services since estuarine habitats (marshes and intertidal flats habitats) are created and only adjacent land (with no estuarine ecosystem services) is lost. The habitat and supporting service has a very positive expected impact. Other services with a positive expected impact are the cultural services and some regulating services such as erosion and sedimentation regulation and water quantity regulation. No impact is expected regarding provisioning services, as an intertidal area does not supply the three considered provisioning estuarine services. Of course, the conversion

of agricultural land negatively affects food provisioning (agricultural crops) but this is not an estuarine service.

- o Quantitative and monetary valuation: Based on the gathered data (surface of involved habitat types, recreants, bio-physical data and monetary data per ES), the impact of the management measure on the different estuarine ES could be calculated both in bio-physical and in monetary terms. Overall, the creation of an intertidal area (50 ha mudflat and 50 ha marshland) generates a positive result of between 1 and 16 million € per year, meaning that the project is beneficial for human well-being. This is without a monetary value for flood provisioning. The range of the total result is however very large, reflecting the large range of data found in literature for some ecosystem services (e.g. P-burial and potential sedimentation on mudflats). Nevertheless, it gives a first impression of the impact of the project which is positive. For a more accurate result, it is advised to use more specific local data. When considering the per hectare result, a value of between 10,000 and 160,000 €/ha/y (project area of 100 ha) is calculated, this is very high compared with the monetary value for estuarine habitats found in literature (a range from 122 to 22,920 £/ha/y, (Woodward and Wui 2001; Shepherd et al. 2007; Turner et al. 2007). In addition, when considering the lost agricultural land (e.g. gross marginal product for maize land is valued at between 1,003 and 1,526 €/ha/y (data 2008-2010, Flanders, Liekens et al. 2013), then the creation of an intertidal area proves to be beneficial in net terms.

- Part 3: The Net Present Value of the measure after 50 years, using a discount rate of 4% and an increasing monetary value for climate regulation, amounts to between 17 and 356 million €. The calculated result could then be used in management plans to compare the longer term costs and benefits of the introductions of a management measure and to compare the net benefits (total benefits minus total costs) of different measures over their effective lifetimes. However, when using the bio-physical and monetary data as presented in order to calculate the impact of measures on ES, it is important to consider the results as being a rough estimate, with the use of more detailed data from specific project sites recommended if a high accuracy quantification and comparison is required.

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5 Management Initiatives and Governance

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5.1 Estuarine management objectives

5.1.1 Background and aims

One of the challenges in estuarine management is to enhance the integration of the planning and management framework where a multi-manager sectoral framework is often already in place. Whilst there have been considerable developments in integrated coastal zone management arising from amongst others, EU strategy research and policy over the last decade or so (e.g. the Commission Communication on Integrated Coastal Zone Management (2007/308/EC) and the recent adoption of the Proposed Directive on Marine Spatial Planning and Integrated Coastal Management (13/210/EC), there remain a number of challenges in delivering such integration at an individual estuary level given the often sectoral nature of available management tools.

The aim for successful management integration is therefore, without considerable large scale revision to existing organisational powers, to better co-ordinate the operation of existing management frameworks and associated enabling organisations, developing an inclusive management system which utilises the legal powers, expertise and understanding of a range of key stakeholder groups.

Such management within European estuaries is often required to be undertaken within the context of considerable economic development pressure such as ports, power generation and navigation, as well as the maintenance of adjacent social provisions, e.g. flood protection, residential housing and infrastructure. Furthermore, many European estuaries are designated under the Birds and Habitats Directives (2009/147/EC & 92/43/EEC), with associated protection of key interest features required through national legislation. As such, in many instances it will be necessary to include conservation-based management objectives with other economic and social requirements, with the potential for sectoral management aims to therefore be in partial conflict. A core aim for such estuaries is therefore to align management practices to remove or reduce the potential for conflict.

Based on this broad aim, questions considered to be of relevance to estuarine management and integration include:

- What should be legitimate management priorities for estuaries and how can we better integrate these in Natura 2000 estuaries?
- Where are the main areas of spatial and sectoral 'conflict' and what methods can we employ to address these?
- How do we integrate traditional planning and assessment structures with developing tools, e.g. ecosystem services approach within the Water Framework Directive (2000/60/EC)?

In order to address the above, it is necessary to understand:

- Who are the key estuarine users/uses?
- Which users/uses create the main pressures and management issues?
- What methods and tools currently deliver the management of these?
- How effective is management delivery?
- Are other tools available to meet management needs?
- Gaps in the provision of management and associated tools?

In addressing these estuarine management questions, estuarine uses and user conflicts have been characterised for 4 case study estuaries from the North Sea Region (the Elbe, Weser, Scheldt and Humber estuaries), the analysis for this undertaken within the TIDE project. These case study estuaries are considered to be representative of many north-west European systems.

Information from the case study sites was collated and assessed using a matrix approach, the information being characterised on a sectoral basis and at several scales (salinity zone, estuary specific, and estuary generic). This matrix analysis approach to characterising uses and user conflicts within the estuarine systems was employed in order to identify:

- The users and uses of the system (both legal and illegal, desirable and undesirable)
- *Sectoral* areas that most require management (or improved management), e.g. contribute to the greatest level of user conflict in an estuary
- *Spatial* areas that most require management (or improved management), e.g. feature the greatest level of user conflict in an estuary
- Synergistic opportunities and how they might be expanded or better utilised
- Areas where conflict levels are lower than expected (e.g. systems are in place that may be particularly good at managing multi-user issues) and *vice versa* (e.g. areas of unusually high conflict and potential management failure)

User characterisation for each case study estuary was undertaken through regional estuary working groups which comprised representatives of a range of user groups and sectoral managers involved in each individual case study estuary's management. This provided a sufficient breadth of expert knowledge on the estuarine system to be able to populate the matrices without user bias.

The matrices were developed based on an expectation of uses and users regularly encountered in north-west European estuaries, and whilst the categories of use were broad, sub-categories allowed further focus to specific activities that might be addressed via specific management plans or suite of measures. Where possible, these uses were correlated to the established TEEB categories of Ecosystem Services (as described in Jacobs et al. 2013 at www.tide-toolbox.eu).

As such, and using Figure 5.1 as a broad guide, the impact or conflict of a single use or user on other uses or users is bi-directionally 'scored', with the severity of any interaction between uses not always directly reciprocal.

Figure 5.1. Theoretical matrix approach to establish two-way multi-user interactions.

The user assessment process is discussed in greater detail as relevant later in text but effectively required the estuary working groups to provide an indication of the level of each individual use within each management zone of each case study estuary, and to identify a generic conflict 'score' for each user interaction as shown in Figure 5.1. These data were then processed to provide a user conflict score (positive or negative) for each user interaction for each estuary zone. The broad outcomes from this analysis are described later in text.

5.1.2 Potential moderators of use and conflict

Estuarine physical and biological conditions will vary along system length, and will have some influence on the potential uses and associated conflicts present within a management area, either directly through changes in presence/absence of uses, or through a modification to their relative importance. Salinity will vary along an estuary and will influence a range of physical and biological conditions and as such, where possible, this was considered as a parameter for management consideration.

It is however important to note that where undertaking a conflict characterisation and assessment process, management zone length variations also need to be considered. For instance, a series of high conflict scenarios within a long estuary zone may be more of a management priority than those from a relatively short reach.

However, the identification of uses and conflicts may also be influenced by user perspective, and outcomes from the matrix approach applied here will vary between users. As such, a working group approach was applied in order to provide a more representative view of management issues on each estuary, together with the more detailed analysis of group composition, issues and concerns.

5.1.2.1 The use of the salinity zonation for management

The application of salinity as a basis for management zonation was examined within the TIDE project, and these zonation methods are discussed by Geerts et al. (2012 at www.tide-toolbox.eu). The case study estuaries described here were divided into a series of zones with, where practicable, zonation based upon the salinity conditions of the section, but often also reflecting broader estuarine management requirements where applicable, as in practice, the use of already established zonation units may be a more practicable approach to management in many European estuaries than the development of new ones.

By placing the management zones for each of the case study estuaries within the four main salinity classes (Limnetic (Freshwater), Oligohaline, Mesohaline and Polyhaline), clear differences in relative zone size can be seen (Figure 5.2). Given this variability in comparative zone length, consideration should therefore be given to weighting conflict severity and associated management responses.

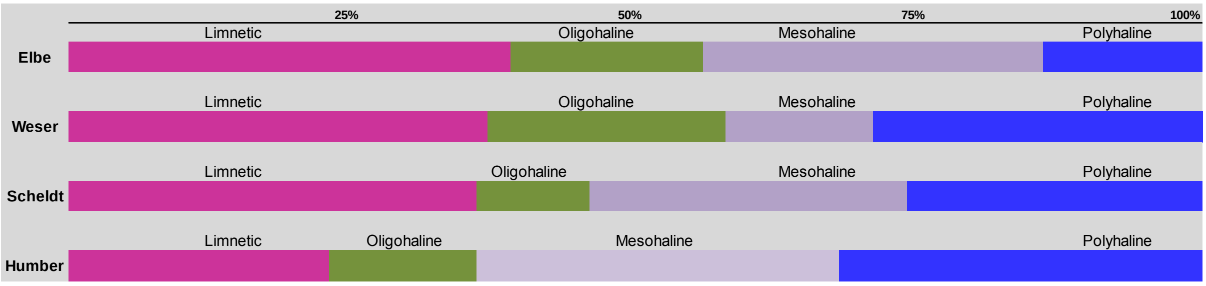

Figure 5.2. Salinity zone relative extent for the TIDE estuaries.

5.1.2.2 Working group bias

Regional working groups were established for each case study estuary in order to minimise the bias in coverage of the range of management topics and concerns present within each estuary. In order to identify any potential bias as well as key sectors of concern, individual member weighting of the main areas of estuary function and management importance/concern were considered, e.g. *Transport & Accessibility*; *Flood Protection & Assimilation*; *Ecological Function & Diversity*; and *Recreation & Social Use*. Whilst representative parity in membership coverage across these broad function areas was not required within the composition of each of the working groups, variations in weighting were noted and incorporated in the detailed analyses. Estuary management priorities were identified from the estuary working groups and these are summarised in Figure 5.3.

Regional Working Group Conflict Matrix Composition and Concerns

Estuary	Number in RWG	Transport & Accessibility	Flood Protection and Assimilation	Ecological Function and Diversity	Recreation and Social Use	Total
Elbe	5	1.8	1.2	1.6	1.2	5.8
Weser	6	1.8	2.0	1.8	1.0	6.7
Scheldt	5	1.4	1.6	1.8	1.2	6.0
Humber	8	1.0	1.9	1.9	0.8	5.5
Estuaries Combined		1.5	1.7	1.8	1.0	6.0

Values above based on individual 'scores' of importance per broad activity area:

High Importance	2
Moderate Importance	1
Zero to low Importance	0

Figure 5.3. Regional Working Group composition and function topic area weighting summary. What is orange?

Across all the case studies, *Ecological Function & Diversity* was identified as the most important topic area, with *Flood Protection & Assimilation* also highly rated whilst *Recreation & Social Use* was only considered to be moderately important.

However, there were differences in topic weighting between estuary groups, perhaps relating to group composition, but also perhaps to management concerns. For instance, the Elbe group identified *Transport & Accessibility* as the most important estuarine use, the Weser *Flood Protection & Assimilation*, the Scheldt *Ecological Function & Diversity*, and the Humber *Flood Protection & Assimilation* and *Ecological Function & Diversity* of equal greatest importance. Recreation & Social Use were scored lowest by all case study groups.

Whilst the values generated from this exercise are considered to be simplistic in terms of describing and prioritising ecosystem functions for estuaries, they are considered to be of value in providing an initial focus on the main functional areas of importance and concern in each estuary.

5.2 Estuary uses and users

As noted above, estuarine systems provide a range of ecosystem services (supporting/habitat services, provisioning services; regulating services, and cultural services), which broadly translate into a series of sectoral uses and users, and with associated sectoral management often applied in estuaries. The range and level of uses will vary both between estuaries and between zones within estuaries, but will fall into a number of broad topic areas including biological extraction (harvesting); physical extraction (aggregates); waste disposal (sewage); recreation; conservation; flood control etc. (e.g. Frid and Dobson 2013).

As part of the analysis process, a level of ‘use’ or ‘activity’ was assigned for each management (primarily salinity) zone within the case study estuaries. These values were assigned by the working group allowing a range of use criteria to be identified and compared between estuaries and zones.

5.2.1 Estuary use comparison

‘Use’ values from each estuary are given in Figure 5.4 (the higher level of ‘use’ coloured a deeper purple), together with an ‘averaged’ value for all of the case study estuaries.

These values indicate that across all the case study estuaries, conservation use was considered high, as might be expected given the ecological value of such systems and the associated protection often afforded them (e.g. Natura 2000 components). The occurrence of coastal squeeze resulting from relative sea level rise and fixed flood protection alignments potentially intensifies the importance and complexity of the future provision and protection of estuarine conservation function.

Similarly, flood protection was identified as a very important function in all estuaries, emphasising the ongoing issues associated with the maintenance of flood provision and public safety in low-lying European flood plain estuaries which may be subject to relative sea level rise resulting from isostatic rebound and climate change, increased tidal pumping from geomorphological modification as well as the need for greater assimilative capacity from potential increased storm event severity and frequency from climate change. Interestingly, the use of managed realignment as a tool for flood protection (and nature conservation provision) was identified as very important in the Humber and important in the Scheldt, but of no importance in the other case study estuaries.

The transit of vessels along estuaries was also identified as an important to very important function for the case study estuaries. The associated stabilisation of navigation channels and dredging activity, which allow fairways to be maintained, were also seen as important activities, although this importance was more variable between estuaries. For instance, channel stabilisation was identified as very important in the Scheldt and Weser, but of low importance in the Humber.

Interestingly, the category ‘Access’ was identified as very important on the Scheldt, with recreational access along the banks also very important on the Humber and recreational access as being of moderate to high importance on the other estuaries.

Port activity was identified as being moderate to high in the Humber and Weser, and moderate in the Elbe (only in relation to intertidal areas – because there is no port activity), but interestingly as being relatively low in the Scheldt.

Activity	All Estuaries	Humber	Elbe	Scheldt	Weser
Landscape - High value landscape feature	**1**	0	2	2	2
Conservation - Protected area adjacent to system	**2**	1	2	2	1
Conservation - Protected subtidal area	**3**	3	3	2	3
Conservation - Protected intertidal area	**3**	3	3	3	3
Archaeology - Archaeology/History protected site	**1**	1	1	0	1
Access - Recreational access on water	**2**	2	2	3	2
Access - Recreational access on banks & intertidal	**2**	3	2	3	2
Access - Commercial	**1**	1	0	3	1
Flood/coast protection - Defence set-back	**1**	3	0	2	0
Flood/coast protection - Flood bank (dyke/gabbion/wall)	**3**	3	3	3	3
Navigation - Channel stabilisation	**2**	1	2	3	3
Navigation - Capital dredging	**2**	2	2	1	2
Navigation - Maintenance dredging	**2**	2	2	2	2
Navigation - Vessel movement	**2**	3	3	3	2
Ports & Harbours - Port land claim (intertidal/subtidal)	**1**	1	1	0	1
Ports & Harbours - Port related activity adjacent to system	**1**	2	1	1	2
Ports & Harbours - Port activity on the intertidal/subtidal area	**1**	2	0	0	2
Infrastructure - Infrastructure on bed or in water column	**1**	2	1	2	1
Industry - Tidal/current energy device	**0**	0	0	0	0
Industry - Water abstraction	**1**	1	1	1	1
Industry - Aggregate extraction	**1**	0	0	2	1
Industry - Industrial discharge	**1**	1	1	1	1
Industry - Industrial activity adjacent to system	**1**	1	1	1	1
Agriculture - Water abstraction	**0**	0	0	0	1
Agriculture - Agricultural run-off	**2**	3	1	2	2
Biological Extraction - Commercial (e.g. fish & shellfish)	**1**	1	1	0	1
Biological Extraction - Recreational	**1**	1	1	1	1
Biological Extraction - Wildfowling	**1**	1	0	1	1
Residential - Waste water discharge	**1**	2	1	1	1
Residential - Housing adjacent to system	**2**	2	1	2	2
Residential - Drinking water abstraction	**0**	0	0	0	0

Figure 5.4. ‘Use’ levels for each estuary and averaged across all case study estuaries. The deeper shading and higher number indicate a higher level of use.

In general, other areas of estuarine use or activity were identified as being of only low to moderate importance within the working groups, although agricultural run-off was identified as being very high in the Humber and high in the Scheldt and Weser. Water abstraction for drinking water and tidal/current energy generation were identified as being absent or near absent, although for the latter activity, this may increase as a use in the future.

5.2.2 Management zone utilisation comparison

The level of individual use sectors was also determined at a management (salinity) zone level for the case study estuaries and the distribution of high levels of individual uses within these zones is shown in Figure 5.5. As might be expected, the dominance of the four main estuary uses as described above (Conservation; Access; Flood Protection; and Navigation) is again evident. However, the importance of individual uses does differ between zones.

Activity	Freshwater	Oligohaline	Mesohaline	Polyhaline
Landscape - High value landscape feature	5	6	6	7
Conservation - Protected area adjacent to system	6	**8**	5	7
Conservation - Protected subtidal area	6	**10**	**12**	**12**
Conservation - Protected intertidal area	7	**10**	**12**	**12**
Archaeology - Archaeology/History protected site	3	3	4	3
Access - Recreational access on water	**9**	**10**	**9**	5
Access - Recreational access on the banks & intertidal	**11**	**10**	**9**	**9**
Access - Commercial	4	4	5	5
Flood/coast protection - Defence set-back	4	3	4	3
Flood/coast protection - Flood bank (dyke/gabbion/wall)	**12**	**12**	**12**	**11**
Navigation - Channel stabilisation	**10**	**9**	**9**	6
Navigation - Capital dredging	4	4	**10**	**10**
Navigation - Maintenance dredging	**8**	7	**9**	**10**
Navigation - Vessel movement	**8**	**9**	**12**	**11**
Ports & Harbours - Port land claim (intertidal/subtidal)	3	3	6	1
Ports & Harbours - Port related activity adjacent to system	6	6	**8**	3
Ports & Harbours - Port activity on the intertidal/subtidal area	5	4	6	2
Infrastructure - Infrastructure on bed or in water column	6	4	6	6
Industry - Tidal/current energy device	1	0	1	0
Industry - Water abstraction	5	6	5	2
Industry - Aggregate extraction	3	3	4	4
Industry - Industrial discharge	6	7	5	1
Industry - Industrial activity adjacent to system	4	5	6	2
Agriculture - Water abstraction	3	3	0	0
Agriculture - Agricultural run-off	**8**	**9**	**9**	7
Biological Extraction - Commercial (e.g. fish & shellfish)	2	3	2	5
Biological Extraction - Recreational	5	4	4	4
Biological Extraction - Wildfowling	3	3	1	1
Residential - Waste water discharge	5	4	5	1
Residential - Housing adjacent to system	**9**	**8**	6	5
Residential - Drinking water abstraction	1	1	0	0
Total Use	172	178	192	155

Figure 5.5. 'Use' levels for each of the management (salinity) zones from all case study estuaries (high usage (e.g. moderate or high in each estuary shown in red).

The provision of flood protection was identified as being of high importance across all zones which would be expected given the range of management challenges for coastal engineers in low-lying flood plain estuaries subject to potential relative sea level rise and increased storm event severity and frequency, as well as more localised estuary-specific problems such as tidal pumping and morphologic alteration.

The protection of the subtidal and intertidal estuarine areas for conservation was identified as being of high importance in the inner, middle and outer (oligohaline, mesohaline and polyhaline) estuarine zones, but of relatively low importance in the freshwater zone. This to some degree reflects Natura 2000 designation extent and the distribution and value of habitats included within the associated designation criteria, but also has associations with greater constraint to channel function and adjacent habitat, e.g. through historical canalisation. This is also seen in the 'channel stabilisation' criteria within the navigation topic where it is of greatest importance in the freshwater zone and lowest in the outer estuary, whereas the dredging and vessel movement criteria were seen to be of greatest importance in the middle and outer estuary zones.

Ports industry activity both in the estuary and adjacent to it was marginally concentrated to the mesohaline zone, with the lowest level of activity indicated in the polyhaline zone, and a moderate use in both the inner estuary and freshwater zones (with the Elbe as an exception). This positioning, away from the mouth of estuarine systems may be a result of operational requirements (e.g. shelter and channel depth), or historical social linkages (e.g. industry and population sources) The positioning of ports related infrastructure some distance upstream, for example in the Elbe system, often reflecting historical location requirements is a potential management issue in many estuaries, given modern vessel passage requirements, and in particular, increased vessel beam and draught and the associated requirement for fairway maintenance and/or enlargement.

Recreational access was identified as an important use across the estuary system, although with a reduction, primarily for water-based activity, in the outer estuary polyhaline zone. Agricultural run-off was rated as an important issue in all zones, although with a reduction in the polyhaline zone, possibly reflecting increased mixing. The provision of residential housing was identified as important in the freshwater and inner estuary areas.

The abstraction of potable water and provision of tidal and current energy devices were identified as being absent or near absent in all zones, although the latter may become more important in the future, with the switch to a range of renewable energy sources for diversification and maintenance of energy supply.

Overall, the middle estuary (mesohaline) zone of the case study estuaries was identified as supporting the greatest level of use and highest number of high scoring uses, followed by the inner estuary oligohaline zone. The outer estuary polyhaline zone was identified by the working groups as supporting the lowest level of overall use and high scoring uses. Very low scoring use criteria were also most numerous from this zone, and would suggest that in general, potential use pressure would be the lowest in this zone. To some extent this reflects the historical geographical and social legacy of human development in estuarine systems although its also presents a management issue in realtion to port operations, In particular, the economies of scale from increases in vessel size means that modern large-scale port operations often require widened and deepened navigation fairways to accomodate increased vessel beam and draught. Whilst the accommodation of such vessels might be more easily accomodated in the outer estuary polyhaline zone, the ports are often located further upstream, with a substantial relocation inertia from a range of factors including legacy infrastructure (ports, rail, road), skills base, competion and cost.

5.2.3 Case study use summary

Figure 5.6 summarises the uses/issues scores for each estuary and zone, as well as for all estuaries combined. Analysis of the working group scoring has indicated that the zone with the greatest uses/issues is the mesohaline zone with the polyhaline zone featuring the lowest uses/issues, having *c*. 80% of the usage level identified in the mesohaline zone.

Usage Scores for Estuaries & Zones				
Freshwater				
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	

Figure 5.6. Summary of uses/issues scores for each estuary zone and for all estuaries combined (maximum usage scores for each estuary shown in darker grey).

Across the case study estuaries, the greatest level of uses/issues was identified for the Scheldt estuary, with the Elbe featuring the lowest score (*c*. 75% of the score for the Scheldt).

5.3 Management and governance framework

5.3.1 Introduction

Due to the complexity of estuaries, their dynamic nature and the internal and external pressures impacted upon them (Imperial and Hennessey 1996), their management needs to be adaptive with proactive intervention to ensure higher resilience levels and adaptability to changing situations (Elliott and Whitfield 2011; Chapman 2012). Ballinger and Stojanovic (2010) believe the greater challenge is the need for the governance and associated decision-making systems to be sufficiently robust, adaptive and balanced to be able to tackle the myriad of complex issues associated with the multidimensional estuary system.

The many uses and users of estuaries have led to extensive current management measures driven by legislation and policy from the international level down to the national/federal province policies. In Europe, the European Union (EU) is a pre-eminent player in the field of sustainable regional development and in recent decades, it has adopted more than 200 directives, regulations and many other forms of legislation and amendments in the area of environmental policy that have direct repercussions for regional development (Beunen et al. 2009). Framework directives are the principal means of regulatory intervention under the EU's environmental policy and allow Member States a degree of control and considerable discretion as to how the policy is transposed into national legislation (van Leeuwen et al. 2012). Therefore in practice, the implementation of the EU rules in the national legislation of individual Member States may differ from each other.

In order to understand estuarine planning and governance, it is necessary to understand the individual Member State's legislative management frameworks including the high level and local drivers, the management organisations and groups and their responsibilities. The four TIDE estuaries showcase 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. For many estuaries in Europe and worldwide, a large number of management plans and sectoral strategies are developed addressing regional, national and sometimes international policies which try to manage the very diverse sectors of uses and activities. Plans are largely sectoral and occasionally spatially constrained. The main gap lies in the coordination and integration of the different management approaches. Sometimes the plans are not very well adjusted or, stakeholders are unaware of the existence of a multitude of plans.

This chapter will look at the EU legislation driving management of the TIDE estuaries, the resulting governance and the management plans implemented for these and other European estuaries.

5.3.2 Legal framework

Drivers for the management of estuaries come from International, European and national legislation and policy. Many environmental directives, such as the Birds and Habitats and Directives, the Water Framework Directive (WFD), the Marine Strategy Framework Directive

(MSFD) and the Flood Risk Management Directive (FRMD) directly impact on estuarine management and have been formulated to include environmental issues in planning and decision making processes which are outlined below. As EU Member States, the TIDE countries are required to transpose these directives into national legislation.

In general, legislation seeks to regulate specific activities or operations and to a large degree determines the management questions relevant to estuaries, including planning and consents procedures. Within estuaries, legislation overarches the assessment process and provides context to the decision-making process (ABPmer 2007).

It has been shown that many countries have an unnecessarily complex marine legislation and administration framework (e.g. Ducrotoy and Elliott 1997; Fernandes et al. 1995; Boyes et al. 2003a, b; Boyes and Elliott 2003; Elliott et al. 2006) which can lead to complex management systems in estuaries, coastal and marine areas. Countries have internal regional and national policies, laws and agreements, external regional agreements and laws such as the Oslo and Paris Commission (OSPAR) for the NE Atlantic, the International Council for the Exploration of the Sea (ICES) and, within Europe, the European Union and European Environment Agency. In addition to this, they are signatories to global initiatives such as the UN Convention of the Law of the Sea (UNCLOS), the International Maritime Organisation (IMO) and the Convention on Biological Diversity. They have laws, agreements and administrative bodies which control the many marine sectors such as pollution disposal, fisheries, seabed extraction of sand and gravel, oil spill response, habitat use and protection, etc (Elliott et al. 2006).

5.3.2.1 Birds Directive and Habitats & Species Directive

Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds (this is the codified version of Directive 79/409/EEC as amended) is the EU’s oldest piece of nature legislation and one of the most important, creating a comprehensive scheme of protection for all wild bird species naturally occurring in the Union. It was adopted unanimously by the Members States in 1979 as a response to increasing concern about the decline in Europe's wild bird populations resulting from pollution, loss of habitats as well as unsustainable use. It was also in recognition that wild birds, many of which are migratory, are a shared heritage of the Member States and that their effective conservation required international co-operation[2]. The Birds Directive also meets the EU obligations for bird species under the Bern Convention and the Bonn Convention.

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[2] http://ec.europa.eu/environment/nature/legislation/birdsdirective/index_en.htm

Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (Habitats & Species Directive) is the means by which the EU meets its obligations under the Bern Convention. The Directive was amended in 1997 by a technical adaptation directive with further amendments of the annexes by the Environment Chapter of the Treaty of Accession 2003 and in 2007 when Bulgaria and Romania joined the EU. The Habitats & Species Directive obliges Member States to promote the maintenance of biodiversity by requiring measures to maintain or restore natural habitats and wild species listed on the Annexes to the Directive at a favourable conservation status and introducing robust protection for those habitats and species of European importance. In applying these measures, Member States are required to take account of economic, social and cultural requirements, as well as regional and local characteristics. The Directive protects over 1000 animals and plant species and over 200 "habitat types" (e.g. special types of forests, meadows, wetlands, etc.) which are of European importance.

In the words of the European Commission, the Habitats & Species Directive, together with the Birds Directive, constitutes the ‘cornerstone of the EU’s conservation policy’. Table 5.1 shows how these two directives have been transposed into national and federal law within the four TIDE countries.

Table 5.1. National implementation of the Birds Directive and Habitats & Species Directive

TIDE Estuary	National/Federal Implementation
Humber (England)	Conservation of Habitats and Species Regulations 2010 (as amended) Wildlife and Countryside Act 1981 (as amended)
Elbe & Weser (Germany)	National level: Federal Nature Conservation Act (BNatSchG 2010) Federal state level: The conservation acts of the Federal states Bremen (BremNatG 2010), Lower Saxony (NAGBNatSchG 2010) and Schleswig-Holstein (LNatSchG 2010), Hamburg (HmbNatSchG 2010)
Scheldt (The Netherlands)	Nature Conservation Act and the Flora and Fauna Act.
Scheldt (Belgium)[3]	Law on Nature Conservation 1973. It has been adapted to the regional context by the Nature Protection Order of 1995 in the Brussels Capital Region, the Nature Decree of 1997 (modified in 2002) in Flanders and the Natura 2000 Decree of 2001 in Wallonia.

All EU governments have provided considerable guidance to their national conservation bodies on how to apply the requirements of the Habitats & Species and Birds Directives at the national level and although not mandatory, any competent authority can establish a

[3] The Belgian situation is particularly complex since most competences relating to biodiversity and territorial issues are dependent on the three different regions (Brussels Capital Region, Flanders and Wallonia). This means that Belgium generally has three sets of legislation for a given thematic area, or more when some competences still remain at federal level.

management scheme for an estuary as an optional requirement of the directive and national legislation. For many European estuaries, competent authorities have combined to establish management schemes, with steering groups adopted to ensure that the European Marine Sites (EMS) are protected from potentially damaging activities. For example, the Humber Estuary management scheme in the UK is a partnership of over 30 Relevant Authorities that have jurisdiction on or around the Humber Estuary. They are all equal members of the Humber Estuary Relevant Authorities Group (HERAG) that has developed the scheme and are now tasked with implementing it with the ongoing advice and support of the Humber Advisory Group. The HERAG collectively funds the Humber Management Scheme and employs a Project Officer to coordinate the implementation of the scheme on a day to day basis. All Humber Management Scheme business is discussed and agreed by involving all the members. Similar management schemes have been adopted for many European estuaries.

5.3.2.2 Water Framework Directive (WFD)

In October 2000 the 'Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy' (Water Framework Directive or WFD) was adopted and came into force in December 2000. The overriding goal of the Directive is that Member States should aim to achieve "Good Chemical and Good Ecological Status" or in case of Heavily Modified Water bodies (HMWB) "Good Chemical Status" and "Good Ecological Potential" of inland surface waters (rivers and lakes), transitional waters (estuaries), coastal waters and groundwater and also to prevent deterioration in the status of those water bodies by 2015.

Water in rivers, estuaries (transitional waters), coasts and aquifers will improve under measures set out in Programs of Measures for the River Basins, drawn up for river basin districts. The WFD considers the ecological health of surface water bodies (defined as a slight variation from undisturbed natural conditions), as well as achieving traditional chemical standards. In particular it will help to deal with diffuse pollution which remains important after improvements to most point source discharges. Successful implementation of the WFD will help to protect all elements of the water cycle and enhance the quality of groundwaters, rivers, lakes, estuaries and seas. All the EU Member States have transposed the WFD into national, federal or regional legislation, with Table 5.2 showing how the WFD has been transposed for the four TIDE estuaries.

Table 5.2. National implementation of the WFD

TIDE Estuary	National/Federal Implementation
Humber (England)	The Water Environment (Water Framework Directive) (England and Wales) Regulations 2003
Elbe & Weser (Germany)	Federal Water Act (Wasserhaushaltsgesetz (BGBl. I S. 2585)) from 31 Juli 2009, last amendment December 2011 Bund-Länderarbeitsgemeinschaft Wasser (LAWA) has developed national guidelines on the WFD to support and to some extent harmonise the activities of the individual federal states.
Scheldt (The Netherlands)	Implementation Strategy EG Water Framework Directive, thereby altering the Waterwet; Water Act
Scheldt (Belgium)	Decreet Integraal Waterbeleid; Decree Integrated Water Policy

Working groups have been formed at a national or regional level to provide coordinated advice for technical aspects of the directive and its implementation within each Member State. This is through the LAWA in Germany and UKTAG in the UK. A Scheldt treaty has been concluded between France, Belgium and the Netherlands regarding the protection of the water quality and the implementation of the WFD. The International Scheldt Commission has taken on the role of implementing the WFD which is based in Antwerp. International long-standing working groups at the European level serve as an instrument for harmonising the implementation process between the Member States. For example the Geographic Intercalibration Group for the North East Atlantic (NEA GIG) aims at a harmonised assessment of coastal and transitional waters from Norway to Portugal, including the UK, Belgian, Dutch and German North Sea coasts.

5.3.2.3 Marine Strategy Framework Directive (MSFD)

In 2008, the Marine Strategy Framework Directive (MSFD) (2008/56/EC) was adopted. The MSFD seeks to establish an integrated framework for the management of marine spaces, and aims at achieving or maintaining a good environmental status (GES) for community waters by 2020 at the latest (OJ L 164/19, Chapter I, Article 1.1; 2008). It is the first legislative instrument in relation to the EU marine biodiversity policy, as it contains the explicit regulatory objective that "biodiversity is maintained by 2020", as the cornerstone for achieving GES. It enshrines in a legislative framework the ecosystem approach to the management of human activities having an impact on the marine environment, integrating the concepts of environmental protection and sustainable use. The MSFD is very wide-ranging and sets out eleven descriptors of GES relating to biological diversity, non-indigenous species introductions, commercially exploited fish and shellfish populations, food webs, human-induced eutrophication, sea floor integrity, hydrographical conditions, concentrations of contaminants, contaminants in fish and other seafood, litter and noise. In order to achieve the objective, Member States have to develop Marine Strategies which serve as Action Plans which apply an ecosystem-based approach to the management of human activities.

The MSFD builds upon a range of mechanisms already implemented within estuarine, coastal and offshore systems across Europe. These mechanisms include the Regional Sea Conventions, the Habitats & Species Directive and the Water Framework Directive. Table 5.3 shows how the MSFD has been transposed into national law for the four TIDE estuaries.

Table 5.3. National implementation of the MSFD

TIDE Estuary	National/Federal Implementation
Humber (England)	The Marine Strategy Regulations 2010
Elbe & Weser (Germany)	The Federal Water Act (Wasserhaushaltsgesetz (BGBl. I S. 2585) from 31 July 2009, last amendment 24 February 2012 (BGBl. I S. 212)
Scheldt (The Netherlands)	Water Act (2009) and Water Decree (2010)
Scheldt (Belgium)	Royal Decree on the Marine Strategy of the Belgian sea (2010)

5.3.2.4 Flood Risk Management Directive (FRMD)

Directive 2007/60/EC on the assessment and management of flood risks entered into force on 26 November 2007. Its aim is to reduce and manage the risks that floods pose to human health, the environment, cultural heritage and economic activity by ensuring that flood risk from all sources is assessed and managed in a consistent way. This Directive requires Member States to assess if all water courses and coast lines are at risk from flooding, to map the flood extent and assets and humans at risk in these areas and to take adequate and coordinated measures to reduce this flood risk. The Directive needs to be implemented in co-ordination with the Water Framework Directive, notably by aligning flood risk management plans with river basin management plans, and by consulting with the public on the content of flood risk management plans. All assessments, maps and plans must be made available to the public and the active involvement of interested parties in the preparation of flood risk management plans must be encouraged. The Directive applies to inland waters as well as all coastal waters across the whole territory of the EU. Table 5.4 shows the new enabling legislation or adaptation of existing laws in the four TIDE estuaries. Advisory groups within the respective countries are currently deciding on management actions to implement this Directive.

Table 5.4. National implementation of the MSFD

TIDE Estuary	National/Federal Implementation
Humber (England)	Flood Risk Regulations 2009
Elbe & Weser (Germany)	Federal Water Act (Wasserhaushaltsgesetz (BGBl. I S. 2585)) from 31 July 2009, last amendment 24 February 2012 (BGBl. I S. 212).
Scheldt (The Netherlands)	Water Act (2009)
Scheldt (Belgium)	Adaptation of the Decree on Integrated Water policy (July 2010)

5.3.2.5 Proposed Framework for Maritime Spatial Planning and Coastal Management

This newly-proposed directive (March 2013) aims to promote the sustainable growth of maritime and coastal activities and the sustainable use of coastal and marine resources by establishing a framework for the effective application of Maritime Spatial Planning in EU waters and Coastal Management in coastal areas of Member States. The proposed framework, promoting the ecosystem-based approach, ensures the protection of natural resources as the basis on which the various activities are carried out EC (2013). Plans and implementation strategies will then produce the identified benefits of Maritime Spatial Planning and Coastal Management. These plans and strategies should mostly build upon existing national rules and mechanisms to minimise the additional administrative burden. If accepted then this directive will have implications for estuarine management with regards measures to prevent erosion, adaptation to climate change, combating coastal and marine litter and developing green infrastructure. In doing so, Member States should consider all relevant coastal activities and pay particular attention to cross-sectoral and land-sea interactions between these activities.

5.3.3 Governance

European countries have had to develop governance systems to address the impacts affecting estuarine management, and to specifically protect important habitats and species and their conservation objectives. This approach is no different from that adopted in other countries, for example the United States Clean Waters Act and the Australian Environment Protection and Biodiversity Conservation Act. They also need to respond to the plethora of legislation and tools dictated by international measures, regional seas programmes, European Directives, national legislation and other regulatory tools (Elliott and Ducrotoy 2010; Basset et al. 2013).

Recently, greater attention has been paid to estuarine governance mechanisms, particularly with a focus on ecosystem-based management. The recent emphasis on governance emerges from the need to adopt approaches that: (i) consider the problems from an integrated perspective, (ii) allow the mediation of conflict between private and public interests, by consensus building; and (iii) include the participation of stakeholders and civil society in the formulating and implementing policies (EC 2001). This change in attitude and new pattern of governance has allowed all interested parties to share a vision, objectives, strategies, resources, power and authority in the management of an estuary (Carvalho and Fidelis 2013). Governance involves setting priorities that may establish hierarchies of interests, but the basis is a recognition of what is excluded, as well as what is given priority in certain situations. Good governance is based on recognition of the interests of all stakeholders and inclusion of their interests where possible (Sutherland and Nicols 2006), with stakeholder participation widely considered a precondition for sustainable processes (Bossel 1999; Empacher and Wehling 2002).

A review undertaken by Carvalho and Fidelis (2013) made in the context of estuaries has highlighted the importance of estuary management approaches being supported in governance systems that consider integration mechanisms, adaptive management and participation and collaboration of all stakeholders and the general public in a joint decision process. Even with such specificities, these principles are the key to building a framework for collaborative governance (summarised in Figure 5.7).

A shift from predominantly top-down governance structures to a more complementary 'top-down bottom-up' balanced approach, has led to greater transparency and communication throughout the levels of management, with stakeholder engagement used to support the management of estuaries. This has also been accentuated through newer EU directives like the WFD and MSFD being more holistic in nature, tackling systems as a whole and not just single problems.

Open communication between statutory authorities, stakeholders and users within the estuaries has led to the development of good management and governance. Cooperation between scientists and policy makers seems satisfactory as well as the involvement of many interest groups and the sharing of information through the establishment of steering committees, public or specific meetings, reports and newsletters (Boyes et al. 2006). All four of the TIDE estuaries have shown good practice in using stakeholder and advisory networks to develop many of their plans, for example the River Basin Management Plans (RBMPs) and other programmes of measures as required under the Water Framework Directive. These RBMPs have been successfully developed both at the local scale (e.g. Humber Estuary) and at the international scale (e.g. the Elbe) thus overcoming administrative boundaries.

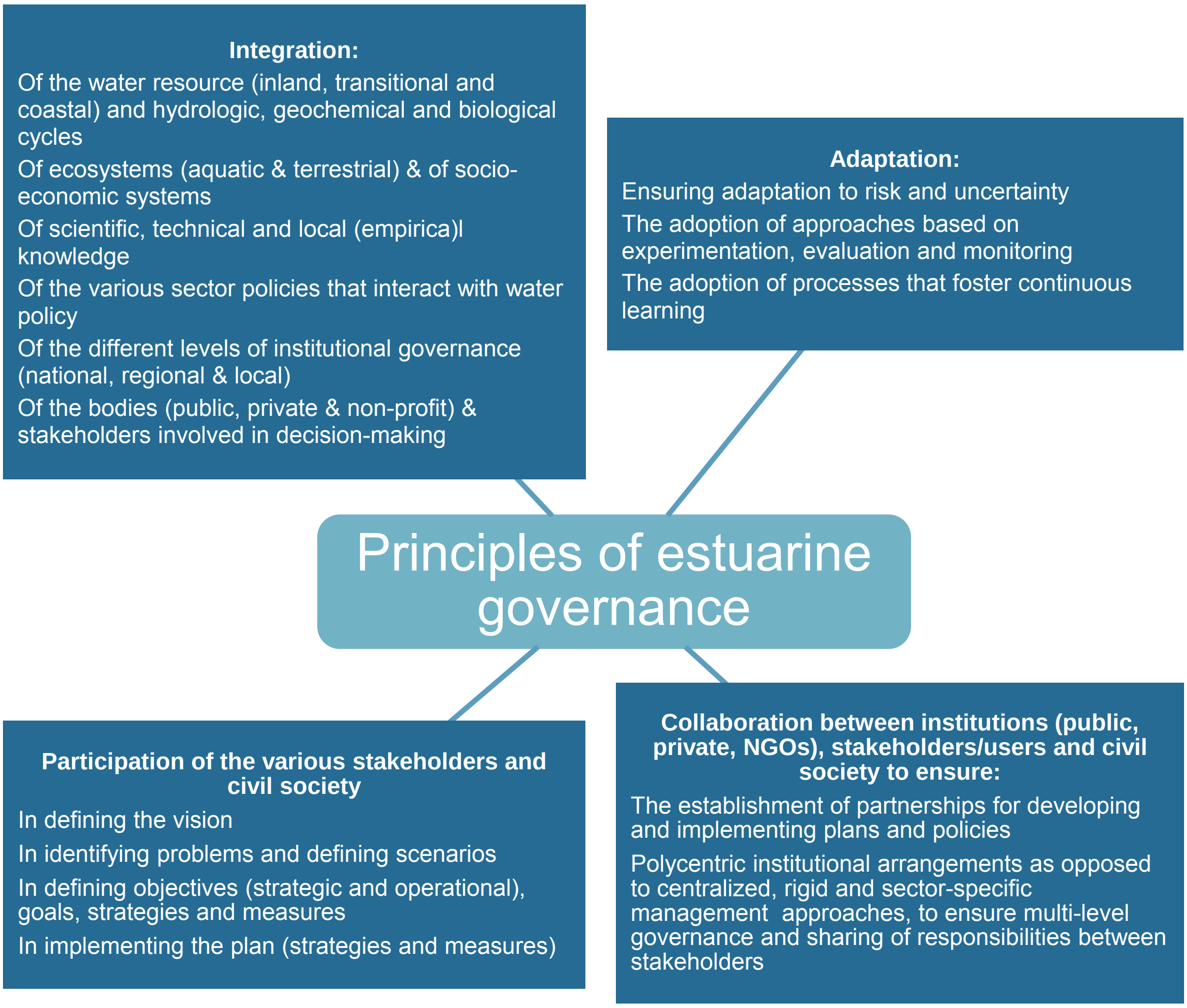

Figure 5.7. Principles of governance to be followed in the planning and management of estuaries (taken from Carvalho and Fidelis 2013).

5.3.4 Estuarine management plans

Estuarine ecosystems are where many industrial and social activities coexist in juxtaposition with highly important areas of conservation. As discussed earlier, these activities and features are managed by a multitude of government agencies and statutory and competent authorities each having their own jurisdiction, powers, responsibilities and legislation (Imperial and Hennessey 1996; Elliott et al. 2006). This can often lead to conflicting use and resulting pressures associated with the multiplicity of users and organisations which can threaten the sustainability of the estuarine ecosystem, as well as its values and functions (ABPmer 2007).

Legislation and associated management initiatives can place considerable constraints on activities within estuaries, however a progression towards more holistic management planning frameworks dedicated to estuarine protection and improvement are now building on and have a good understanding of the following issues:

- 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)

The development of a more holistic approach in terms of estuarine and coastal management has been brought about by the recent evolution of EU directives. Directives such as the Water Framework Directive, Marine Strategy Framework Directive, Birds and Habitats Directives and the Strategic Environmental Assessment Directive formulate objectives which do not relate to administrative boundaries but to all uses and users, larger geographical areas, and their implementation requires changes in perspective (Qui and Jones 2013). Examples of this include the Natura 2000 management plans for the Elbe and Weser estuaries in Germany and the Humber Management Scheme in the UK which have brought together and consulted with various interest groups and relevant authorities around the estuaries to ensure that the habitats and species of these estuaries maintain their favourable condition. The Water Framework Directive also requires the cross-border cooperation of countries with shared river basins to produce national River Basin Management Plans (RBMPs). This was seen for the Weser and Elbe, which were jointly developed by the federal states (“*Bundesländer”)* adjacent to the river catchment areas.

Examples of best practice derived from the TIDE work include:

- Management plans which engage all users and use of the estuary. Although non-statutory in nature, successful plans have been implemented in all four of the TIDE estuaries to ensure that 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 FRMD, all four TIDE estuaries have comprehensive flood risk management plans in place

derived through their environmental protection agencies and local authorities/federal states. These plans have been developed on a whole estuary scale, instead of based on administrative boundaries 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 TIDE estuaries have shown good practice in using stakeholder and advisory networks to develop their plans, for example the River Basin Management Plan and other programmes of measures required under the WFD. The plans have been successfully developed both at the local scale (e.g. Humber) and the international scale (e.g. Elbe) thus overcoming administrative boundaries.

5.3.5 Case studies

5.3.5.1 Humber, England

There have been several management attempts in the Humber Estuary, and various management plans and strategies have been produced. However they are largely sectoral and occasionally spatially constrained. The main gap lies in the coordination and integration of the different management approaches. Although many plans have been produced, stakeholders are sometimes unaware of their existence and many have never entered an implementation phase. There may also be tension between different plans which have different aims and objectives. The Humber Management Scheme has in some ways overcome these issues, bringing together and consulting with various interest groups and relevant authorities around the Humber in advisory groups primarily to ensure that the habitats and species of the Humber maintain their favourable condition. The newly revised plan launched in 2012 aims to enhance this user group and plan integration.

5.3.5.2 Scheldt Estuary, Netherlands & Belgium

In the past decade, management of the Scheldt estuary has been realised not only on a transnational basis by the Netherlands and Belgium (Flanders) governments but also in a multi-sectoral way. In an attempt to reconcile the often competing interests of the Netherlands and Flanders governments, the Scheldt Development Outline 2010 was created and published in 2005. It integrates goals for nature conservation, accessibility of the Antwerp port, and flood safety issues. It is also the starting-point for joint policy–making by the Flemish and Dutch governments, aiming at a more sustainable development in the Scheldt estuary.

5.3.5.3 Elbe & Weser, Germany

Most of the plans within these German estuaries are sectoral, linked strictly to administrative borders, and do not encompass all of use requirements and statutory regulations the estuaries are affected by. However, in the last ten years, the development of more holistic plans has started with the ongoing implementation of the WFD, MSFD and the Birds and Habitats Directives. Since these directives formulate objectives which do not relate to administrative boundaries but to river basins, marine areas and protected areas, their implementation requires changes in perspective.

Related to the WFD, an example of cross-border initiatives are the national RBMPs for the Weser and Elbe, which were jointly developed by the federal states ("*Bundesländer")* adjacent to the river catchment areas. Cross-sectoral cooperation is also seen in the foundation of Regional Cooperation Groups in Lower Saxony and Bremen. These groups which involve all relevant regional stakeholder groups, operate at the level of sub-basin survey areas and should contribute to the successful implementation of the WFD in both states.

The Tidal Rivers Weser and Elbe have several different management plans with different focus. The most holistic of these are possibly the Natura 2000 management plans. Here the three federal states in charge (Schleswig-Holstein, Lower Saxony, Hamburg and Bremen) and the Federal Administration for Waterways and, for the Elbe, the Hamburg Port Authority have finalised joint Natura 2000 management plans, which will guide all future activities at the estuaries and include a large list of measures which now successively are to be implemented[4]. The implementation at the Elbe will be controlled by a steering group, the practical work will be coordinated by a joint working group. In the Weser, the plan was finalised in February 2012 and, where the state cooperation is only bilateral, working groups are foreseen only on the project level. Nevertheless an observing group of the two states and the federal administration should deliver progress reports to the stakeholders. Both plans have been produced on the basis of a broad and active stakeholder involvement so that they are founded on principal mutual agreement.

5.3.5.4 Portuguese estuaries

In Portugal, the management of estuaries has historically been characterised by a mix of sector approaches, such as port activities, navigation, nature conservation, fisheries or urban management, leading to fragmented management strategies (Carvalho and Fidelis 2013). If estuary management strategies existed, they were sectoral and lacked integration of issues affecting the whole system and showed a lack of coordination between the

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[4] www.natura2000-unterelbe.de

management bodies and existing legislation. However, more recently through the enactment of the Water Law (No.58/2005) and a specific Decree Law (No.129/2008), estuaries have received special attention through the creation of a set of plans specifically dedicated to the planning and management of estuaries. These are meant to be applied to the estuary and estuarine margins and seek to protect their waters, beds and banks and the ecosystems associated, pursuing an integrated management perspective, including the improvement of the estuary as well as its associated environmental, economic, social and cultural assets. In 2013, a newly proposed piece of legislation “Planos de Ordenamento de Estuários” (POE) (Estuary Land Use and Management Plan) aims to ensure the full integration of the various sets of values, stakeholders and institutions into estuarine management.

5.3.6 The way forward

In order to develop holistic management planning frameworks for estuaries, it is necessary to build on existing structures and use multi-manager sectoral framework including the incorporation and understanding of:

- The management issues
- The methods used to deliver the management
- The basis that management is delivered
- The efficacy of the management tools
- The best tools/plans available to meet these needs
- Gaps in management

5.4 Estuary user conflicts

As previously described, estuarine systems provide many ecosystem services through a range of functions and uses. Whilst many north-west European estuarine management user issues are to some extent generic, the distribution and importance of these uses will vary between estuaries and both spatially and temporally within each system. Using working groups representative of a range of key users for each of the four case study estuaries, the main uses have been characterised (Section 5.2).

This characterisation process identified case study estuary specific variability in patterns of use, which can be used in conjunction with both antagonistic and synergistic user interaction information, to populate estuary specific ‘conflict matrices’. The outcomes from these matrices can then be employed to assist in the identification of management priorities, both on a sectoral and spatial basis.

5.4.1 Case study user conflict characterisation

5.4.1.1 Elbe estuary

Background

The majority of the intertidal and subtidal area of the tidal Elbe is protected under the Habitats and Species Directive as a Natura 2000 site, with only the reach around the main city and port of Hamburg not included within this designation and with further designation upstream. In addition, sections of adjacent terrestrial habitat are also designated, e.g. agricultural land east of Freiburg and around Krautsand.

Considerable modification to the channel occurs around the city of Hamburg (arising from the Süderelbe and Norderelbe channels), with anabranch modification for vessel traffic and port related activity in this area.

Downstream from Hamburg, the Elbe contains a series of islands and sub-channels, but with the main fairway maintained through maintenance dredging to allow safe vessel transit.

User interactions

A series of conflict interactions were identified (Table 5.5), these primarily relating to the impact of conservation protection of intertidal habitat on recreational access and navigation; flood protection from dykes on the conservation of the intertidal area; navigation (dredging and vessel movement) on the conservation of the intertidal areas; and agricultural run-off on intertidal and subtidal habitat protection. Synergistic interactions were also recorded largely from within the various aspects of conservation protection as well as with landscape character; various aspects of navigation requirements as well as flood protection; and flood protection and residential housing provision.

The Elbe estuary analysis indicates that the main potential management problems are associated with the provision of safe navigation requirements stretching from the estuary mouth to the port of Hamburg, with the most severely scored conflicts from this use occurring with requirements for the protection of Natura 2000 interests in the estuary. Similarly, the need to meet the requirements of the Natura 2000 Directives incurs a potentially high conflict on the need to maintain safe navigation along this part of the estuary and further upstream.

As might be expected, the absence of Natura 2000 interests within the main City of Hamburg urban area as well as the ports industry centre, means that the impacts of nature conservation concerns are reduced in this reach. In general, the frequency of high scoring conflict interactions between users reduces towards the mouth of the estuary (away from the urban and ports centres around Hamburg), despite these reaches being included in the

Natura 2000 designation. However, issues relating to navigation requirements and conservation interests remain in these areas.

Very highly scored user interactions (antagonistic and synergistic) are shown in Table 5.5.

Table 5.5. Strongest associations between uses/users for the Elbe estuary. Those in red text are negative user associations, green positive.

Impact of		Impact on	
Category	Activity	Category	Activity
Conservation	Protected area adjacent to system	Flood/coast protection	Flood bank (dyke/gabion/wall)
Conservation	Protected intertidal area	Access	Recreational access on water
Conservation	Protected intertidal area	Access	Recreational access on the banks & intertidal
Flood/coast protection	Flood bank (dyke/gabion/wall)	Conservation	Protected intertidal area
Navigation	Vessel movement	Conservation	Protected intertidal area
Conservation	Protected subtidal area	Conservation	Protected intertidal area
Conservation	Protected intertidal area	Conservation	Protected subtidal area
Navigation	Channel stabilisation	Navigation	Vessel movement

5.4.1.2 Weser estuary

Background

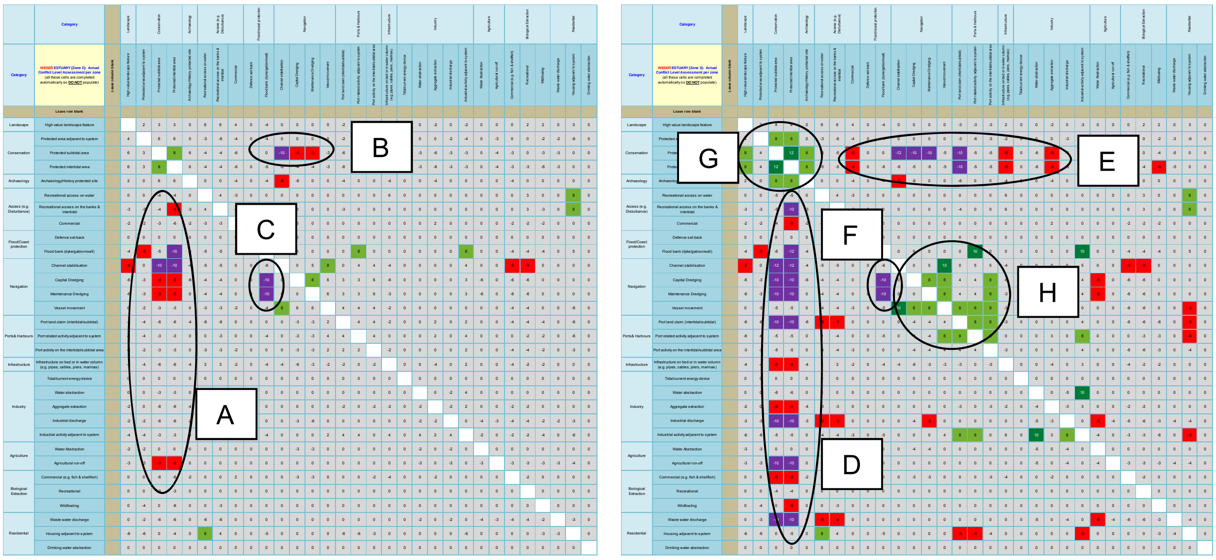
The majority of the intertidal and subtidal area within the estuary is included within the Natura 2000 designation, with only part of the main urban and port area of Bremen excluded from this. The other main urban and port centre within the system is located at Bremerhaven towards the mouth of the estuary, an area where areas of extensive marsh and mudflat are included within the Natura 2000 designation.

The majority of the remaining system features agricultural use with smaller urban centres, and with the main channel both constrained by flood protection structures and dredged in order to maintain navigation. Several large islands are present in the middle estuary, e.g. Harriersand and Strohauser Plate.

User interactions

Although the highest scoring user interactions for the Weser are summarised in Table 5.6, the detailed conflict matrix analysis for the Weser indicated a considerably greater number of moderate to high scoring conflict interactions (c. 30) for the majority of zones than for the Elbe, but with a similar level of very high scoring conflicts to the Elbe. Similarly, a greater number of moderate to high scoring synergistic interactions (c. 20) were also recorded, but with a broadly similar number of very high scoring relationships. This might suggest that there are management factors ameliorating the severity of user interactions.

An example of the level and variation in the patterns of user interactions is shown in Figure 5.8. Downstream from the City of Bremen (Zone 2), the area features primarily agricultural land use along the banks, although with the estuary zone being included in the Natura 2000 designation. However, a small cluster of issues (cluster A) associated with navigation requirement impacts on nature conservation protection are noted (with vessels transiting to Bremen and associated fairway management required), and with agricultural run-off also identified as an issue, although at a low severity. A corresponding conflict cluster (although with reduced frequency and severity), is also evident for nature conservation uses acting on navigation needs (cluster B). A further small but high severity cluster is noted for dredging activity on flood bank provision (cluster C).



Weser - Zone 2 **Weser - Zone 3**

Figure 5.8. High scoring user interactions for two management zones on the Weser estuary. Purple and red interactions are user conflicts (purple scored as highest) and green interactions are synergistic (dark green scored as highest).

Zone 3, which lies primarily within an area of agricultural land with marsh areas and with inclusion in the Natura 2000 designation, is shown in Figure 5.8 to feature an elevated level of high conflict and synergistic use interactions. Many of the high conflict interactions relate to a range of uses acting on the conservation interests (cluster D), with high scores arising from not just navigational requirements but also flood protection, port land claim, industrial and residential discharges and agricultural run-off. Further conflict interactions arise from nature conservation needs on navigation and port expansion (land claim) in cluster E, and with navigation needs (dredging) also affecting flood protection (cluster F). However, a cluster of synergisms relating to nature conservation, landscape value and archaeological sites are present (cluster G), as well as between the aspects of navigation use and port industry activity (cluster H).

The outcomes from the matrix analysis process are interesting in that they indicate that the greatest severity of conflict interactions arise towards the outer estuary, primarily, but not exclusively relating to navigation related activity on the nature conservation aspects of the estuary. These issues largely arise from the need for management actions along the outer estuary to maintain the navigable fairway for traffic to and from the port of Bremen. It is also apparent that the corresponding requirements for conservation protection (the Natura 2000 site) produce conflicts with the need for the maintenance of navigational access.

Table 5.6. Strongest associations between uses/users for the Weser Estuary. Those in red are negative user associations, green positive.

Impact of		Impact on	
Category	Activity	Category	Activity
Conservation	Protected subtidal area	Navigation	Channel stabilisation
Flood/coast protection	Flood bank (dyke/gabion/wall)	Conservation	Protected intertidal area
Navigation	Channel stabilisation	Conservation	Protected subtidal area
Navigation	Channel stabilisation	Conservation	Protected intertidal area
Conservation	Protected subtidal area	Conservation	Protected intertidal area
Conservation	Protected intertidal area	Conservation	Protected subtidal area

5.4.1.3 Scheldt estuary

Background

As with the other case study estuaries, the majority of the intertidal and subtidal area of the Scheldt is protected as a Natura 2000 site, with only the extreme upper reach of the study area excluded from this.

The system upstream from the City of Antwerp features a relatively narrow dyked channel running through a mix of agricultural land with small urban areas. However, despite the embanking, there are areas of intertidal marsh present as well as managed realignments, e.g. the Kruibeke site.

The main urban centre of the system is the City of Antwerp with estuarine width increasing downstream from the conurbation. The port area extends through much of the middle estuary and includes extensive modifications to morphology and channels (e.g. Kanaaldok and the Schelde-Rijnverbinding) as well as land claim around Doel. There are however extensive intertidal marsh and mudflat habitats in this zone (between Doel and Kruispolderhaven), including areas of managed realignment.

There is a further widening of the estuary towards its mouth and this includes the Westerschelde. The zone includes large areas of intertidal and subtidal habitat included within the Natura 2000 designation, but also with the port complex of Flushing-Nieuwdorp.

<u>User interactions</u>

Analysis indicates that despite a high number of conflict interactions, these are somewhat lower in severity than for the other estuaries, suggesting that either the management of conflicts on the Scheldt is more effective than on the other case study estuaries, or that the scores attributed to the conflict interactions by the working group are lower across the estuary. Whilst the latter cannot be discounted, analysis of working group responses would indicate that the severity of impact values ascribed were consistent with the other groups.

The outcomes from the Scheldt analysis are also of interest in that whilst the use level scoring indicates substantial ports related activity including navigation uses in the mid to outer estuary (oligohaline to polyhaline zones), together with conservation protection (Natura 2000) in the same zones, the number of severe conflict interactions between components of these two uses is relatively infrequent when compared to the same interaction combinations from the other estuaries.

Furthermore, the scoring of these interactions indicates that there is some asymmetry between the two user topics in terms of severity of impact, with higher conflict scores identified from the impact of conservation protection requirements on navigation and ports activity, than from navigation and ports activity on conservation protection needs. This is atypical in terms of the responses seen from other estuaries and would appear to indicate either an effective navigation and ports management strategy in terms of impacts to the Natura 2000 protection requirements, or perhaps it is an artefact of the working group perception of the issues.

Table 5.7. Strongest associations between uses/users for the Scheldt Estuary. Those in red are negative user associations, green positive.

Impact of		Impact on	
Category	Activity	Category	Activity
Conservation	Protected intertidal area	Access	Recreational access on the banks & intertidal
Flood/coast protection	Flood bank (dyke/gabion/wall)	Residential	Housing adjacent to system
Navigation	Channel stabilisation	Access	Commercial
Navigation	Channel stabilisation	Navigation	Vessel movement
Navigation	Maintenance dredging	Navigation	Vessel movement
Infrastructure	Infrastructure on bed or in water column (e.g. pipes, cables, piers, marinas)	Access	Commercial

5.4.1.4 Humber estuary

Background

The entire estuary and the lower reaches of the freshwater system are included within the Natura 2000 designation (SPA & SAC), including the lower tidal freshwater/upper oligohaline reaches of the system. However, the majority of the main two fluvial tributaries into the estuarine system are excluded from the designation. These tributaries feature fringing dykes with very little intertidal mud or marsh habitat available. Commercial navigation occurs along both of the tributaries to inland ports and wharves, but with the fairways of these fluvial systems not subject to any maintenance dredging.

The oligohaline zone features a largely agricultural hinterland and is used as a navigation. However, this zone is characterised by several extensive and mobile sandbanks and vegetated islands.

The inner middle estuary mesohaline zone includes the City of Hull frontage and port complex and no active maintenance dredging of the main navigation channel is undertaken. Instead, a system of sounding and navigation marker repositioning is employed. The outer middle mesohaline/polyhaline zone includes an extensive ports frontage on the south bank of the estuary with dredging of harbours and berthing pockets undertaken, and with associated industrial development on the near-hinterland. Historically, the morphology of the estuary in this zone has been modified through landclaim for agriculture.

The outer polyhaline zone features a much wider estuarine morphology which includes the extensive mudflats of Spurn Bight and the sand spit of Spurn Head. Coastal recreation occurs on the outer south bank. The only large active fairway dredging programme (Sunk Dredged Channel) is also located in this zone.

User interactions

The conflict matrix outputs for the Humber (Table 5.8) indicate that there are a number of high scoring potential conflicts, many of which are either acting from or on conservation protection requirements. Many of these interactions are with navigation needs and those of the associated ports industry, although also in relation to flood protection requirements.

Interestingly, the abundance and severity of these interactions is possibly greatest in the middle estuary, reducing somewhat in the outer estuary, although the latter zone includes the only area of fairway subject to maintenance dredging. This may be due to the presence of a recently produced dredge management strategy for the estuary and implemented to meet requirements under the Habitats Regulations.

Consistent interactions occur between conservation protection, ports activity and flood protection in the middle and outer estuary, this reflecting resource limitation in these areas, particularly in relation to intertidal habitat and compensatory provision. In the inner estuary and tidal freshwater tributaries, the level of user conflicts reduces both in terms of frequency and severity, although the presence of flood protection banks and access along them is identified as a high impact on conservation protection, and with conservation protection conversely impacting on public access and the provision of set-back for flood protection.

Synergisms are however identified from flood protection set-back with conservation protection and recreational access although with a dislocation of any reciprocal synergisms.

Table 5.8. Strongest associations between uses/users for the Humber Estuary. Those in red are negative user associations, green positive.

Impact of		Impact on	
Category	Activity	Category	Activity
Conservation	Protected subtidal area	Ports & Harbours	Port activity on the intertidal/subtidal area
Conservation	Protected intertidal area	Access	Recreational access on the banks & intertidal
Conservation	Protected intertidal area	Flood/coast protection	Defence set-back
Conservation	Protected intertidal area	Ports & Harbours	Port activity on the intertidal/subtidal area
Access	Recreational access on the banks & intertidal	Conservation	Protected intertidal area
Flood/coast protection	Flood bank (dyke/gabion/wall)	Conservation	Protected subtidal area
Flood/coast protection	Flood bank (dyke/gabion/wall)	Conservation	Protected intertidal area
Ports & harbours	Port activity on the intertidal/subtidal area	Conservation	Protected subtidal area
Ports & harbours	Port activity on the intertidal/subtidal area	Conservation	Protected intertidal area
Conservation	Protected intertidal area	Conservation	Protected subtidal area
Flood/coast protection	Defence set-back	Conservation	Protected subtidal area
Flood/coast protection	Defence set-back	Conservation	Protected intertidal area
Flood/coast protection	Flood/coast protection	Access	Recreational access on the banks & intertidal
Flood/coast protection	Flood/coast protection	Residential	Housing adjacent to system

5.4.2 Typology of estuarine user interactions

5.4.2.1 Salinity zone associations

Based on the information from the conflict matrix process, multi-dimensional scaling MDS ordination and cluster analyses were performed on the activity scores per salinity zone and by estuary (Figure 5.9). Analysis of similarity (2-way ANOSIM) was performed using both the activity levels in each of the estuaries and salinity zones.

Results indicate a significant difference in activity levels amongst the TIDE estuaries with the Scheldt Estuary being distinct from the others. Additional, less defined differences in activity levels were largely observed between estuaries rather than between comparable zones. However, there are some groupings of note within the analysis, with the A groups in general exhibiting higher levels of activity overall.

Group A1 (Humber Estuary - outer mesohaline and inner polyhaline) shows the highest overall level of activity, in particular high port activity, infrastructure on the bed, and industrial activity, although notably, no channel stabilisation. This is compared to group A2 which is predominantly comprised of zones from the Weser Estuary which have higher water abstraction.

Group B clusters featured lower activity levels, again grouped around the different estuaries (Humber B1, Elbe B2, and Scheldt B3) rather than salinity zone.

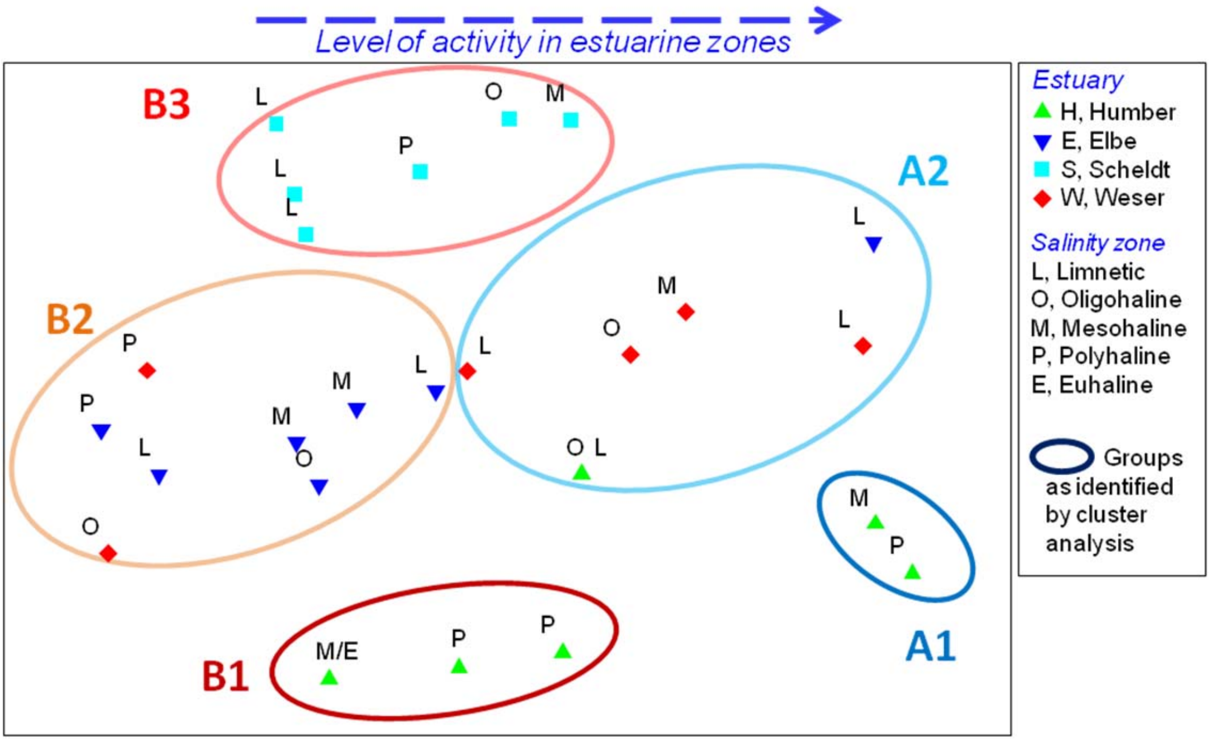


Figure 5.9. MDS ordination of estuarine zones based on dominant estuarine activities.

The analysis suggests that in most cases there are a number of specific management requirements for each estuary, these requirements based on differing usage levels on a sectoral and spatial basis.

As such, there is no common typology of use for each salinity management zones, with the characterising parameters of use possibly more linked to morphology and use. However, despite this, all estuaries are also identifiable as having specific management requirements, with some clear cross-cutting user conflicts identified from the case study analysis.

5.4.2.2 Conflict interaction typology

A series of user interactions have been identified that are present across most zones in the case study estuaries, and these are shown as a mean score across all zones and all estuaries in Figure 5.10 and Table 5.9. Table 5.9 therefore summarises the main interactions observed from the conflict matrix process for both antagonistic and synergistic uses.

Eight high scoring conflicts were recorded. These centre around:

- Conservation on navigation
- Conservation on access
- Access on conservation
- Flood protection on conservation
- Navigation on conservation.

Within these categories, further typologies are identified.

- Conservation on the intertidal zone is impacted by:
    - Recreational access along the banks & intertidal zone
    - Provision of flood bank protection
    - Capital dredging for navigation
- Conservation on the subtidal zone is impacted by:
    - Capital dredging for navigation
    - Maintenance dredging for navigation
- Capital dredging for navigation impacted by:
    - Conservation of the subtidal zone
- Maintenance dredging for navigation impacted by:
    - Conservation of the subtidal zone
- Recreational access along banks and the intertidal zone impacted by:
    - Conservation on the intertidal zone

In addition, a series of synergisms were also identified. Unsurprisingly, many of these were within a high level topic, e.g. intertidal conservation on subtidal conservation, and maintenance dredging on vessel movement. However, there were some high scoring inter-topic associations also identified. These were in relation to the provision of flood protection banks/dykes and port related activity adjacent to the estuary, industrial activity adjacent to the estuary, and housing provision adjacent to the estuary.

An average of the conflict scores across all zones and all case study estuaries (Figure 5.10) illustrates the main sectors of potential estuarine user conflict which may require management focus (shaded red), together with areas of synergistic potential (shaded green) in the severity of the conflict (or value of synergism) indicated by the intensity of the shading with darker shading for more intense interactions.

As noted earlier in text, antagonistic interaction areas are frequently aligned with the topic areas of conservation protection; flood protection; and ports and navigation requirements, with some specific synergisms resulting from flood protection services also notable within these.

As such, the identification of relatively generic high scoring interactions (both negative and positive) are of value in terms of establishing a typology of management needs, this in turn providing a basis for the translation of management requirements into an Ecosystem Service common currency, and thus linking this to the provision of mitigation and compensation measures.

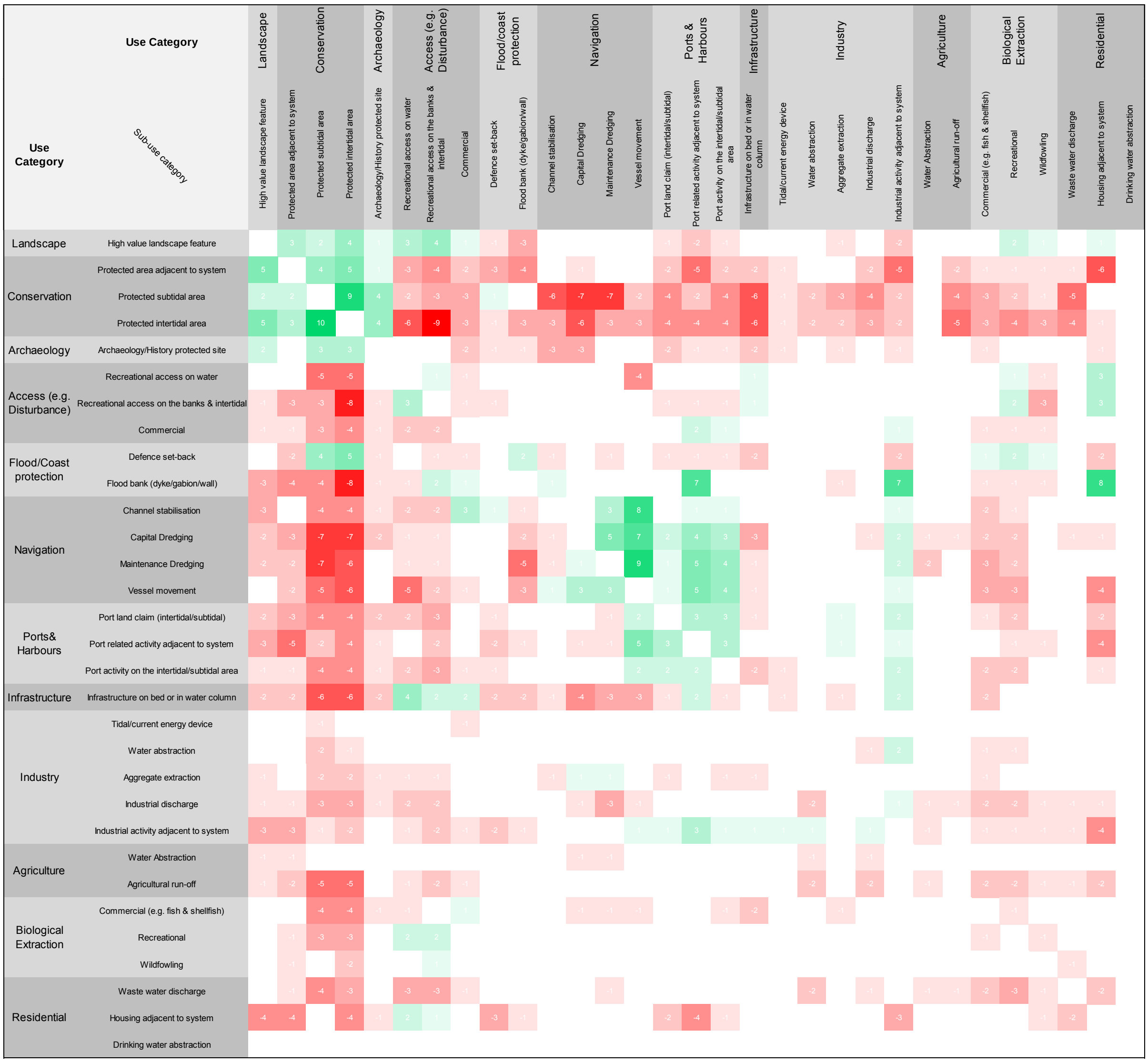


Figure 5.10. Summary of antagonistic and synergistic user interactions for all zones and all TIDE estuaries.

However, whilst these high level typologies provide an indication of the main interaction areas, it is important to emphasise that estuary specific interactions will require specific management focus. This focus needs to have both estuary and topic specific components, although again, the application of these using appropriate mitigation/compensation measures can be assessed using an Ecosystem Services approach (Jacobs et al. 2013).

Table 5.9. Strong negative and positive associations between uses/users for all estuaries combined (those in bold are the strongest noted).

Impact of		Impact on	
Category	Activity	Category	Activity
Conservation	Protected subtidal area	Navigation	Capital dredging
Conservation	Protected subtidal area	Navigation	Maintenance dredging
Conservation	**Protected intertidal area**	**Access**	**Recreational access on the banks & intertidal**
Access	Recreational access on the banks & intertidal	Conservation	Protected intertidal area
Flood/Coast protection	Flood bank (dyke/gabion/wall)	Conservation	Protected intertidal area
Navigation	Capital dredging	Conservation	Protected subtidal area
Navigation	Capital dredging	Conservation	Protected intertidal area
Navigation	Maintenance dredging	Conservation	Protected subtidal area
Conservation	**Protected subtidal area**	**Conservation**	**Protected intertidal area**
Conservation	**Protected intertidal area**	**Conservation**	**Protected subtidal area**
Flood/coast protection	Flood bank (dyke/gabion/wall)	Ports & Harbours	Port related activity adjacent to system
Flood/coast protection	Flood bank (dyke/gabion/wall)	Industry	Industrial activity adjacent to system
Flood/coast protection	Flood bank (dyke/gabion/wall)	Residential	Housing adjacent to system
Navigation	Channel stabilisation	Navigation	Vessel movement
Navigation	Capital dredging	Navigation	Vessel movement
Navigation	**Maintenance dredging**	**Navigation**	**Vessel movement**

5.4.3 Estuarine user management

The case study analysis has highlighted a number of well established antagonisms between key sectoral uses in estuaries, as well as areas of synergistic opportunity. This has allowed the comparison of conflict levels to be made and for a series of conflict and benefit relationship typologies to be identified which are considered to be applicable at a north-west European estuarine level (see Section 5.4.2.2).

From the case study analysis, there are clearly a series of recurring user conflicts in estuaries, although the detail and severity of these does vary on an inter and intra estuary basis. This variability to some extent will reflect the estuary specific ecosystem service provision, but may also reflect management efficacy.

5.4.3.1 Summary of key user interactions from the case studies

Across the case study estuaries a series of 8 high level conflict interactions were noted (Table 5.9).

Conservation protection : Navigation (reciprocal interactions)

Many of these interactions related to Conservation Protection requirements and Navigation aspects. Conservation protection of the subtidal area (e.g. via SPA or SAC designation for interest features) was regularly identified as having a considerable impact or constraint on both maintenance and capital dredging activity. These user conflicts were reciprocal with both maintenance and capital dredging work identified as impacting on subtidal conservation protection needs. Capital dredging activity was also identified as having an high conflict level with the conservation protection of the intertidal area, but with interestingly at a high scoring level this was not identified as a reciprocal conflict, and nor was the effect of maintenance dredging identified as having a conflict interaction with intertidal conservation protection needs.

The ecological impacts of capital dredging works on estuarine communities are well documented and they are incorporated into development specific assessments (e.g. EIA, HRA). However, whilst mitigation measures can be applied to reduce such impacts, there will be residual effects from such works. These will be primarily (although not solely), associated with direct habitat loss, particularly as in many instances capital dredging will be undertaken as a precursor to some form of development with associated long-term loss of subtidal or intertidal habitat (e.g. port development).

Given the limited potential for effective mitigation measures to be applied where such habitat loss occurs (other than through compensation measures such as habitat creation at an alternative location), it is unsurprising that the impact of capital dredging on areas of intertidal and subtidal habitat afforded conservation protection are routinely and highly scored as a conflict interaction. Similarly, the principles of no net loss of habitat applied to estuaries afforded SPA and SAC protection, together with the likelihood of capital dredging activities to incur residual impacts which may affect the integrity of a European Marine Site, means that a reciprocal high conflict interaction association will regularly occur.

Management can be implemented to potentially reduce the scale of these interactions through high level estuarine structure planning and the development of collaborative strategies between statutory conservation and economic development planning agencies, as well as the navigation and ports organisations. However, many capital dredge plans will be development project specific and ultimately addressed through EIA and planning enquiry procedures, and as such may not necessarily be fully integrated into an active management strategy other than through conent compliance. Potential management measures and EIA best practice are covered elsewhere in this document.

Maintenance dredging and conservation protection was also identified as a potential reciprocal conflict interaction, and as with capital dredge works, the ecological impacts of this activity are understood in principle. However, the scale of effects will vary on an estuary basis, e.g. depending on the dredging work undertaken. For instance, the maintenance of fairway depth (following capital deepening) in canalised or semi-canalised reaches has the potential to have a significant effect on *in situ* and adjacent ecological function if it is required across most of the estuary profile and for a considerable proportion of the reach, which occurs in some of the areas of some of the case studies. However, where limited fairway or berthing pocket dredging is required in a larger system, then the effects may be considerably reduced.

Clearly, in scenarios where considerable maintenance dredging is required, then a range of strategies may be necessary to address not just ecological function loss, but also other issues, such as tidal pumping with increased tidal range upstream. However, even with such strategies in place, for instance in the Elbe, in some estuaries there would appear to be a potential for substantial residual impacts, including loss of ecological function and associated impacts to European site interest feature integrity, potentially requiring compensatory measures such as habitat creation. However, where the scale of operation is lower, then there is greater potential for management to effectively offset impacts on site integrity. For instance, on the Humber, maintenance dredging activity is relatively small scale and undertaken over a smaller percentage area of the estuary system. The ecological impacts are reduced/offset through the application of several measures (see below for further detail), and through the development of a maintenance dredge strategy by the navigation agency and main port operator in conjunction with the statutory nature conservation agency. The efficacy of this strategy would appear to be borne out by a relatively low interaction score for the Humber, compared to the other case study estuaries.

As such, whilst the implementation of capital dredge programmes are likely to generate reciprocal user conflicts with conservation protection requirements which can be difficult to 'manage out', maintenance dredging effects may be at least partially mitigated, and any user conflicts particularly with conservation protection needs can be addressed through management identification and measure implementation.

Access: Conservation protection

The analysis from several several of the case study estuaries identified Access Provision and Conservation Protection as another key area of potential user conflict. Indeed, the impacts of conservation protection of the intertidal zone on recreational access along the adjacent flood protection banks was the highest ranked negative user interaction, with a slightly lower reciprocal antagonistic association also observed.

The potential for impacts of recreational activity on estuarine ecological components are evident and complex, with a considerable range of divergent recreational activities undertaken in the coastal and estuarine system. Indeed, many permitted recreational activities will produce potential negative intra-topic user interactions, e.g. wildfowling (hunting) and bird watching which often require management themselves. For instance, the Humber Management Scheme is currently undertaking a long-term, multi-phase project to characterise the types and levels of recreational activity on the Humber as well as the impacts that these activities have on the waterbird assemblage of the European Marine Site. This information will then be used to develop targeted management actions.

The identification of user conflicts between recreational access along flood banks and intertidal nature conservation protection needs is therefore expected, given well documented disturbance impacts (e.g. Cutts et al. 2013), although it should be noted that the relationship is complex and not all recreational activity on flood banks will have a similar impact level. For instance, the presence of people with dogs has been shown to often have a greater bird disturbance effect than the presence of people alone, whilst a vehicle using a flood bank will usually elicit a lesser response. Furthermore, substantial variability in waterbird disturbance response will occur even for an individual vehicle whereby many waterbird assemblages will be considerably more tolerant to a moving vehicle than to one that has stopped, although this, and other similar associations will further vary due to a number of additional variables including background activity, time of year, weather conditions etc (e.g. Cutts et al. 2013).

Therefore, whilst recreational access along flood banks and associated disturbance will have a potential to impact on waterbird communities and potentially interest feature(s) and thus site integrity, there are a series of management actions available to reduce many of these. These can include the spatial restriction of the most ‘disturbing’ activities from the areas of greatest sensitivity (e.g. wildfowl refugia where hunting is not permitted), seasonal restriction of some activities outwith breeding or over-wintering periods, modification of access points to reduce impacts (e.g. barriers to restrict motorbike access along flood banks; screening of walkways to avoid visual stimuli to receptors), and the promotion of access to areas where receptor sensitivity and importance is lowest (e.g. ‘honey-pot’ sites).

However, the high level of conflict score attributed to the impact of conservation protection of the intertidal zone on recreational access along flood banks is of note. There are certainly areas where recreational activity in a specific area of an estuary may be restricted in some way (as described above). However, such restrictions can also result from other uses, including ports activity, flood protection and even other recreational uses. The relative severity of the interaction (the highest mean level recorded from the case study analysis) suggests therefore that other factors may be influencing this. In particular, public perception and education are suggested as potential contributory factors to the strength of the relationship. The public perception study undertaken in the Elbe (Ratter and Weig 2012) identified conservation protection as the greatest area of concern, with significant constraints on agricultural uses around the estuary recorded in rural areas and constraints on industrial activity in the conurbations.

Whilst conservation protection based constraints relating to the recreational uses of estuaries are often applied as part of a suite of management measures, it is postulated that the relative severity of the associated conflict interactions may be a result of public perception and understanding. In estuarine systems where there are a series of often competing user demands for services, the needs for aspects of economic development and flood protection are relatively easy to understand and attribute an economic or socio-economic cost to. Nature conservation aspects, as well as recreational uses (of which aspects of conservation use are often intrinsically linked) are however less readily valued, or will have a perceived value which will vary between users. The Ecosystem Services approach described in this report (e.g. Chapter 3) provides a basis for the comparable valuation of differing services, and where integrated into wider planning processes and decision making can provide clarity on management actions.

Flood / Coastal protection: Conservation protection

The provision of flood protection in the form of banks, dykes and walls was identified as having a strong conflict impact on the conservation protection of the intertidal habitats of Natura 2000 estuaries. This interaction relates primarily to the problems relating to ‘coastal squeeze’ whereby the natural inland movement of the shore profile in response to relative sea level rise is stopped by the presence of hard defences, with a corresponding loss of intertidal habitat over time. However, there will be further indirect issues resulting from the presence of such flood protection structures associated with the potential for increased access potential (and thus disturbance) which usually occurs along such defences as well as physical process issues such as increased wave refraction and scour etc.

A number of management responses are available to address issues associated with coastal squeeze and hard defences. The technique of managed realignment or the setting back of defence alignments has been used as a tool in a number of estuaries and the application of this is discussed in Chapter 5, with other soft engineering options available.

The managed realignment technique is therefore often employed as a tool to offset sea level rise related habitat and function losses in Natura 2000 estuaries. However, whilst its application can be of considerable value in addressing Natura 2000 habitat losses (see Chapter 5), the user/use conflict analysis results show that the application of the tool will often entail other user conflicts, including with agricultural land use and public access. As such, a range of potential user issues need to be considered, not least the provision of information to inform stakeholder engagement, given, as described above, the reasons for management actions relating to conservation protection are not always clearly understood by the public (e.g. Ratter and Weig 2012 and see Chapter 7).

Positive synergistic user relationships

The estuarine user interaction analysis undertaken on the case study estuaries also identified a series of positive synergisms between uses. The majority of these were, as might be expected, for supporting services, for instance the strongest positive association was identified within the navigation topic area between maintenance dredging and the movement of shipping.

There were however further strong positive associations identified between differing topic areas but where linkages are transparent, for instant between the provision of flood protection and residential housing adjacent to the estuary. These associations are listed in Table 5.9.

However several less evident positive use associations were also identified from the process, and although individual interactions were not scored sufficiently highly to be included in Table 5.9, they are evident from user interaction summary in Figure 5.9. In particular, a cluster of positive interactions were identified between the conservation protection topic area and the landscape value and archaeology topics. The clustering of these positive associations is of interest given that they refer to uses that have are difficult to provide an economic value to (conservation, landscape and cultural heritage), but that were rated as important topic areas by all working groups undertaking the case study analysis process. The role of the Ecosystem Services approach is considered important in the integration of such uses into management objectives and plans for estuaries, and in the acceptance of such uses as valid management objectives by the wider stakeholder audience.

5.4.3.2 Spatial scale variability

Although the process has allowed inter estuarine comparisons to be made and typologies to be established, the analysis has also identified that in most instances the spatial distribution of these interactions was variable both at an inter and intra estuarine scale.

Furthermore, statistical analysis of use levels and salinity zonation did not identify any strong correlations, suggesting that whilst salinity can be an important factor in determining ecological functions within an estuary, other factors will also influence a range of uses and thus user conflict scenarios. The Humber in particular showed considerable dissimilarity in terms of use levels and conflict interactions compared to the other case study estuaries, with reduced conflict levels arising from navigation related issues on Natura 2000 protection requirements and *vice versa*.

This somewhat atypical outcome in relation to ports services and conservation protection is considered primarily due to the positioning 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 than the other estuaries. This reduction in conflict level is assisted both by natural processes maintaining navigation depth in most reaches of the estuary and tributaries and the application of an adaptive fairway management process whereby changes in channel position are monitored and the fairway alignment altered accordingly, thus substantially reducing the need for maintenance dredging. Navigation depth in the inner estuary and fluvial tributaries is not subject to maintenance and/or deepening through dredging, with restrictions therefore placed on vessel draught.

5.4.3.3 Sectoral use variability

Although estuaries are subject to many often similar competing and conflicting uses and users and thus high level management needs are the same across most north-west European estuaries, e.g. 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. These vary both between and within estuaries such that whilst a framework of management aims and measures can be established, a 'one size fits all' management strategy is unrealistic. The conflict analysis process 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 sites, whilst the presence of flood protection dykes/banks 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 tool or measure to mitigate for the impacts of coastal squeeze arising from the presence of fixed flood protection dykes, then the issues identified from the analysis indicate a potential management pinch-point, despite the tool itself having an important role in

European estuary flood risk management. The technique is also used as a compensation measure for development related habitat loss in Natura 2000 estuaries, and again, therefore requires attention if, as a technique, it is to be effectively deployed effectively without associated conflicts occurring.

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, primarily this would occur through competition or restriction in land availability. Again therefore, given the potential for the tool to be used as a measure to increase flood assimilation capacity and wider flood protection, then the success of the technique requires both management focus and possibly additional stakeholder involvement.

5.4.3.4 Conflict management

Stakeholder integration

As described earlier, the requirements for conservation protection in many estuaries raise a number of management conflicts with other uses, including the ports industry, flood protection requirements and recreational access to the estuary and *vice versa*.

As such, mechanisms are necessary to assist in stakeholder inclusion and conflict resolution as part of a wider integrative management strategy. A study investigating the public perception of estuary management was undertaken on the Elbe as part of the TIDE project (Ratter and Weig 2012), and reported that nature conservation provision had the most serious potential for conflict with other uses primarily agriculture in rural areas and industry in the population centres.

Estuary-specific surveys which identify stakeholder issues are therefore considered a useful tool to confirm key areas of conflict, and incorporate local variations in both spatial and sectoral severity. They also have the potential to identify areas where wider public participation and education may assist the integration process.

Such methods can include the Ecosystem Services approach which allows a value-based comparison of differing services (and thus uses), including those with no readily evident economic value such as aspects of nature conservation, heritage and landscape.

Integrated & targeted management

The analysis process has identified a series of high level conflict interactions between Natura 2000 requirements and the ports industry and related requirements such as the maintenance of navigation routes (and vice versa), with the Humber however showing atypical values. Whilst this is primarily a result of the positioning of the main Humber ports industry towards the mouth of the estuary, the development of a dredging strategy for the

Humber in the context of requirements under the Habitat Regulations Assessment is considered to have assisted in the reduction of conflict potential, with the strategy developed by the ports authority in conjunction with statutory agencies charged with environmental protection.

Whilst the Humber provides a good example of sectoral-based management development, the conflict process identified a high number of high scoring conflict issues, within the estuary, as well as on the Elbe and Weser particularly in the context of those derived for the Scheldt estuary. The Scheldt, whilst having some very high level conflicts present, primarily between navigation requirements and Natura 2000 protection needs, in general featured a reduced number of conflict areas and an increased number of synergistic activities.

Of course this lower scoring may be to some extent an artefact of the RWG assessment process, and the successful application of management actions have not been specifically identified from the review of legislation and SWOT analysis (Section 5.3).

However, based on the outcomes of the analysis process, it is possible to conclude that management on the Scheldt appears to be effective in a number of areas. This reduction in the level of conflicts and indeed the relatively high level of synergistic interactions may be a result of its relatively long period of integrated management arising from the ´Long term vision Westerscheldt´ plan, integrating ´safety accessibility and environment´ aspects, including requirements for trans-national action and data sharing between Belgium and the Netherlands.

Indeed, it may be that the need to establish a trans-national management approach, with associated co-ordination of monitoring and data provision, has meant that a more effective integrated management approach has been developed than for estuaries where such a requirement is unnecessary and a more sectoral and less integrated management approach can be developed.

5.4.4 Measures interactions and disbenefits

The conflict matrix analysis has highlighted that in some instances measures employed to mitigate one management problem can produce other conflict areas. For instance, managed realignment can be employed as a specific tool or measure to offset intertidal habitat loss from both direct land claim and/or coastal squeeze, in order to maintain Natura 2000 integrity as well as offsetting losses in flood assimilation capacity.

However, based on the results of the conflict matrix analysis from the case study estuaries, the application of this technique can in itself impact on aspects of Natura 2000 provision as well as on flood protection requirements as well as potential provision for housing, industry and agriculture.

As such, whilst the potential of the tool to be of value as a measure to increase flood assimilation capacity and wider flood protection, in addition to providing compensatory/mitigatory Natura 2000 function is evident, the success of the technique within the wider process of estuarine management requires both management focus and possibly additional stakeholder involvement.

5.4.5 Summary and links to other approaches

Based on the outcomes from the user conflict analysis undertaken on the case study estuaries, a number of conclusions can be drawn.

At an individual estuary level:

- The Weser estuary has a relatively large number of moderate to high severity conflicts (29), however only 4 (or 14%) of these are potentially severe.
- The Humber has a marginally lower number of moderate to high conflicts (24) but a considerably greater number of severe interactions (9 or 38%).
- The Elbe, whist having considerably less moderate to high conflicts (12) has 5 of them rating as severe (42%).
- The Scheldt analysis indicates that there are very few moderate to severe conflicts and a low proportion of these are actually scored as severe.
- The Weser issues although more numerous are generally less severe than identified for the other estuaries, and the Elbe, whilst having relatively few issues, faces a larger proportion of these being severe.
- Whilst there are synergisms identified for all estuaries, the Scheldt has many more and these tend to be rated more positively.

North-west European estuaries are multi-user environments, and it is already understood that they require management to ensure the best and most equitable use of resources amongst the variety of legitimate stakeholders. However, whilst many high level management needs are generic across these estuaries, there are clear differences in priorities for specific management actions, and these will vary both between estuaries and, as usage potential is not uniform, also along an individual estuarine system.

This means that for key sectoral interactions between users, there may often be several spatial hot-spots, whilst sector interactions will develop in different areas. As such, management needs to reflect this spatial and sectoral interaction variability and target resources at specific areas.

There are clear indications that the requirements for conservation protection raise a number of management conflict pinch-points with other uses, including the ports industry, flood protection and access to the estuary, whilst ports related activity is often a common cause of conflict with conservation needs. However, this may in part be due to aspects of user perception and issue understanding, linked also to problems in the attribution of an economic value to ecosystem services such as biodiversity, landscape and heritage. The conflict analysis approach used here therefore provides a useful transparent medium to inform stakeholders of the basis for management options and decisions.

Furthermore, whilst this typology of high level conflict was seen on the Elbe, Weser and Humber in largely similar levels, there was a clear reduction in this on the Scheldt, and given the relatively long period of integrated management in this system, including requirements for trans-national action and data sharing, it is possible to conclude that management of these conflicts can be effective over time.

Whilst, a uniform management approach may not be the most effective use of resources and some management initiatives will often require a quite specific spatial focus. This is not to discount the broad tenet of holistic management, but to emphasise the spatial variability in some management issues and the need for targeted action. A typology of estuarine user interaction conflicts and synergisms has provides a generic priority list of management topics for estuaries, as well as indicating areas where beneficial outcomes may occur.

Loose linkages have been identified between the estuarine users/uses and ecosystem service criteria, although there is not a direct correlation between these. As such, the use of the conflict typology described above provides a useful indication of likely conflict areas which can be linked to ecosystem service provision. Furthermore, through linkages established between ecosystem services and management mitigation measures (Chapter 6), it is possible to establish a conceptual basis to link estuarine user conflicts and management measures using ecosystem service terminology as the common ‘currency’ (Figure 5.11).

It is concluded that whilst north-west European estuaries present many generic management challenges, initiatives need to be site-specific in order to accommodate both the natural and human systems. Furthermore, the application of the Ecosystem Services and conflict analysis approaches employed in this study have the potential to be combined to assist in effective management, particularly when used in combination with targeted measures.

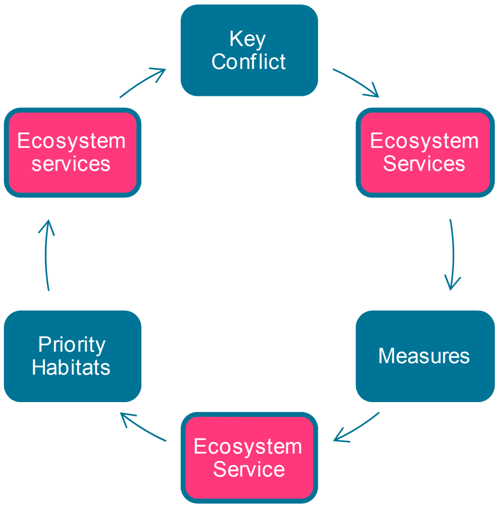


Figure 5.11. Conceptual framework showing linkages between conflict areas, mitigatory measures and priority habitats using the Ecosystem Services approach as common currency.

However, importantly it is necessary to understand that measures employed to provide a management solution for a specific user problem can also generate their own management issues. Based on the outcomes of the user analysis from the case study estuaries, this is particularly the relevant for measures used to address flood protection, land claim offset and Natura 2000 requirements.

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6 Measures for Management and the Delivery of Ecosystem Services

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Management measures applied to estuaries are anthropogenic actions designed to maintain, restore or enhance the functioning of the system for one or more services (these may be for ecological, economic or societal gain). Such measures can in particular be focussed on providing mitigation and/or compensation for actual or potential changes to estuary function as a result of developments which have been designed to utilise aspects of estuarine ecosystem services for a variety of plans or projects.

Hence, estuarine management measures are both driven by an aspiration to protect or to improve the ecological and landscape status of large European estuaries which are often in poor or suboptimal condition, whilst also permitting the resource exploitation of parts of the same estuaries for socio-economic development (e.g. port extension).

In principle, each management measure (in particular larger ones) has to be assessed regarding whether: a) it has met or will be able to meet the primary objectives, b) it has had an impact on other estuarine uses and functions, and c) it meets EU legislation objectives.

In order to identify examples of good practice in relation to this comprehensive assessment process, a set of estuarine management measures has been evaluated within the TIDE project. These management measures were compiled within the case estuaries, relate to different measure types and aim at different development targets. Each management measure is related to specific management questions in estuaries, e.g. how to improve the ecological status or how to enable better navigation in fairways.

Since there was no established appropriate methodology for measure evaluation available, a new tool was developed within TIDE. It identifies and assesses both the targeted and additional benefits that the management mitigation and compensation measures may provide, e.g. for the delivery of ecosystem services, EU environmental law such as Water Framework Directive and Natura 2000 (i.e. Birds and Habitats Directives), and was therefore applied to the set of management measures identified above (on-the-road-test).

As such, this chapter contains three main sections. The first sections describes the management measures that have been compiled within TIDE for each of the case estuaries, and explains the methodological approach for the assessment of measure efficacy and the results of each assessment step. The second section aims, based on an overall classification approach, to merge the results of the single assessment steps in order to identify good practice examples in terms of additional benefits offered by the measure. Finally, the third section describes the lessons learned from the application of the measures as well as the assessment process outcomes, in order to assist in the implementation of future ‘real world’ management measures.

The developed assessment scheme and the results of its application are discussed according to the three main research questions:

1. On what spatial scale (area of measure, estuary zone or entire estuary) is the assessment scheme able to support the estuarine management?
2. Which management measures could adequately be assessed by the assessment scheme?
3. What general conclusions can be drawn based on the on-road-test of the assessment scheme?

Among those measures evaluated within the TIDE project, there have been some dealing with sediment management. However, broader estuarine sediment management normally incorporates an extensive and complex suite of measures and hence may have a crucial impact on the status and development of an individual estuary. As such, in order to identify good practice in this topic area, sediment management activities have to be analysed within a broader management scope and therefore the strategies which lie behind the implementation of single measures have also been addressed and are discussed.

6.1 Management measures in the case study estuaries

This section describes in general, the management measures that have been applied in the case estuaries. 39 management measures have been selected to be evaluated according to the assessment scheme, with each management measure assigned to a specific management type and categories in line with their development targets (Section 6.1.1). Special focus has been given to two management types, i.e. managed realignment measures and sediment management strategies, given their importance as current and proposed management tools and in order to indicate the value and relevance of these management types to the management of estuaries (Section 6.1.2, see also Section 6.3.1).

In the second part of this section the focus will be on the application of the assessment scheme to evaluate the chosen management measures in relation to both the targeted and additional benefits that are provided by the management measures in the case estuaries. To answer this question specific criteria have been identified and applied to these management measures (see Sections 6.1.3 and 6.1.4). These criteria are based on the concept of estimating their potential to deliver ecosystem services (ES), the contribution to beneficiaries linked to the concept of the Total Economic Value (TEV) and the potential benefit to EU environmental laws, i.e. Water Framework Directive (WFD, EC 2000) and the Birds and Habitats Directives (EC 1992; EC 2009).

6.1.1 Identification and categorisation of management measures

39 well documented management measures from the case estuaries have been selected in order to develop and test an assessment tool and to identify good practice examples. This chapter provides basic information on the management measures that have been compiled from the case study estuaries. Specific terms will be defined and explained regarding the categorisation of management measures.

6.1.1.1 Measure categories and development targets

The chosen management measures have been carried out in the estuaries for various reasons and include those which have been or will be implemented within the river channel, the adjacent embankments or on the marshes. Consequently, each management measure will have differing initial targets, and the management measures were therefore separated according to the broad target categories *biology/ecology*, *hydrology/morphology* and *physical/chemical quality*. The differentiation is based on the accompanied development targets of each measure, which are shown in Table 6.1.

Table 6.1. Description of measure categories and assigned development targets. The development target number (#) is needed because some management measures are linked to several development targets

Measure category	Development target	Target #
Biology / Ecology	Measure to develop and/or protect specific habitats	1
	Measure to develop and/or protect specific species	2
	Other measure to develop natural gradients & processes, transition & connection	3
	Measure to prevent introduction of or to fight against invasive species	4
Hydrology / Morphology	Measure to reduce tidal energy, range, asymmetry and pumping effects	5
	Measure for flood protection	6
	Measure to improve morphological conditions	7
	Measure to decrease the need for dredging	8
Physical / Chemical Quality	Measure to reduce pollutant loading (point and diffuse sources)	9
	Measure to reduce nutrient loading (point and diffuse sources)	10
	Measure to improve oxygen conditions	11
	Measure to reduce physical loading (e.g. heat input by cooling water entries)	12
	Other measure to improve self-purifying power	13

6.1.1.2 Management types and overview of the set of selected measure examples

Each management measure was categorised according to the different development targets required by the management action, with focus primarily on three different types of management measures: managed realignment measure (MRM), sediment management strategy (SMS) and morphological management strategy (MMS). However, the boundaries between types are often not clearly defined, in particular regarding types SMS and MMS. Table 6.2 gives an overview of selected measure examples, measure categories as described in Table 6.1, measure types and allocated development targets.

Table 6.2. A list of all management measures of the case estuaries assigned to the measure category, measure type and their development targets. MRM: managed realignment measure, SMS: sediment management strategy, MMS: morphological management strategy. Some measures are highlighted because they are assigned to more than one management category

Category	No.	Estuary	Short title	Abbreviation	Type	Target
Hydrolody/Morphology	1	Elbe	Spadenlander Busch	E-Sp.B.	MRM	1, 3, 5, 7
	2	Elbe	Medemrinne Ost	E-M.O.	SMS	5, 7, 8
	3	Elbe	Köhlfleet "deflection wall"	E-K.	MMS	7, 8
	4	Elbe	Bunthaus	E-B.	MMS	7, 8
	5	Elbe	Sediment trap Wedel	E-S.W.	SMS	7, 8
	13	Scheldt	Lippenbroek	S-Lip.	MRM	1, 6
	19	Scheldt	Sediment relocation Keteplaat	S-S.K.	SMS	5
	20	Scheldt	Walsoorden 2004	S-W2004	SMS	1, 7
	21	Scheldt	Walsoorden 2006	S-W2006	SMS	1,7
	22	Scheldt	Sandbars 2010	S-Sand2010	SMS	1, 7
	32	Humber	MudBug	H-Mud	Others	8
Biology/Ecology	1	Elbe	Spadenlander Busch	E-Sp.B.	MRM	1, 3, 5, 7
	6	Elbe	Hahnöfer Elbe	E-Hahn.E.	MMS	1, 11
	7	Elbe	Wrauster Bogen	E-Wr.B.	MRM	1, 3
	8	Elbe	Hahnöfer Sand	E-Han.S.	MRM	1, 2, 3
	9	Elbe	Spadenlander Spitze	E-Sp.Sp.	MRM	1, 2, 3
	10	Elbe	Reed settlement Haken	E-Haken	Others	1
	13	Scheldt	Lippenbroek	S-Lip.	MRM	1, 6
	14	Scheldt	Groynes Waarde	S-Waarde	SMS	1
	15	Scheldt	Ketenisse wetland	S-Ket.	MRM	1, 3
	16	Scheldt	Paddebeek wetland	S-Pad.	MRM	1,3
	17	Scheldt	Paardenschoor wetland	S-Paard.	MRM	1, 3
	18	Scheldt	Heusden LO wetland	S-Heusd.	MRM	1, 3
	23	Scheldt	Fish pond	S-Fish	Others	1, 2
	24	Weser	Tegeler Plate	W-Teg.P.	MRM	1, 3
	25	Weser	Rönnebecker Sand	W-Ron.S.	MRM	1
	26	Weser	Vorder- und Hinterwerder	W-VorHin	MRM	1, 3
	27	Weser	Kleinensieler Plate	W-Kl.P.	MRM	1, 3
	28	Weser	Cappel-Süder-Neufeld	W-Cap.S.	MRM	1, 2
	29	Weser	Werderland	W-Werderl.	MRM	1, 3
	30	Humber	Alkborough	H-Alk.	MRM	1, 6
	31	Humber	Paull Holme Strays	H-PHS	MRM	1
	33	Humber	Chowder Ness	H-Ch.N.	MRM	1, 2

	34	Humber	Welwick	H-Wel.	MRM	1, 2
	35	Humber	Kilnsea Wetlands	H-Kil.W.	MRM	1, 2
	36	Humber	South Humber Gateway Roosting	H-SHGR	Others	2
	37	Humber	Trent Falls	H-Trent.F.	MMS	5, 8
	38	Humber	Donna Nook & Skeffling	H-D.N.S.	MRM	1, 6, 8
	39	Humber	Tunstall Realignment	H-Trun.R.	MRM	1, 6, 8
Physical/ Chemical Quality	5	Elbe	Sediment trap Wedel	E-S.W.	SMS	7, 8
	11	Elbe	METHA	E-METHA	SMS	9
	12	Elbe	Managing Reihersteg sluice	E-Reiher.S.	Others	11

In total, more than half of the management measures assessed were managed realignment measures (MRM), with around one third of the management measures dealing with sediment or morphological management issues (Table 6.3).

Table 6.3. Overview of total amount of management measures assigned to different management types in case estuaries

Management type	MRM Managed Realignment Measures	SMS Sediment Management Strategies	MMS Morphological Management Strategies	Others
Total amount	22	8	4	5

In terms of management measure contributions according to categories and case estuaries, two thirds of the measures were assigned to the *biology/ecology* category (Table 6.4).

Table 6.4. Amount of management measures assigned to the management categories. (Three management measures were assigned to more than one measure category)*

Measure category	Elbe	Humber	Scheldt	Weser	Total	Ratio
Biology/Ecology	6	9	7	6	**28**	**67%**
Hydrology/Morphology	5	1	5	0	**11**	**26%**
Physical/Chemical Quality	3	0	0	0	**3**	**7%**
Total*	14	10	12	6	**42**	**100%**

Many of the management measures were conducted either in the limnic (freshwater) or the polyhaline zone (Table 6.5), with relatively few management measures implemented in the oligohaline or the mesohaline zones of the estuary. This distribution probably reflects a range of factors although these are generally outwith the aim of the chapter and so will not be described in detail.

Table 6.5. Overview of management measures according to the estuary zones

Case estuaries	Estuary zone				Total
	Limnic	Oligohaline	Mesohaline	Polyhaline	
Elbe	11	0	1	0	**12**
Humber	0	1	2	7	**10**
Scheldt	3	0	4	4	**11**
Weser	3	2	0	1	**6**
Total	17	3	7	12	**39**

6.1.2 Introduction to selected management types

More than half of the management measures were assigned as managed realignment measures (MRM, Table 6.3), hence some detailed investigations of these have been conducted in the case estuaries. Furthermore, managing the sediment and morphological development of an estuary can pose crucial questions for estuarine management and therefore a detailed analysis of the sediment management measures was undertaken for the case study estuaries. Consequently, these two broad management approaches were selected to be described in more detail, focussing on the lessons learned from the inter-estuarine comparison of the measures in the case study sites.

6.1.2.1 Managed Realignment Measures (MRM)

Most of the MRM are aimed at more than one management target, and the targets cover a wide range of topic areas, e.g. habitat conservation, recreation or research. Most of the MRM were implemented in order to conserve or compensate habitats (Figure 6.1).

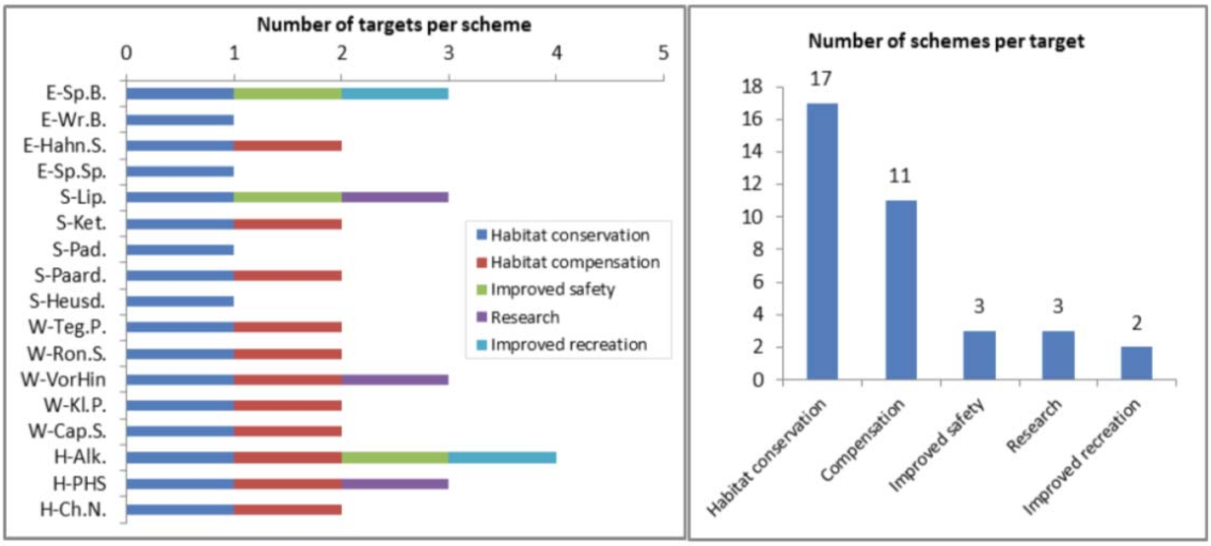

Figure 6.1. Overview of the measure targets per case estuary MRM (left) and number of MRM schemes with each target (right). E: Elbe, S: Scheldt, H: Humber, W: Weser. Explanations of abbreviations for measure denominations see Table 6.2. Source: APA 2013

Due to the range of MRM targets, the implementation techniques of MRM can differ (Figure 6.2). At the Elbe, MRM were implemented through the complete removal of the sea wall accompanied by the lowering of the surface of the land to enable easier tidal influence. For some MRM, mainly on the Weser, the sea wall was not completely removed, but instead a single dyke (wall) breach was implemented, whilst on the Humber the MRM were executed only by sea wall removal or breaching with no other techniques incorporated.

MRM are mainly aimed at habitat conservation or compensation (Figure 6.1). The main habitat type which has been created by MRM in the case estuaries is ‘marsh’, effectively the supralittoral area of the site following the application of tidal influence (Figure 6.3). MRM are also used to address the creation of 'intertidal flats', with the creation of other habitat types such as 'subtidal deep' or 'subtidal moderate deep' of lesser importance. The distribution of these measures effects are dominated by the sites at Alkborough (Humber) and Tegeler Plate (Weser) which are the largest measures in terms of area, that have been assessed (440 ha and 210 ha respectively).

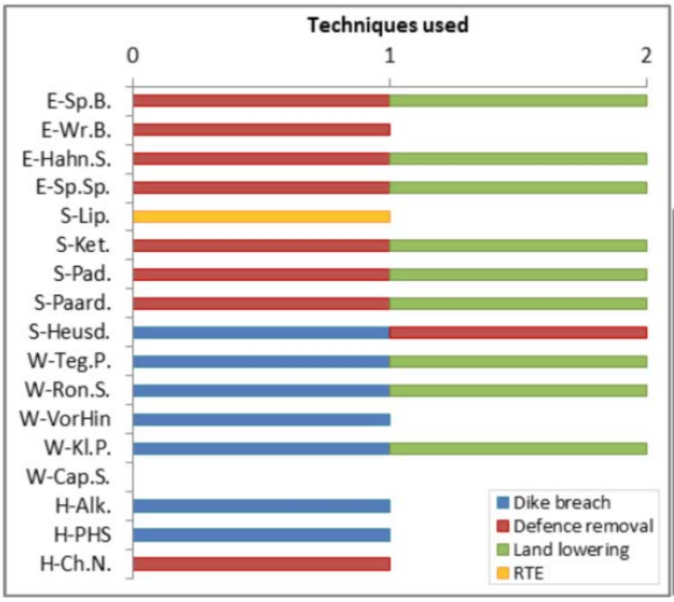

Figure 6.2. Overview implementation techniques used for MRM in case estuaries. E: Elbe, S: Scheldt, H: Humber, W: Weser, RTE: Regulated Tidal Exchange. For explanations of abbreviations for measure denominations see Table 6.2. Source: APA 2013

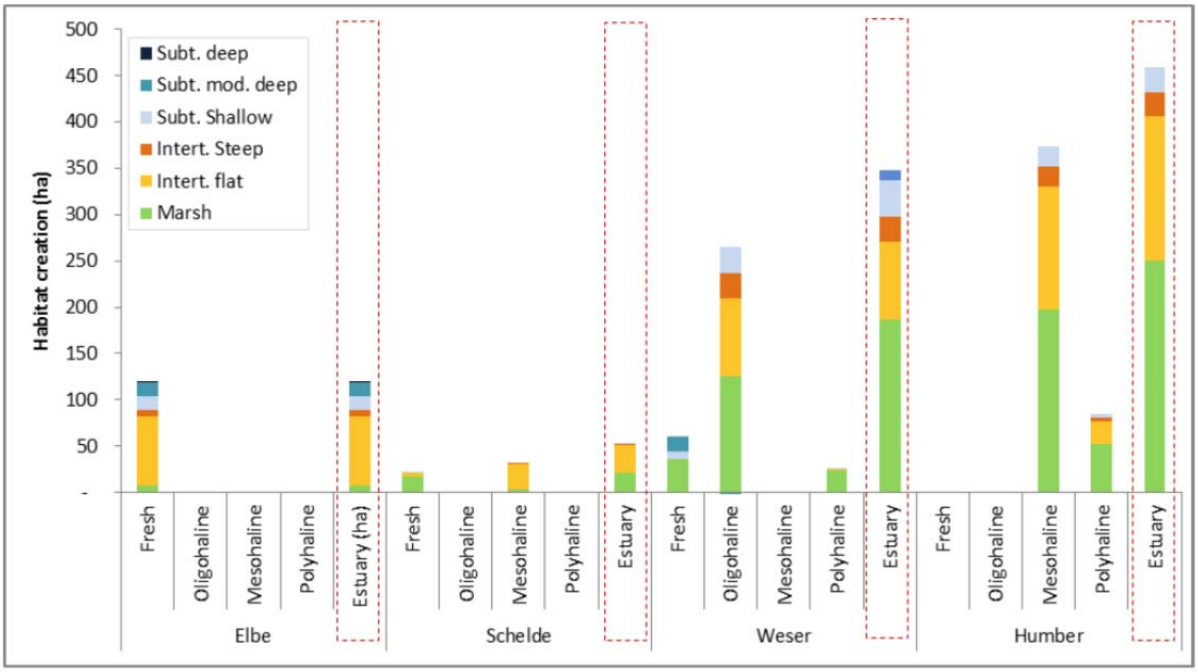

Figure 6.3. Overview of habitat creation by MRM per case estuary and per estuary zone (in hectares). The term 'marsh' as habitat type could synonymously be named 'supra littoral'. Source: APA 2013

6.1.2.2 Sediment management activities

The term sediment management has previously meant simply the dredging and placement of sediments within the framework of fairway deepening and maintenance and has been a cost-effective management technique used by port authorities. However, sediment management now not only requires the integration of measures to manage the accessibility of ports by ships and vessels via fairways, but also the protection against floods as well as legal environmental and ecological requirements and thus, aspects of geomorphological, hydrological and ecological management. Morphological management (deepening, maintenance dredging, managed retreat, placement strategies, etc.) clearly influences accessibility, safety and ecological functioning. Managing the hydrology (mainly storing storm water and managing freshwater discharge) affects safety and ecological functioning. Finally, nature restoration and conservation may influence ecological functioning, safety and accessibility and by this, affects sediment management (BioConsult and NLWKN 2013).

Here the term *sediment management* encompasses the relocation of sediments (dredging and placement in water or disposal on land), the factors creating the need for this relocation and the factors influenced by the relocation of material. Thus, sediment management is interrelated with morphological management, which is primarily aimed at shaping hydro- and morphodynamics, and includes both sediment relocation and river engineering measures by hard structures (Figure 6.4, BioConsult and NLWKN 2013).

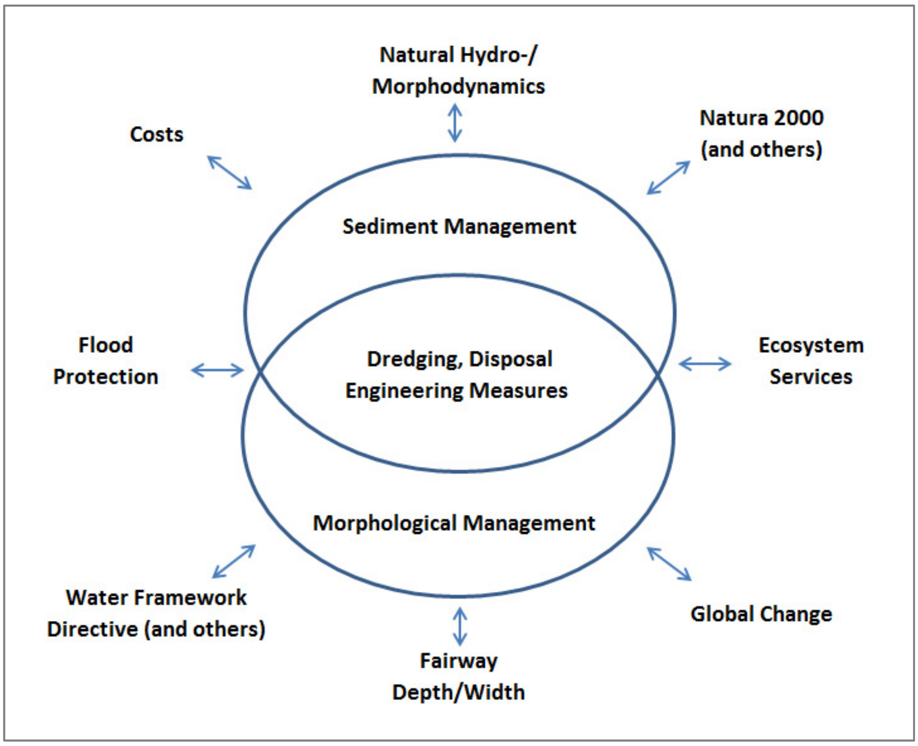

Figure 6.4. Visualisation of the term sediment management. Source: BioConsult and NLWKN 2013

In Figure 6.5 to Figure 6.8, the dredging volumes in the four estuaries are displayed for the periods 2004 – 2010 (Humber) respectively 2000 – 2009 (Scheldt, Weser, Elbe) (Source: BioConsult and NLWKN 2013), with all relevant dredging activities included (within data availability). The dredge volumes shown vary from year to year, depending on management measures as well as changing natural boundary conditions (e.g. freshwater discharge).

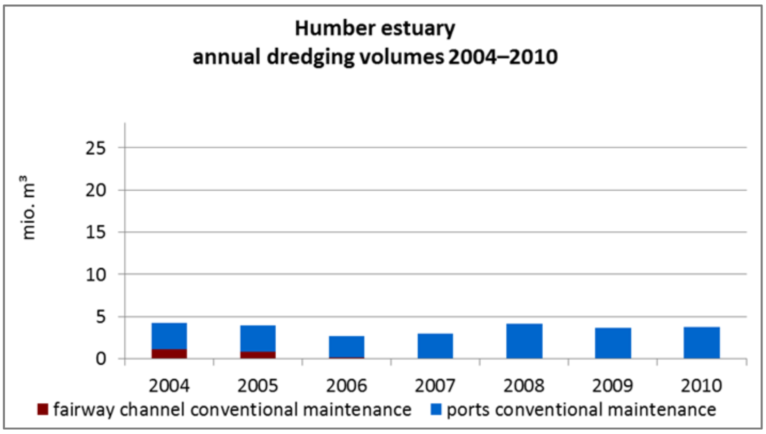

Figure 6.5. Annual dredging volumes of the Humber estuary (ABP) (2004-2010). No data for water injection and plough dredging; capital dredging was not conducted during this period. Data: Environment Agency (UK)

It can be seen that the amounts of dredging volumes are quite different between the Humber and the Elbe, Scheldt and Weser. In the Elbe and the Scheldt the dredging volumes are between 15 and 25 M m³ (Figures 6.6 and 6.8), and in the Weser they average approximately 10 M m³ (Figure 6.7). The volumes in the Scheldt, Elbe and Weser are considerable and show the importance of sediment management within estuarine management. In chapter 6.3.1 the specific sediment management activities and strategies are briefly characterised and lessons learned from their application are described.

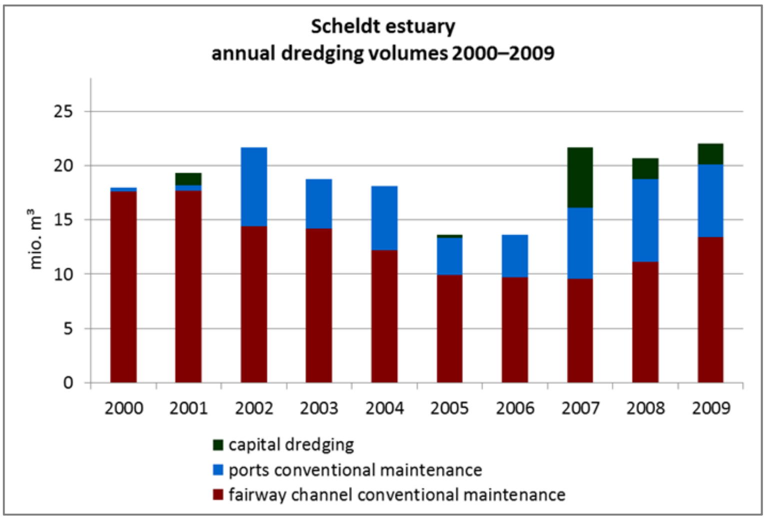

Figure 6.6. Annual dredging volumes of the Scheldt estuary (2000-2009). Data of ports behind the locks is not available; fairway conventional maintenance includes sand extraction; WID data is only available in working hours. Data: Flemish Government

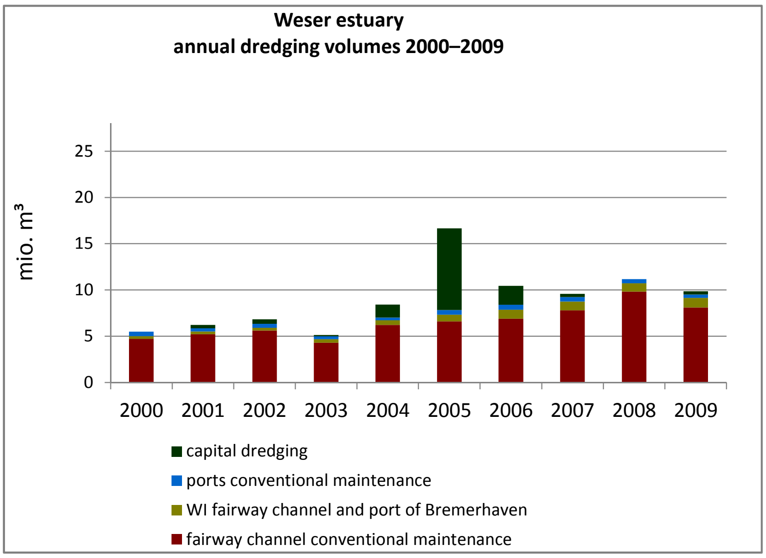

Figure 6.7. Annual dredging volumes of the Weser estuary (2000–2009). Capital dredging of Bremerhaven turning site between 2005 and 2008 were given for a period and not specifically assigned to years; fairway conventional maintenance includes sand extraction for third parties; WID data for the port of the City of Bremen is not available. Data: TIDE report Weser.

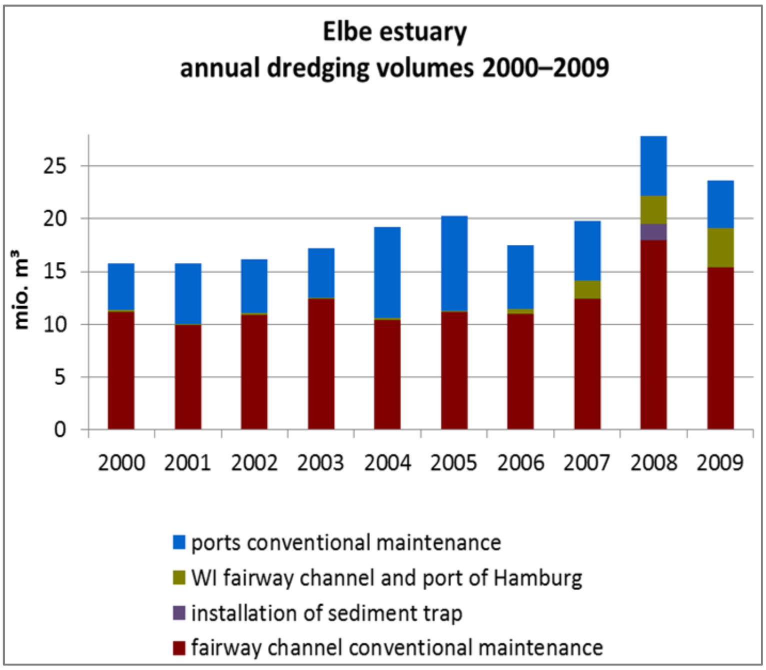

Figure 6.8. Annual dredging volumes of the Elbe estuary (2000–2009). Ports conventional maintenance: dredging work in the port of Hamburg including Elbe fairway down to km 639 = TIDE km 53. Data: HPA

6.1.3 Assessment scheme for management measures

In this section the assessment scheme is described in detail, with the focus on description of the results rather than on the methodology. Further detail on the methodology for the evaluation of the measures impacts on ecosystem services and beneficiaries is explained in detail in Section 4.6. and in APA (2013) and Saathoff et al. (2013) (both at www.tide-toolbox.eu).

6.1.3.1 Development targets

As mentioned in Section 6.6.1 each management measure is targeted at one or more development aim. This analysis step assesses the degree of achievement by each management measure ('high', 'medium' or 'low') in relation to respective development targets.

6.1.3.2 Expected impacts on ecosystem services

Despite the fact that management measures are focused on meeting certain development targets these development targets can usually be related to specific ecosystem services (ES). In Section 4.6 and in APA (2013) as well as in Saathoff et al. (2013) (at www.tide-toolbox.eu) the methodology on how to evaluate the expected impacts of the management measures towards ecosystem services has been explained. For each management measure the so-called 'targeted ES' have been identified which should reflect the main development targets transformed into the framework of ES. Furthermore, for each management measure a score has been calculated for all ES identified as being relevant in estuaries (see Section 4.6). Untargeted ES with a score (i.e. it is expected that the management measure has a positive impact on this ES) can be considered as 'co-benefits', i.e. additional benefits of the measure that were not targeted.

It is important to note that this method is based on the estimated delivery of ES of a certain habitat type. Therefore the score that is awarded reflects the "change in habitat type" that is induced by the measure within the boundaries of the measure. Hence, the delivery of ES outside these boundaries is not taken into account. Further on in this chapter, it is discussed how this influences the results.

6.1.3.3 Expected impacts on beneficiaries

Based on the Total Economic Value model (TEV; Barbier 1989; Pearce and Turner 1990) the management measures have been assessed based on the expected impacts on beneficiaries (see Section 4.6 and APA as well as Saathoff et al. 2013, at www.tide-toolbox.eu). The term '*beneficiary*' encompasses the different typologies of utilisation. One typology is linked to the spatial scale, i.e. answering the question on which level the impact is expected - either on local, regional or global. The second typology is linked to the TEV which divides the values into use and non-use values. Furthermore, the use values are divided into direct and indirect use values. Consequently, the second typology answers the question on the expected impact of the management measure to a certain type of utilisation, i.e. direct, indirect or future use.

6.1.3.4 EU environmental law

Although, the management measures are implemented because of a certain development targets, they might provide benefits according to other aspects (see Sections 6.1.3.2 and 6.1.3.3). Within the assessment scheme each management measure has also been assessed on the provision of positive effects on EU environmental law. For this purpose, two EU Directives have been selected, i.e. the Water Framework Directive (EC 2000) and the Birds and Habitats Directives (EC 1992; EC 2009). The following text describes the assessment of the additional benefit of management measures according to these EU environmental laws.

<u>Water Framework Directive</u>

At this time the majority of the European surface water bodies do not meet WFD requirements (NLWKN 2010). In order to achieve the Directive`s aims, suitable measures have to be designed, planned and implemented. To do so successfully, the specific pressures on a water body should be taken into account. This means that a measure is most effective, if it tackles the main pressures of the respective surface water section (Saathoff et al. 2013 at www.tide-toolbox.eu).

To identify the main pressures within the case estuaries, different categories of "Environmental Integration Indicators" (EII) as defined by Aubry and Elliott (2006) were taken as a basis. These EII provide basic functions as follows (Aubry and Elliott 2006):

- To simplify: Amongst the diverse components of an ecosystem, a few indicators are selected according to their perceived relevance for characterising the overall state of the ecosystem.
- To quantify: The value of the indicator is compared with reference values considered to be characteristic of pristine or heavily impacted ecosystems. For example, the ecological status of water bodies assigned under the Water Framework Directive related to the determination of changes from reference to expected conditions.
- To communicate: The use of indicators facilitates communication on environmental issues to stakeholders and policy makers by promoting information exchange and comparison of spatial and temporal patterns.

Application of the assessment:

To identify the major pressures, two groups of indicators have been used: *State Indicators* (S.I.) indicate the current state of a system (= estuary zone) looking at the changes that took place in the past, whilst Driver Indicators (D.I.) indicate the processes and activities which caused the current (or future) state of the system.

The identification of the main pressures (Table 6.6) was based on surveys completed by Regional Working Groups (RWGs) at each of the case estuaries. For each estuary zone the identification of a maximum of 6 main presures was permitted.

Table 6.6. The identification of main pressures in the case estuaries reflected by Environmental Integrative Indicators per estuary zone (f = fresh water, o = oligohaline, m = mesohaline, p = polyhaline, '+': as a main pressure identified, '-': no main pressure identified). Pressures identified for the case estuaries are highlighted.

State Indicators		Main pressure for			
Code*	Indicator	Humber	Scheldt	Elbe	Weser
1.1	Habitat loss and degradation during the last 100 years: intertidal	+ (m, p)	+ (f, o, m, p)	+ (f, o, m, p)	+ (f, o, m, p)
-	Habitat loss and degradation during the last 100 years: subtidal	-	-	+ (f, o, m, p)	+ (f, o, m, p)
1.4	Gross change in morphology during the last 100 years	+ (o, m)	-	+ (f, o, m)	+ (f, o, m)
1.5	Gross change of the hydrographic regime during the last 100 years	-	+ (f, o, m)	+ (f)	+ (f, o, m)
3.1/3.2	Decrease of water and sediment chemical quality	+ (o)	+ (f, o, m, p)	+ (f, o, m, p)	+ (p)
3.3	Increased chemical loads on organisms	-	+ (p)	-	-
3.4	Decrease of mircobial quality	-	-	-	-
3.8	Aesthetic pollution	-	-	-	-
Drive Indicators		**Main pressure for**			
Code*	**Indicator**	**Humber**	**Scheldt**	**Elbe**	**Weser**
1.3	Land claim during the last about 100 years	-	+ (f, o, m)	+ (f, o)	+ (f, o, m)
1.7	Relative Sea Level Rise	+ (m)	+ (f, o, m, p)	+ (p)	+ (f, p)
2.3	Discharge of nutrients and /or harmful substances	-	-	+ (f, o, m, p)	+ (p)
2.6	Capital dredging	+ (p)	+ (p)	+ (f, o, m, p)	+ (f, o, m, p)
2.4	Maintenance dredging	+ (m, p)	+ (f, o)	+ (m)	+ (o, m)
2.5a	Relocation of dredged material	+ (m, p)	-	-	-
2.9	Aquaculture	-	-	-	-
2.10	Fisheries activities	-	-	-	-
2.8	Wind farm development	-	-	-	-
2.11	Marina developments	-	-	-	-
2.12	Port developments	+ (m, p)	+ (m, p)	-	-
-	Industrial development	-	-	-	-
2.13	Installation of pipelines and cables	+ (m)	-	-	-
2.14	Oil and gas exploration and production	-	-	-	-
2.16	Tourism and recreation	-	-	-	-

** Codes for Environmental Integrative Indicators (EII) according to Aubry and Elliot (2006); EII without indication of code were added in the frame of TIDE.*

The results of the pressures screening were then taken as a basis to produce template tables referring to the different estuary zones defined for each of the case estuaries. These were then used to indicate and describe the measure effects regarding the main pressures identified for the estuary zone where the measure is planned or has been implemented. This enabled an appraisal of the effects of measures referring to the estuary zones based on the assessment provided by the regional experts (example from the Weser estuary see Table 6.7).

Table 6.7. Example: Effects of measure 'Tidal habitat Vorder- und Hinterwerder' (Saathoff and Klugkist 2012) on main pressures identified for freshwater zone of Weser estuary (S.I. = state indicator, D.I. = driver indicator, '--': very negative, '-': negative, '0': neutral, '+': positive, '++': very positive; code according Tabel 6.6).

Indicator Group	Code	Main pressures freshwater zone Weser	Effect					Description
			--	-	0	+	++	
S.I.	-	Habitat loss and degradation during the last 100 years: Subtidal					X	Additional subtidal area was created (shallow water zone).
S.I.	1.1	Habitat loss and degradation during the last 100 years: Intertidal				X		Intertidal habitats were developed (e.g. reeds and mudflats).
S.I.	1.4/ 1.5	Gross change in morphology/hydrographic regime during the last about 100 years					X	Due to Weser deepening, many side habitats of the river including shallow water got lost. The compensation measure creates new side habitats and therefore contributes to mitigating negative effects of the gross changes in morphology/hydrographic regime.
D.I.	1.3	Land claim during the last about 100 years				X		By partly lowering a summer dyke and increasing the tidal influence on the project area, land formerly used for agricultural purposes was given back to the river.
D.I.	1.7	Relative Sea Level Rise				X		Project area provides additional holding capacity.
D.I.	2.6	Capital dredging			X			There are no direct effects to be stated, but measure generally contributes to mitigating the negative effects of capital dredging.

<u>NATURA 2000</u>

Major areas of the case study estuaries (for the Humber the entire estuary) are designated as parts of the Natura 2000 network (see Section 5.3.2.1). The conservation objectives associated with this designation were taken into account to estimate the synergistic effects of the management measures in the context of the Natura 2000 aims. The analysis was only performed if the measure was implemented in a Natura 2000 site, or had an influence or effect on an adjacent Natura 2000 designation.

Application of the assessment:

The implementation of the evaluation criteria describing potential synergistic effects and conflicts of management measures regarding the Natura 2000 network differs between the case estuaries. For the estuaries of the Elbe and Weser, the analysis is based on the Integrated Management Plans (AG Elbeästuar 2011; NLWKN and SUBV 2012). The Natura 2000 analysis of the Scheldt measures is based on the content of the Long-term Vision for the Scheldt estuary (2001) and the Scheldt Estuary Development Outline 2010 (2005).

The analysis of the management measures for the Humber estuary is based on information provided by the Humber Management Scheme (HMS) (HMS 2011 a, b). The marine areas (land covered continuously or intermittently by tidal waters) of the Humber Estuary SAC (Special Area of Conservation), SPA (Special Protection Area) and Ramsar sites form the Humber Estuary European Marine Site (EMS), with the HMS being established as a Relevant Authorities partnership tasked to deliver the sustainable management of the Humber Estuary EMS.

The analysis of potential synergistic effects and conflicts of measures was carried out in different ways reflecting the context and scope of the individual estuary management plans. In the Weser a two-step approach describing the effectiveness regarding the conservation objectives was undertaken, whilst in the other three estuaries the analysis of conservation objectives was conducted as a single step.

The overall aim of the analysis was to appraise the efficacy of the implemented or planned management measures which had evolved in the context of the conservation objectives of Natura 2000 designation. The investigation at the Weser started with a high level screening of the effectiveness of measures for the area of the measure itself. In a second step the effects of every measure referring to the tidal zone in which it is located were estimated. This was performed by a valuation approach which categorised the conservation objectives of the reviewed measures in five steps ranging from very positive to very negative (Table 6.8).

Table 6.8. Valuation system of NATURA 2000 analysis: Indication of potential effects on NATURA 2000 objectives

Measure name	Effects of measure				
	Very positive (++)	Positive (+)	No effects (0)	Negative (-)	Very negative (--)
Conservation objective 1		x			
Conservation objective 2	x				
Conservation objective 3			x		
…					

The screening of measures in the other estuaries was conducted in a similar way, allowing a clearly structured method to assemble the sometimes divergent indicators used or amount of conservation objectives considered.

6.1.4 Results of the assessment scheme

In the previous paragraphs the methodology has been briefly explained. In this section the results of the assessment scheme are described.

6.1.4.1 Degree of target achievement

Half of the management measures were identified as achieving their original targets to a reasonable extent ('high' or 'medium'), and only two were scored as 'low' (Table 6.9). However, for eight management measures the degree of target achievement is not possible, because they have not yet been implemented or the monitoring process does not show a clear picture of achievement. Half of the management measures which were assigned to the management category *biology/ecology* are rated as 'high' for achieving their development targets (see also Table 6.4)

Table 6.9. Degree of target achievement of the management measures according to the management categories.

Case estuary	Degree of target achievement			
	High	Medium	Low	Not yet clear
Elbe	**4**	**5**	**2**	**3**
Hydrology/Morphology	1	1	1	2
Biology/Ecology	2	3	-	1
Physical/Chemical Quality	1	1	1	-
Humber	**2**	**4**	**0**	**4**
Hydrology/Morphology	1	1	-	0
Biology/Ecology	1	3	-	4
Physical/Chemical Quality	-	-	-	-
Scheldt	**8**	**3**	**0**	**1**
Hydrology/Morphology	2	2	-	1
Biology/Ecology	6	1	-	-
Physical/Chemical Quality	-	-	-	-
Weser	**6**	**0**	**0**	**0**
Hydrology/Morphology	-	-	-	-
Biology/Ecology	6	-	-	-
Physical/Chemical Quality	-	-	-	-
Total	20	12	2	8

6.1.4.2 Expected impacts on ecosystem services

The complete results of the assessment of the expected impacts of the management measures on ES are shown in Figure 6.9. The methodology on how to assess these expected impacts is described in section 4.2 and APA as well as Saathoff et al. 2013, at www.tide-toolbox.eu). The list of the 20 most relevant ES for estuaries consists of one habitat service, three provisioning services, twelve regulating services and four cultural services. Hence, the overall expected impact on the beneficiaries is dominated by the regulating services which are mostly linked to indirect and future, as well as local and regional, use.

It can be seen that about half of the management measures are targeted only at a single ES, with most of the others targeted at more than one ES (explanation of ‘targeted ES’ see Section 6.1.3.2). Nevertheless, all management measures are expected to have impacts on at least one untargeted ES (‘co-benefits’ of the management measure). In the cases where the measures are expected to have an impact on ES, the impact is predominantly scored as ‘slightly positive’, ‘positive’ or ‘very positive’. Negative scores are the exception.

‘Co-benefits’ are often recorded for cultural services (aesthetic information, information for cognitive development, opportunities for recreation and tourism) and for a couple of regulating services (e.g. erosion and sedimentation; regulation by water bodies respectively by biological mediation, water quantity regulation: landscape maintenance, climate regulation: carbon sequestration and burial, regulation extreme events or disturbance: flood water storage). Provisional services are less impacted.

Legend: expected impact*	
3	very positive
2	positive
1	slightly positive
0	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 pollutants and excess nutrients	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
No.	Estuary	Measure	Zone	Categ.	S	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	P1	P2	P3	C1	C2	C3	C4
1	Elbe	Spadenlander Busch	Fresh	H/B	3	3	1	1	1	1	0	1	1	1	0	1	1	1	0	0	2	3	3	2
2	Elbe	Medemrinne Ost	Meso	H	1	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	1	1	1	1
3	Elbe	Köhlfleet	Fresh	H	1	1	0	1	0	0	0	0	0	0	0	0	0	1	1	0	1	1	1	1
4	Elbe	Bunthaus	Fresh	H	1	1	0	1	0	0	0	0	0	0	0	0	0	1	1	0	1	1	1	1
5	Elbe	Sediment trap Wedel	Fresh	H/P/C Q	1	1	0	1	0	0	0	0	0	0	0	0	0	1	1	0	1	1	1	1
6	Elbe	Hahnöfer Nebenelbe	Fresh	B	-1	0	0	1	0	-1	0	-1	-1	1	-1	0	-1	0	0	1	-1	0	0	1
7	Elbe	Wrauster Bogen	Fresh	B	3	3	3	0	0	2	0	2	3	0	1	1	3	0	0	0	3	3	3	2
8	Elbe	Hahnöfer Sand	Fresh	B	3	3	1	0	1	2	0	2	2	1	1	1	1	0	0	0	2	2	2	1
9	Elbe	Spadenlander Spitze	Fresh	B	3	3	3	0	0	2	0	2	3	0	1	1	3	0	0	0	3	2	2	2
10	Elbe	Reed settlement Haken	Fresh	B	3	2	3	0	0	2	0	2	3	-1	1	1	3	0	0	0	2	2	2	2
11	Elbe	METHA	Fresh	P/C Q	1	1	0	1	0	0	0	0	0	0	0	0	0	1	1	0	1	1	1	1
12	Elbe	Managing Reiherstieg sluice	Fresh	P/C Q	1	1	0	1	0	0	0	0	0	0	0	0	0	1	1	0	1	1	1	1
13	Schelde	Lippenbroek	Fresh	H/B	3	3	3	0	0	2	0	2	3	0	1	1	3	0	0	0	3	2	2	2
14	Schelde	Groynes Waarde	Meso	B	2	1	1	0	0	1	0	1	1	1	1	1	0	0	0	0	1	1	1	1
15	Schelde	Ketenisse wetland	Meso	B	2	2	1	0	0	1	0	1	1	1	1	1	1	0	0	0	1	2	1	1
16	Schelde	Paddebeek wetland	Fresh	B	3	3	3	0	0	2	0	2	3	0	1	1	3	0	0	0	3	2	2	2
17	Schelde	Paardenschor wetland	Meso	B	3	3	2	0	0	2	0	2	2	2	2	1	0	0	0	0	3	3	2	2
18	Schelde	Heusden LO wetland	Fresh	B	3	3	3	0	0	2	0	2	3	0	1	1	3	0	0	0	3	2	2	2
19	Schelde	Sediment relocation Ketelplaat	Meso	H	1	1	0	1	0	0	1	0	0	0	0	0	0	0	1	0	0	1	1	1
20	Schelde	Walsoorden 2004	Meso	H	1	0	1	-1	0	1	-1	1	1	2	0	1	0	0	0	0	0	0	0	0
21	Schelde	Walsoorden 2006	Meso	H	0	0	1	-1	0	0	-3	1	0	1	0	0	0	-2	-3	1	0	0	0	0
22	Schelde	Sandbars 2010	Poly	H	1	0	1	-2	0	1	-3	2	1	3	0	1	0	-2	-3	1	0	0	0	0
23	Schelde	Fish pond	Meso	B	3	3	1	2	1	1	0	2	1	3	0	1	0	0	0	1	2	2	2	2
24	Weser	Tegeler Plate	Oligo	B	3	3	2	0	0	2	0	3	3	2	2	2	3	0	0	1	3	3	3	2
25	Weser	Rönnebecker Sand	Fresh	B	3	3	3	1	0	2	1	2	2	0	1	1	2	0	1	0	2	2	2	2
26	Weser	Vorder- und Hinterwerder	Fresh	B	3	3	2	1	0	1	1	1	2	0	0	1	1	1	1	0	2	2	2	2
27	Weser	Kleinensieler Plate	Oligo	B	3	3	3	0	0	2	0	2	2	0	1	1	2	0	0	0	2	2	2	2
28	Weser	Cappel-Süder-Neufeld	Poly	B	3	3	3	1	0	3	0	3	3	1	2	1	1	0	0	0	3	3	3	3
29	Weser	Werderland	Fresh	B	3	3	3	1	0	3	0	3	3	2	1	1	1	0	0	0	3	3	3	3
30	Humber	Alkborough	Meso	B	3	2	2	0	0	2	0	2	2	1	1	1	1	0	0	0	2	2	2	2
31	Humber	Paull Holme Strays	Poly	B	3	3	3	1	0	3	0	2	3	1	1	1	1	0	0	0	2	2	2	3
32	Humber	MudBug	Poly	H	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
33	Humber	Chowder Ness	Meso	B	2	2	1	0	0	1	0	1	1	2	1	1	0	0	0	0	2	2	1	1
34	Humber	Welwick	Poly	B	3	2	2	0	0	2	0	2	2	1	1	1	0	0	0	0	2	1	2	2
35	Humber	Kilnsea Wetlands	Poly	B	1	1	1	0	0	1	0	0	1	0	1	0	0	0	0	0	1	1	1	1

Figure 6.9. Overview on the results of the ES assessment in view of expected impacts on ES due to induced habitat changes within the boundaries of the measure. Explanations of ES are given in Section 4.6. B, H and P/C Q indicate the management categories biology/ecology, hydrology/morphology and physical/chemical quality. Ecosystem services categories: S – habitat services, R – regulating services, P – provisioning services, C – cultural services.

6.1.4.3 Expected impacts on beneficiaries

The expected impact of the management measures on the different beneficiaries is very similar (mainly indirect and future and mainly local and regional, Figure 6.10). This is a consequence of the measure selection, as well as on the list of ES considered (Figure 6.9).

Legend: expected impacts	
3	very positive
2	positive
1	slightly positive
0	neutral
-1	slightly negative
-2	negative
-3	very negative

					Beneficiaries					
No.	**Estuary**	**Measure**	**Zone**	**Categ.**	Direct use	Indirect Use	Future Use	Local Use	Regional Use	Global Use
1	Elbe	Spadenlander Busch	Fresh	H/B	0	2	3	2	2	1
2	Elbe	Medemrinne Ost	Meso	H	0	1	1	1	1	0
3	Elbe	Köhlfleet	Fresh	H	0	1	1	1	1	0
4	Elbe	Bunthaus	Fresh	H	0	1	1	1	1	0
5	Elbe	Sediment trap Wedel	Fresh	H/P/C Q	0	1	1	1	1	0
6	Elbe	Hahnöfer Nebenelbe	Fresh	B	0	0	-1	0	0	0
7	Elbe	Wrauster Bogen	Fresh	B	0	2	3	3	2	1
8	Elbe	Hahnöfer Sand	Fresh	B	0	2	3	2	1	1
9	Elbe	Spadenlander Spitze	Fresh	B	0	3	3	3	3	2
10	Elbe	Reed settlement Haken	Fresh	B	0	2	3	2	1	1
11	Elbe	METHA	Fresh	P/C Q	0	2	3	2	1	1
12	Elbe	Managing Reiherstieg sluice	Fresh	P/C Q	0	1	1	1	1	0
13	Schelde	Lippenbroek	Fresh	H/B	0	2	3	3	2	1
14	Schelde	Groynes Waarde	Meso	B	0	1	1	1	1	1
15	Schelde	Ketenisse wetland	Meso	B	0	1	2	1	1	1
16	Schelde	Paddebeek wetland	Fresh	B	0	2	3	2	2	1
17	Schelde	Paardenschor wetland	Meso	B	0	2	3	2	1	1
18	Schelde	Heusden LO wetland	Fresh	B	0	2	3	3	2	1
19	Schelde	Sediment relocation Ketelplaat	Meso	H	0	1	1	1	1	0
20	Schelde	Walsoorden 2004	Meso	H	0	0	1	1	0	0
21	Schelde	Walsoorden 2006	Meso	H	0	-1	0	0	-1	0
22	Schelde	Sandbars 2010	Poly	H	0	-1	1	0	-1	0
23	Schelde	Fish pond	Meso	B	0	2	2	2	1	1
24	Weser	Tegeler Plate	Oligo	B	0	2	3	3	2	1
25	Weser	Rönnebecker Sand	Fresh	B	0	2	3	2	2	1
26	Weser	Vorder- und Hinterwerder	Fresh	B	0	2	2	2	1	1
27	Weser	Kleinensieler Plate	Oligo	B	0	2	3	2	1	1
28	Weser	Cappel-Süder-Neufeld	Poly	B	0	3	3	3	2	1
29	Weser	Werderland	Fresh	B	0	2	3	3	2	1
30	Humber	Alkborough	Meso	B	0	2	3	2	1	1
31	Humber	Paull Holme Strays	Poly	B	0	2	3	2	2	1
32	Humber	MudBug	Poly	H	0	1	1	1	1	0
33	Humber	Chowder Ness	Meso	B	0	1	2	1	1	1
34	Humber	Welwick	Poly	B	0	1	2	2	1	1
35	Humber	Kilnsea Wetlands	Poly	B	0	1	1	1	1	0

Figure 6.10. Overview on the results of the ES assessment in view of expected measure impacts on beneficiaries. Detailed explanation is given in Saathoff et al. (2013) and Figure 6.9.

6.1.4.4 Benefit according to EU environmental law

Water Framework Directive

Most management measures are implemented in order to provide benefit in accord with the aims of the WFD (Table 6.10). Some management measures were identified from the analysis to have a 100% positive effect on the identified pressures within the estuary and the respective zone, whilst three management measures were identified as having no positive effects on the identified pressures according to WFD, these being technical measures targeting specific aspects of sedimentation. In addition, the Walsoorden measures (No. 20, 21) which are only small pilot projects initiated in preparation of the large Sandbars measure (No. 22), illustrate the importance of the scale of implementation.

Predominantly, the measures belonging to the category 'biology/ecology' and the measure type 'managed realignment measure' (classification given in Table 6.2) have a higher impact than those belonging to other categories or types.

Table 6.10. Result of the assessment according to the benefit of the measure for the Water Framework Directive. Percentage: Percentage of pressures, as described in Table 6.6, been impacted positively and/or very positively.

Measure category	#	Estuary	Short title	# of pressures positively affected	# of pressures	%
Hydrolody/Morphology	1	Elbe	Spadenlander Busch	5	8	63%
	2	Elbe	Medemrinne Ost	3	7	43%
	3	Elbe	Köhlfleet "deflection wall"	0	8	0%
	4	Elbe	Bunthaus	0	8	0%
	5	Elbe	Sediment trap Wedel	0	8	0%
	13	Scheldt	Lippenbroek	5	6	83%
	19	Scheldt	Sediment relocation Keteplaat	1	6	17%
	20	Scheldt	Walsoorden 2004	1	6	17%
	21	Scheldt	Walsoorden 2006	1	6	17%
	22	Scheldt	Sandbars 2010	3	6	50%
Biology/Ecology	1	Elbe	Spadenlander Busch	5	8	63%
	6	Elbe	Hahnöfer Elbe	2	8	25%
	7	Elbe	Wrauster Bogen	2	8	25%
	8	Elbe	Hahnöfer Sand	2	8	25%
	9	Elbe	Spadenlander Spitze	1	8	13%
	10	Elbe	Reed settlement Haken	2	8	25%
	13	Scheldt	Lippenbroek	5	6	83%
	14	Scheldt	Groynes Waarde	1	6	17%
	15	Scheldt	Ketenisse wetland	4	6	67%
	16	Scheldt	Paddebeek wetland	6	6	100%

	17	Scheldt	Paardenschoor wetland	6	6	100%
	18	Scheldt	Heusden LO wetland	6	6	100%
	23	Scheldt	Fish pond	2	6	33%
	24	Weser	Tegeler Plate	5	7	71%
	25	Weser	Rönnebecker Sand	5	7	71%
	26	Weser	Vorder- und Hinterwerder	5	7	71%
	27	Weser	Kleinensieler Plate	5	7	71%
	28	Weser	Cappel-Süder-Neufeld	3	6	50%
	29	Weser	Werderland	5	7	71%
	30	Humber	Alkborough	2	7	29%
	31	Humber	Paull Holme Strays	2	5	40%
	33	Humber	Chowder Ness	6	7	86%
	34	Humber	Welwick	5	5	100%
	35	Humber	Kilnsea Wetlands	5	5	100%
	36	Humber	South Humber Gateway Roosting	5	5	100%
Physical/ Chemical Quality	5	Elbe	Sediment trap Wedel	0	8	0%
	11	Elbe	METHA	1	8	13%
	12	Elbe	Managing Reihersteg sluice	1	8	13%

NATURA 2000

Almost all management measures provide benefits according to the conservation objectives relating to the Birds and Habitats Directives and the associated Natura 2000 network (Table 6.11). Some of the management measures have been identified as delivering 100% positive and/or very positive effects, with only a few delivering less than a 20% rating of positive effects on the conservation objectives.

As with the WFD requirements, those measures associated with Natura 2000 delivery primarily belonged to the measure category ‘biology/ecology’ and to the measure type ‘managed realignment measure’ (classification given in Table 6.2) have the highest impact.

Table 6.11. Results of the assessment according to the benefit of the measure for NATURA 2000. Percentage: Percentage of conservation objectives been impacted positively and/or very positively.

Measure Category	#	Estuary	Short title	Number of conservation objectives			%
				Positively affected	Very positively affected	Total	
Hydrolody/Morphology	1	Elbe	Spadenlander Busch	5	0	6	83%
	2	Elbe	Medemrinne Ost	1	0	6	17%
	3	Elbe	Köhlfleet "deflection wall"	0	0	6	0%
	4	Elbe	Bunthaus	0	0	6	0%
	5	Elbe	Sediment trap Wedel	1	0	8	13%
	13	Scheldt	Lippenbroek	0	2	2	100%
	19	Scheldt	Sediment relocation Keteplaat	0	0	1	0%
	20	Scheldt	Walsoorden 2004	1	0	5	20%
	21	Scheldt	Walsoorden 2006	1	0	5	20%
	22	Scheldt	Sandbars 2010	6	0	11	55%
Biology/Ecology	1	Elbe	Spadenlander Busch	5	0	6	83%
	6	Elbe	Hahnöfer Elbe	4	0	8	50%
	7	Elbe	Wrauster Bogen	4	0	6	67%
	8	Elbe	Hahnöfer Sand	6	0	6	100%
	9	Elbe	Spadenlander Spitze	4	0	6	67%
	10	Elbe	Reed settlement Haken	0	0	6	0%
	13	Scheldt	Lippenbroek	0	2	2	100%
	14	Scheldt	Groynes Waarde	2	1	3	100%
	15	Scheldt	Ketenisse wetland	1	9	27	37%
	16	Scheldt	Paddebeek wetland	1	0	1	100%
	17	Scheldt	Paardenschoor wetland	10	0	27	37%
	18	Scheldt	Heusden LO wetland	1	0	1	100%
	23	Scheldt	Fish pond	2	0	7	29%
	24	Weser	Tegeler Plate	11	11	24	92%
	25	Weser	Rönnebecker Sand	16	5	22	95%
	26	Weser	Vorder- und Hinterwerder	15	4	22	86%
	27	Weser	Kleinensieler Plate	16	4	24	83%
	28	Weser	Cappel-Süder-Neufeld	9	2	24	46%
	29	Weser	Werderland	14	6	22	91%
	30	Humber	Alkborough	0	1	1	100%
	31	Humber	Paull Holme Strays	0	1	1	100%
	33	Humber	Chowder Ness	1	0	1	100%
	34	Humber	Welwick	1	0	1	100%
	35	Humber	Kilnsea Wetlands	1	0	1	100%
	36	Humber	South Humber Gateway Roosting	1	0	1	100%
Physical/ Chemical Quality	5	Elbe	Sediment trap Wedel	1	0	8	13%
	11	Elbe	METHA	0	0	6	0%
	12	Elbe	Managing Reihersteg sluice	2	0	6	33%

6.2 Identification of good practice examples

Based on the classification scheme described in Section 6.2.1, 'good practice examples' will be identified in terms of additional ecosystem service benefits, these being described in more detail in section 6.2.2.

6.2.1 Classification of good practice examples

The selection process to classify 'good practice examples' is based on the main criteria 'expected impacts on ES' (see Figure 6.9) and 'expected impacts on beneficiaries' (see Figure 6.10) as well as the two EU Directives (see Tables 6.10 and 6.11). The classification scheme aggregates these assessments within three criteria. Each criterion is described by two indicators which are based on the available data sets and information provided (Table 6.12). For each of these management measures, targeted ES have been identified, and the expected impact of the management measures on the ES assessed (Figure 6.9). The first indicator is called '*quality*' and describes the ratio of the total sum of expected impacts on targeted ES divided by the amount of targeted ES per management measure. The indicator shows the total relative score on targeted ES. The indicator '*quantity*' represents the total relative score on supported ES per management measure. This means that for each management measure, impacts are also expected on ES other than the targeted ES. For example, a management measure such as saltmarsh creation which is expected to have a positive impact on the ES '*biodiversity*' also provides a positive impact on other ES '*erosion and sedimentation regulation*'.

The second criterion is the delivery of ES according to the identified beneficiaries as described in Section 6.1.4. The total sum of the beneficiaries related to the spatial typology and the use typology (Figure 6.10) have been calculated. The appraisal of the beneficiaries (Figure 6.10) for each management measure has been added and the result has been translated to selection scores as described in Table 6.12.

The third criterion is based on the benefits the management measures deliver to the EU environmental legislation (Water Framework Directive; Wild Birds and Habitats Directives) as described in Section 6.1.4. The benefits which could be gained for the respective EU Directives are expressed by the relationship between the identified conservation objectives and the actual positive or very positive effect of the management measure on these objectives. The percentage of the positive effects relating to the Water Framework, Birds and Habitats Directives were therefore used as the indicators.

The classification of the management measures is solely based on the criteria supported by the indicators described in Table 6.12. Therefore, the classification scheme predominantly represents the *degree of additional benefit* that a management measure could provide.

Table 6.12. Description of the classification scheme to identify 'good practice examples'

Selection criterion	Ecosystem services		Beneficiaries		EU Directives	
Selection indicator	Quality	Quantity	User typology	Spatial typology	WFD	NATURA 2000
Explanation of indicator / Score	Ratio of total sum of expected impacts on targeted ES divided by amount of targeted ES	Ratio of total sum of expected impacts on targeted ES divided by amount of supported ES	Total sum of expected impacts	Total sum of expected impacts	Percentage of pressures positively affected by measure	Percentage of conservation objectives very positively and/or positively affected by measure
3	> 2	> 2	> 5	> 5	> 60%	> 60%
2	>1	>1	3 - 5	3 - 5	31%-60%	31%- 60%
1	< 1	< 1	< 3	< 3	< 31%	< 31%

Results of the Classification Scheme

Almost all management measures could be assessed by the application of the classification scheme (Figure 6.11), with only a few without a classification, because no data sets were available, either because management measures are not yet implemented or the information has not been provided by the project managers. A management measure has been classified as '*low*' if it scores less than seven points out of 18, classified as '*medium*' if it achieves between seven and 12 points and as '*high*' if it gets more than 12 points (Figure 6.11).

In total this classification approach identified four management measures which were classified as '*low*', 12 management measures classified as '*medium*' and 19 measures classified as '*high*'. Almost half of the management measures were identified as providing additional benefit to that for which they were originally implemented, and thus delivering a '*high*' degree of additional benefit.

No.	Estuary	Short title	Zone	Categ.	Ecosystem services		Beneficiaries		EU Directives		Selection	Classification
					Quality	Quantity	user	spatial	WFD	NATURA 2000	score	
1	Elbe	Spadenlander Busch	Fresh	H/B	2	1	2	2	3	3	13	high
2	Elbe	Medemrinne Ost	Meso	H	2	1	1	1	2	1	8	medium
3	Elbe	Köhlfleet "deflection wall"	Fresh	H	2	2	1	1	1	1	8	medium
4	Elbe	Bunthaus	Fresh	H	2	2	1	1	1	1	8	medium
5	Elbe	Sediment trap Wedel	Fresh	H/P/C Q	2	2	1	1	1	1	8	medium
6	Elbe	Hahnöfer Elbe	Fresh	B	1	1	1	1	1	2	7	medium
7	Elbe	Wrauster Bogen	Fresh	B	3	3	2	3	1	3	15	high
8	Elbe	Hahnöfer Sand	Fresh	B	2	3	2	2	1	3	13	high
9	Elbe	Spadenlander Spitze	Fresh	B	3	3	3	3	1	3	16	high
10	Elbe	Reed settlement Haken	Fresh	B	2	3	2	3	1	1	12	medium
11	Elbe	METHA	Fresh	P/C Q	2	1	2	2	1	1	9	medium
12	Elbe	Managing Reihersteg sluice	Fresh	P/C Q	2	2	1	1	1	2	9	medium
13	Scheldt	Lippenbroek	Fresh	H/B	3	3	2	3	3	3	17	high
14	Scheldt	Groynes Waarde	Meso	B	2	2	1	1	1	3	10	medium
15	Scheldt	Ketenisse wetland	Meso	B	2	2	1	1	3	2	11	medium
16	Scheldt	Paddebeek wetland	Fresh	B	3	3	2	2	3	3	16	high
17	Scheldt	Paardenschoor wetland	Meso	B	3	3	2	2	3	2	15	high
18	Scheldt	Heusden LO wetland	Fresh	B	3	3	2	3	3	3	17	high
19	Scheldt	Sediment relocation Keteplaat	Meso	H	2	1	1	1	1	1	7	medium
20	Scheldt	Walsoorden 2004	Meso	H	1	1	1	1	1	1	6	low
21	Scheldt	Walsoorden 2006	Meso	H	1	1	1	1	1	1	6	low
22	Scheldt	Sandbars 2010	Poly	H	1	1	1	1	1	1	6	low
23	Scheldt	Fish pond	Meso	B	2	3	2	2	2	2	13	high
24	Weser	Tegeler Plate	Oligo	B	3	3	2	3	3	3	17	high
25	Weser	Rönnebecker Sand	Fresh	B	2	3	2	2	3	3	15	high
26	Weser	Vorder- und Hinterwerder	Fresh	B	2	3	2	2	3	3	15	high
27	Weser	Kleinensieler Plate	Oligo	B	3	3	2	2	3	3	16	high
28	Weser	Cappel-Süder-Neufeld	Poly	B	3	3	3	3	2	2	16	high
29	Weser	Werderland	Fresh	B	3	3	2	3	3	3	17	high
30	Humber	Alkborough	Meso	B	2	2	2	2	3	3	14	high
31	Humber	Paull Holme Strays	Poly	B	3	3	2	2	2	3	15	high
32	Humber	MudBug	Poly	H	2	1	1	1	n.a.	n.a.	5	low
33	Humber	Chowder Ness	Meso	B	2	2	2	2	3	3	14	high
34	Humber	Welwick	Poly	B	2	2	2	2	3	3	14	high
35	Humber	Kilnsea Wetlands	Poly	B	2	1	1	1	3	3	11	medium
36	Humber	South Humber Gateway Roosting	Poly	B	2	1	n.a.	n.a.	n.a.	n.a.	3	n.a.
37	Humber	Trent falls	Oligo	B	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
38	Humber	Donna Nook and Skeffling	Poly	B	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
39	Humber	Tunstall Realignment	Poly	B	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

Figure 6.11. Result of the classification scheme to identify 'good practice examples'. The management measures are classified as 'low' (< 7 scores), 'medium' (7 – 12 scores) and 'high' (> 12 scores). Category: H – hydrology/morphology, B – biology/ecology, P/C Q – physical/chemical quality.

For the Elbe estuary a total of four management measures were classified as '*high*' in providing additional benefit according to the expected impacts on ES and on beneficiaries. The highly ranked management measures show a positive effect on the conservation objectives according to requirements associated with Natura 2000 management aims. Eight management measures were classified as being '*medium*', with positive impacts on ES and beneficiaries, but without any additional high level scoring in relation to EU environmental legislation.

For the Scheldt estuary five management measures were classified as '*high*', most of these providing additional benefit to the expected impact on ES, and delivering positive benefits in relation to EU conservation legislation (e.g. Natura 2000 components). Three management measures were ranked as '*medium*' and three were classified as '*low*'. The lowest ranked measures were in place to address morphological issues in the Scheldt estuary. It is important to note that these scores do not reflect the actual success of the measures, nor the actual additional benefits that these measures created. This can be explained by the method used to score the expected impacts on ES, this being based on a change in habitat type induced by the measure within the boundaries of the measure. However for this type of measure, the benefits are largely situated outside the boundaries of the actual disposal area. For example: the decrease in the percentage of deep water at the site of sediment disposal (e.g. dredge disposal) leads to a negative score for ES “Water for navigation” in Figure 6.9, while in fact this measure would have been scored highly for navigation if the spatial scale had been extended to include a wider area of effect. On the Weser estuary all management measures were classified as ‘*high*’, because all performed well in all selection criteria. In fact these management measures provided a high additional benefit beyond their original development targets.

For the Humber estuary it was only possible for six management measures to be addressed within the assessment scheme, due to a lack of available information in relation to the key selection criteria. For instance it was not possible to assess one of the technical measures in relation to the potential positive effects on EU environmental legislation, because the measure was designed to specifically identify the navigation depth around ports and harbours including the density of fluid mud (No. 32). Indirectly the measure may also be able to provide additional ES benefit based on the monitoring results, but it will not have significant positive effects on the conservation objectives of, for example, the Birds and Habitats Directive requirements on the Humber. Nevertheless, four management measures were classified as achieving a ‘*high*’ degree of additional benefit.

6.2.2 Examples of good practice

This section elaborates on the aspects which led to the classification of the management measure as a ‘good practice example’. Subsequently, the performance of these management measures has been classified to identify examples which display ‘*high*’, ‘*medium*’ and ‘*low*’ scores for the provision of additional benefit. The previous section shows how the results of the classification scheme were applied whereas this section interrogates the classification categories in order to indicate where the ‘good practice examples’ performed better than the other management measures.

<u>Analysis of the results</u>

A short list of highly ranked management measures has been identified, ranked on the basis of the developed classification scheme (Table 6.13, scores based on Figure 6.9 and 6.10 and Table 6.10 and 6.11). These management measures represent the highest level of additional benefit provision according to their individual development target. Consequently, these management measures will be highlighted as ‘*good practice examples*’. Additionally, in Table 6.13 the category and type of the measure are displayed as well as the estuary zone of implementation.

Table 6.13. Overview of the management measures highly classified in respect of the degree of providing additional benefit according to their individual development target. B, H and P/C Q indicate the management categories biology/ecology, hydrology/morphology and physical/chemical quality, MRM, SMS and MMS the measure types managed realignment measure, sediment management strategy, morphological management strategy. The red colour highlights the highest scores.

#	Estuary	Short title	Measure category			Measure type			Estuary Zone				Ecosystem service		Benefi-ciaries		EU Environ-mental Law	
			B/E	H/M	P/C Q	MRM	SMS	MMS	p	m	o	l	Quality	Quantity	Use	Spatial	WFD	NATURA 2000
1	Elbe	Spadenlander Busch	**X**	**X**		X						X	2	1	2	2	63%	83%
7	Elbe	Wrauster Bogen	X			X						X	**3**	**3**	2	**3**	25%	67%
8	Elbe	Hahnöfer Sand	X			X						X	2	**3**	2	2	25%	**100%**
9	Elbe	Spadenlander Spitze	X			X						X	**3**	**3**	**3**	**3**	13%	67%
13	Scheldt	Lippenbroek	**X**	**X**		X						X	**3**	**3**	2	**3**	83%	**100%**
16	Scheldt	Paddebeek wetland	X			X						X	**3**	**3**	2	2	**100%**	**100%**
17	Scheldt	Paardenschoor wetland	X			X				X			**3**	**3**	2	2	**100%**	37%
18	Scheldt	Heusden LO wetland	X			X						X	**3**	**3**	2	**3**	**100%**	**100%**
23	Scheldt	Fish pond	X			X				X			2	**3**	2	2	33%	29%
24	Weser	Tegeler Plate	X			X					X		**3**	**3**	2	**3**	71%	92%
25	Weser	Rönnebecker Sand	X			X						X	2	**3**	2	2	71%	95%
26	Weser	Vorder- und Hinterwerder	X			X						X	2	**3**	2	2	71%	86%
27	Weser	Kleinensieler Plate	X			X					X		**3**	**3**	2	2	71%	83%
28	Weser	Cappel-Süder-Neufeld	X			X			X				**3**	**3**	**3**	**3**	50%	64%
29	Weser	Werderland	X			X						X	**3**	**3**	2	**3**	71%	91%
30	Humber	Alkborough	X			X				X			2	2	2	2	29%	**100%**
31	Humber	Paull Holme Strays	X			X			X				**3**	**3**	2	2	40%	**100%**
33	Humber	Chowder Ness	X			X				X			2	2	2	2	86%	**100%**
34	Humber	Welwick	X			X			X				2	2	2	2	**100%**	**100%**
Total			**19**	**2**	**0**	**19**	**0**	**0**	**3**	**4**	**2**	**10**						

The results obtained by the classification exercise (Table 6.13) do not provide a clear indication of the features common to the management measures, nor do they have any specific feature which singles them out as '*good practice examples*'. In fact a range of differing management measures emerge as '*good practice examples*' with highest scores relevant for different criteria.

Nevertheless, it is obvious that only MRM are scored as 'high'. Although, these management measures are aimed at different specific goals, all are aimed at the creation, restoration or conservation of habitats. Thus, all of them are inherently connected to the ES '*biodiversity*' which is the most targeted ES of the listed management measures (Figure 6.9). However, besides that, all of these highly rated management measures are expected to have positive impacts on several ES listed in the assessment scheme.

The management measures from the measure category *hydrology/morphology* apparently are not primarily aimed at ES, but for some, targeted ES have been mentioned (Figure 6.9). However, the score for the targeted ES for these management measures is not very high (Figure 6.9). The assessment of the potential to deliver ES associated with the *hydrology/morphology* measure might be more difficult than for measures from the *biology/hydrology* category. Whilst this may be because the underlying linkages between natural processes (e.g. morphological responses induced by hydrodynamic changes) and intertidal habitats on the one hand, and the relationship between human interference (e.g. by maintenance dredging or relocation of sediment) and intertidal habitats on the other hand are not yet sufficiently understood to allow a suitable level of assessment (e.g. Wetzel 2006; Nehring and Leuchs 2000). A more likely explanation is that the method used did not integrate the benefits from outside the boundaries of the measure, which are a more important success component for this kind of measure compared to those related to MRM.

6.3 Lessons learned, discussion and conclusions

This section presents lessons learned on the basis of the assessment of the management measures (see Table 6.2). In particular, the strategies associated with the selected management types managed realignment measures and sediment management measures will be discussed.

6.3.1 Lessons learned according to selected management types

The analysis indicated that all of the '*good practice examples*' are related to managed realignment measures (MRM). Measures relating to both the morphological and sediment management strategies were classified as '*low*' or '*medium*' according to the classification scheme. Nevertheless, the importance of sediment management in estuaries, which is closely linked to morphological management, has already been elaborated, and sediment management separately has been investigated with important conclusions having been drawn (see BioConsult and NLWKN 2013). Thus, a condensed overview of the lessons learned according to the managed realignment measures and sediment management strategies will be made here.

6.3.1.1 Managed realignment measures

In collating existing knowledge regarding the planning, implementation, monitoring and optimisation of management measures, a specified inter estuary comparison of measures has been carried out. This study concentrated on the effects of *M*anaged *R*ealignment *M*easures (MRM, see APA 2013). Information concerning structure and general aspects of MRM are provided in section 6.1.2, with the lessons learned from the analysis of the MRM information (Figure 6.12) provided here.

No.	Short title	Number of years implemented	Habitat conservation, creation, restoration				Safety	Research	Recreation
			1. Processes	2. Habitat	3. Species	4. Compensation			
1	Spadenlander Busch	0	+++	+++	+++		+++		+++
7	Wrauster Bogen	21		+	+				
8	Hahnöfer Sand	10		+	+	0			
9	Spadenlander Spitze	10	+	+	+				
13	Lippenbroek	6		+++			+++	+++	
15	Ketenisse	9	+			+			
16	Paddebeek	9	+	+					
17	Paardenschor	8	+	+		+			
18	Heusden LO	6	+	+					
24	Tegeler Plate	15	+++	+++		+++			
25	Rönnebecker Sand	10	+++	+++		+++			
26	Vorder- & Hinterwerder	15	+++	+++		+++		+	
27	Kleinensieler Plate	12	+			+			
28	Cappel-Süder-Neufeld	10			+++	+++			
31	Alkborough	6		+		+	+++		+++
32	Paull Holme Strays	9		+	+	+		+++	
33	Chowder Ness	6	+++	+++	+++	+++			
34	Welwick	6	+++	+++	+++	+++			+++
35	Kilnsea Wetlands	2	+++	+++	+++	+++			+++
38	Donna Nook	1	+++	+++	+++	+++			+++

Figure 6.12. Overview measure targets and degree of target achievement per measure. Degree of target achievement: low (0), medium (+), high (+++). The 'good practice examples' are highlighted in brown. Source: APA (2013).

All listed MRM examples are aimed at the conservation, restoration or creation of estuarine habitat. The targets are diverse but it was possible to identify four main typologies (APA 2013):

- Improve estuarine processes such as sedimentation processes, creek formation, and soil development.
- Create a specific valuable habitat (freshwater or brackish) such as mudflats, marsh habitat, subtidal shallow water habitat, reed, meadows and floodplain forest.
- Support specific species by creating habitat for certain fauna and flora which can typically be found there.
- Compensation: Some of the MRM are driven by compensation targets mainly related to loss of habitats due to port development or relative sea level rise.

Another important target for MRM is to enhance safety against flooding. This encompasses the reduction of the hydraulic effect of tidal energy by reducing the 'tidal pumping effect'.

This can be achieved using a Flood Control Area which also gives benefits for ecological feature enhancement.

Pilot areas are required to enable research and increase knowledge. The ‘Lippenbroek’ pilot project generated much scientific insight with respect to the operation of a Flood Control Area with Controlled Reduced Tide (FCA-CRT) and with intertidal mudflat and marsh in general. The management measure ‘Vor- und Hinterwerder’ is considered as a flagship measure given that several similar compensation measures were implemented after 1997, especially in the field of hydraulic control of water levels (e.g. ‘Kleinensieler Plate’ and ‘Rönnebecker Sand’ at the Weser, APA 2013).

Recreational targets also play an important role, offering the public several activities which will be provided by tidally influenced landscapes (e.g. Alkborough, Welwick and further measures at the Humber, Spadenlander Busch at the Elbe). in particular, most of the ‘*good practice*’ measures cover a wide range of different development targets and simultaneously reach a high degree of target achievement (Tables 6.2 and 6.9). This connection offers insight into how to enhance multifunctional use in order to enlarge the benefits of management measures.

Despite enhancing the benefits, it is always necessary to be aware of the costs. The analysis of the cost-benefit ratio for the reviewed measures indicates that the effectiveness of the measure to reach the objectives and to be sustainable is more important when considering the measure design than the implementation cost.

Hence there is an increasing need for accurate planning, design and implementation of a MRM. In addition to the requirements concerning safety, ownership structure and spatial planning, the more detailed observance of sedimentation and erosion processes will play an important role in the development of MRM. The management of high siltation rates, given unpredictability of a dynamic estuarine system, is complex and difficult and will even increase if the system is operating outside its natural equilibrium, hence, it is important to determine the right place, the right objectives and the right design of a MRM. To do so requires many estuarine factors to be considered, these related to the location of the system (global and local), sedimentation and erosion processes: salinity gradient, suspended particulate matter (SPM) and turbidity maximum, location on the inside or outside of a channel bend, and hydrodynamics in the area as well as measure specific design attributes such as the elevation, inundation, slope, opening to the river, vegetation at the site, drainage and creek system development.

Although, the use of modelling work in the planning phase is quite widespread, consultation with regional experts and the utilisation of knowledge from on-going projects is required to reduce the risk of failure (APA 2013).

6.3.1.2 Sediment management activities

Originally, the purpose of sediment management in the case study estuaries was to ensure the accessibility of harbours and ports by commercial vessels. It includes the adaptation of the fairways (capital dredging) as well as the maintenance of existing depths. For decades the fairways of the Elbe, Weser and Scheldt case study estuaries have been repeatedly deepened to a varying degree although no widening or deepening has been carried out on the Humber. Maintenance dredging has to be carried out continuously in the case study estuaries, including limited maintenance dredge work in the Humber (around the berth pockets and with some fairway maintenance).

Sediment management has developed historically in the individual estuaries and still is continuously adapted to the changing boundary conditions and to an improving knowledge base. Despite the fact that morphological and economical aspects in sediment management and nature conservation and environmental protection have increasingly gained relevance, integrated strategies only partially exist (BioConsult and NLWKN 2013).

The main issues in the sediment management of the case estuaries are reductions in the cost and dredging volumes: since about two decade's environmental and nature conservation aspects have been taken into consideration.

On the Humber estuary the existing maintenance dredging programme is long established. An analysis of the energy flux revealed that the estuary is slowly developing towards a morphological equilibrium which may result in low maintenance dredging needs. The general strategy of maintenance dredging is outlined in the "Humber Estuary: Maintenance Dredge Protocol and Water Framework Directive Compliance Baseline Document" by ABP (2011). The Harbour Authorities handle maintenance dredging in fairways, along riverside berths and within enclosed docks. Most of the dredging occurs in the lower and middle estuary. The 'Channel' (e.g. the fairway of the Humber) requires regular dredging to maintain its depth against on-going siltation and the dredged sediment is relocated in a nearby similar flow environment. Direct material loss is prevented by depositing the fine grained material at various placement sites within the estuary and dredged material from the inner/outer parts of the port areas is relocated within the estuary. In recent years no sand accretion has occurred and land-based treatment of sediment has not been required on the Humber (BioConsult and NLWKN 2013).

The first deepening of the fairway in the Scheldt estuary was carried out without a specific relocation strategy. Dredging was conducted by relocating the material to shallower secondary channels. Since 1990 dredging and the relocation of sediment have been executed following a strategy aimed at meeting morphological processes. The dredging strategy is applied to maintenance as well as capital dredging.

Along with the second deepening the so-called ‘East-West’ strategy was executed. Because of the limited capacity for the placement of dredged material in secondary channels in the eastern part of the Scheldt, the material was transported to the western part. The applied sand-balance approach offers flexibility in using licensed placement sites and where unwanted developments in morphological processes have been identified, either the placement sites were not utilised to full capacity for dredged material disposal, or the relocation of material was discontinued.

In 2001 the concept of morphological management (see report ‘Morphological Management of Estuaries’ at www.tide-toolbox.eu) was developed to create win-win solutions in which dredged material is used to improve the state or the functioning of the estuary. Since 2007 the sand-balance approach was replaced by the cell concept, with morphological cells introduced to enable a strategic disposal of dredged sediment. Today, placement sites in the primary channel (fairway) and on sandbars are used as part of a ’flexible relocation’ strategy in addition to placement sites in secondary channels. The selection of placement sites in the vicinity of the dredging sites minimises cost and effort. The fairway needs to be dredged at natural sedimentation locations and these dredging locations may vary slightly over time. Currently an optimized relocation pattern within the Scheldt estuary is being investigated in advance of the forthcoming review of consent locations (BioConsult and NLWKN 2013).

Sediment management in the Weser estuary has been adapted continuously to the respective requirements. Dredging in the fairway and harbours (open to the estuary and behind locks) is primarily carried out by hopper dredgers. The dredged material is disposed of at various placement sites: contaminated material from the harbours is deposited on land. The annual volume of muddy and contaminated harbour sediments removed depends on both the requirements of the harbours and the capacity of the landfills. Today, particulate matter from the harbours open to the estuary is regularly remobilized by water injection, thus reducing maintenance dredging by hopper dredgers. Additionally, the reduction of maintenance dredging within the harbours closed to the estuary has resulted from structural measures, e.g. by building a new watering facility for a harbour basin in Bremerhaven to reduce the sedimentation rate.

At present no comprehensive strategy is in place, but the Federal Institute of Hydrology, the Federal Waterways Engineering and Research Institute and the Federal Waterways Administration are developing a sediment management concept: however, river engineering is not part of this first approach. It is foreseen that both aspects will be incorporated into an integrated river engineering concept within the next few years (BioConsult and NLWKN 2013).

Along the Elbe estuary and in the harbours, maintenance dredging is executed in the areas of sedimentation and hopper dredgers are mostly used for this process. Moreover, water injection is applied in line with appropriate tidal conditions to eliminate sand ripples in the fairway and harbours as well as in anabranches. Dredged material from maintenance dredging is relocated within the river system according legislation. Contaminated material above boundary values (from the harbour area) is brought on land and treated in the sediment treatment plant METHA – Mechanical Treatment and Dewatering of Harbour Sediments.

Following an increase in dredging in 2004 and 2005 due to re-circulation of sediment within the limnic zone downstream of Hamburg, sediments were brought also to placements in the North Sea. The Federal Waterways Administration and Hamburg Port Authority jointly developed the “River Engineering and Sediment Management Concept for the Tidal River Elbe” (RESMC) (HPA and WSV 2008). It indicates causes for the rise in dredged volumes and on this basis not only develops a strategy for sediment management, but also for the reduction of the dredged volumes, taking into account sediment composition and contamination. Measures to reduce the increase in the tidal range are also part of the concept. Single aspects of the concept have already been implemented although others still have to be initiated. These include amongst others the creation of flooding areas by managed realignment measures or reconnecting side channels to reduce the increase in the tidal range (BioConsult and NLWKN 2013).

The sediment management strategies in the case estuaries display both similarities and dissimilarities. In all case estuaries sediment management is primarily aiming at establishing and maintaining the specified minimum depths in the fairway and at the same time reducing costs. In view of the EU regulations, the legal requirements based on environmental and nature conservation law have been increasingly taken into account in recent years. The dredged material is primarily placed within the estuaries at designated placement sites and often this material was and is still used for further river engineering measures (backfilling of over depths, securing shore and concentration of the current velocity on the main channel).

Differences between the case estuaries include in particular the specific situations in the natural region and the different types of river engineering measures such as groynes (especially in the inner Weser estuary where these are very extensive in order to reduce maintenance dredging). Each estuary is facing individual challenges due to the varying intensity of tidal pumping and thus the varying extent of sedimentation (e.g. the challenges on the Elbe in this context are rather extensive). On the Humber estuary however, the access for large vessels to the ports depends much more on the tides than at Weser, Elbe and Scheldt, with no channel deepening having been used, but rather, an active management of the fairway path undertaken through regular modification to the location of the main buoyed channel. Finally, the flexible relocation strategy at the Scheldt is a fundamentally different approach compared to the other estuaries.

The comparison of the sediment management strategies of the case estuaries clearly shows that the situation varies between systems and requirements, and therefore specific strategies are necessary and meaningful. Sediment management practice has developed historically in all estuaries and has been adapted to changing boundary conditions. Current changes in the boundary conditions include more extensive consideration of requirements based on environmental and nature conservation law. Furthermore, greater interest is given to the necessity for cost reduction and the more frequent occurrence of undesirable morphodynamic developments primarily due to increased tidal pumping. Consequently, sediment management has to tackle these challenges and to challenge historically based approaches. One option is to formulate integrated sediment management strategies which also take into account long-term changes based on an in-depth understanding of the interactions between hydrodynamics and morphodynamics and ecology into account.

The case estuaries have been morphologically modified to a great extent in the past. A close interaction between river engineering and sediment management exists and this should be adequately considered in the future. At the same time, the conditions of nature conservation and environmental protection need to be incorporated into integrated river engineering concepts with regular monitoring and evaluation programmes. Thus, the main challenge is still to balance the estuarine sediment budget for the different estuarine reaches, but in a broader framework by safeguarding sustainably the system functions of the estuarine environment. Thus, sediment management has itself to understand and to act as part of integrated estuarine management (BioConsult and NLWKN 2013).

6.3.2 Discussion and conclusions

The classification of management measures based on the degree of additional benefit provision, beyond the individual development targets of the management measures leads to three efficacy ratings: *'low', 'medium'* and *'high'*. On the basis of the latter rating being the best achievable, '*good practice examples*' were identified (see Figure 6.11, Table 6.12). It was found that 19 out of 39 management measures serve as '*good practice examples*'. The measure examples being analysed here are described in detail within separate reports; and additional information which might be valuable for the implementation of further measures in estuaries can be taken from there (see reports in 'Management measures' at www.tide-toolbox.eu).

The '*good practice examples*' are distributed over all case estuaries, with a concentration on the river Weser where all listed management measures were classified as '*high*'. Additionally, in all estuary zones management measures have been identified as '*good practice examples*' with a concentration in the limnic zone.

Overall, the portion of good practice examples is high. Amongst them, there are also the two largest measures being evaluated here, the measures 'Tegeler Plate' (Weser, oligohaline zone, about 210 ha) and 'Alkborough' (Humber, border from meso- to oligohaline zone, about 440 ha). Despite the fact that both measures are managed realignment measures and both are examples of win-win-solutions, the reasons for their implementation are different, and hence the corresponding development targets. The measure 'Tegeler Plate' has been implemented as a compensation measure for port extension; it mainly aims at restoring tidally influenced habitats. In contrast, the main driver for the 'Alkborough' measure is – besides the provision of Natura 2000 functions – the Humber Flood Risk Management Strategy. Hence, the measure aims at the creation of intertidal habitat, and at providing opportunities for tourism and recreation, but, remarkably the primary aim of this large measure in the upper estuary is for flood defence (reducing extreme high tide levels).

In general, the classification shows a clear majority of the management measures assessed as falling into the to the measure category '*biology/ecology*'. Management measures with focus only on sediment or morphological aspects did not primarily concentrate on delivering ES. However those two measure examples that were assigned to the category hydrology/morphology and also to the category biology/ecology were scored as being 'high' (e.g. 'Spadenlander Busch' at the Elbe and 'Lippenbroek' at the Scheldt). Hence, measures with a broad scope appear to have a higher score.

However, a couple of the hydrology/morphology measures with a broad scope (e.g. the measure "Sandbars 2010") were classified as 'low'. This is partly because the expected impact on ES and beneficiaries are deducted from the change in habitat induced by the measure within the boundaries of the measure. Due to the disposal along sandbars, the deep part of the river is narrowed locally at strategic places outside the boundaries of the measures, inducing a self-eroding effect of the sills in the navigation channel, so that less dredging work is necessary. Further effects of this measure take time; for instance it will take some time before it becomes apparent whether the reduced flow velocities in other parts lead to the targeted positive effect on biodiversity.

Another important limitation of the assessment method is the estuarine specific assessment of provisions for Natura 2000 requirements and WFD impact. Because the measures are assessed against local pressures and conservation objectives, a specific type of measure could have been scored differently in another estuary. Also measures which target many ES are less likely to have non-targeted “additional” effects.

Based on the previous descriptions and findings the three questions formulated in the introduction to Chapter 6 can be addressed:

1. On which spatial scale (area of measure, estuary zone or entire estuary) is the assessment scheme able to support the estuarine management?

   The developed and applied assessment scheme is able to assess the management measures according to the site-specific degree of target achievement. The concept of estimating the potential of delivering ES has been applied and shows promising results (see Figure 6.9). The integration of the ES concept to estimate the different beneficiaries (spatial scales and time frames, see Figure 6.10) in the light of the Total Economic Value can serve as a first attempt for evaluation. According to the aspects of reliability and transferability the assessment has to be further developed.

   The quality and quantity of data play an important role for estuarine management. This encompasses, e.g. the availability and processing of data and information. Regarding gaps in data and information, tangible expert knowledge could be used to overcome this deficit. This scheme presents a first and promising approach to integrate and operationalise expert knowledge in management aspects of estuaries based on the concept of ES.

   Whilst with the assessment scheme it is feasible to assess the contribution of the management measure locally, i.e. on the respective measure site, the next step for estuarine management is the development and application of assessment schemes which are able to estimate the contribution of measures according to the larger reaches of estuaries, e.g. the classified estuary zones. Thus, the challenge emerging from the application of the described assessment scheme is to develop a methodology to adequately estimate the effects of a measure as well as a set of measures to the improvement of the ecological status of an estuary zone or the entire estuary.

2. Which management measure could adequately be assessed by the assessment scheme?

   In general, the results of the assessment scheme showed that all listed management measures could be assessed (see Figure 6.11). None of the management measures have been dropped from the analysis, except those measures where none or sparse information was available. The technical feature ‘MudBug’ was also assessed, but with difficulty in relation to EU environmental legislation. Adequate system parameters have been identified and categorised to classify the management measures.

   The measure categories such as ´biology/ecology´, ‘hydrology/morphology´ and ´physical/chemical quality´ reflect the basic parameters for assessing the quality status of estuaries. Consequently, one important point is the adjustment of the assessment: The provided assessment scheme fits best for managed realignment measures as one of three identified management types. It is obvious that these management measures are concentrating on habitat creation, restoration or conservation, and, thus, mainly deliver high values on supporting ES. On the other hand, the management measures assigned to the measure category ‘hydrology/morphology’ have also been assessed by applying this scheme, but were classified as ‘medium’ or ‘low’, and, hence not chosen as ‘good practice examples’. The estimation of the potential to deliver ES, either regulating or provisioning, is not prominent for some of these measures and, furthermore, difficult to determine. In some cases the developed method was not adequate to get a comprehensive picture of the delivered ES.

   Consequently, two pathways for further research to improve this deficiency emerged: (i) develop an assessment scheme comprising all basic criteria to ensure the adequate assessment of all surveyed management measures by equitably addressing all ES or (ii) improve and foster the knowledge and understanding of dynamic estuarine processes affecting management measures. This would focus attention on the estimation of regulating services provided by near natural occurrence of driving estuarine processes such as sedimentation, morphodynamics or hydrology.

3. Which general conclusions can be drawn based on the on-road-test of the assessment scheme?

   The present assessment delivers promising results in estimating the effectiveness and value of different management measures. This is ensured by using a scientifically founded methodology to categorise and highlight the most important system parameters and adopt and implement an applicable value assignment to estimate the effects of human influence on estuaries addressed by management measures.

Within this framework it has been shown that operationalizing the approaches of ES and Total Economic Value in combination with benefits regarding the EU environmental legislation requirements relating to the WFD and Natura 2000 provision could deliver worthwhile results. The focus on the amount of values gained by the ES 'biodiversity' leads to a disproportionate value assignment for managed realignment measures. This is due to the purpose that managed realignment measures are basically oriented towards e.g. in re-establishing habitat structures. Nevertheless, these new habitats deliver noticeable effects for other ES such as they were outlined in relation to EU led environmental legislation.

To evolve a more holistic approach it seems to be worthwhile to also focus on the main abiotic drivers ruling the structures of the estuary. This would focus attention on the estimation of regulating services provided by near the natural occurrence of estuarine driving processes such as sedimentation, morphodynamics or hydrology (see point 2 above). Working on this approach requires the integration of larger spatial scales and time frames which lead to an assessment of measures that could provide experiences to the effects of human made measures on a larger system, e.g. the complete zone of an estuary. Besides the need to implement management measures tackling different development targets, it is indispensable to develop tailor-made and site-specific measures and accompany them with an appropriate monitoring and evaluation programme.

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7 Monitoring, Assessment and Management in Practice

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7.1 Monitoring framework

7.1.1 Rationale for monitoring

It is axiomatic 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 (usually related to a management measure or an activity) or a statutory/competent authority (in the case of the status of the area). In most cases, permission is granted for a development or an activity on condition that monitoring is performed and hence licence conditions and the implementation of EU directives include stipulations regarding the monitoring required. For example, the EU EIA and Natura 2000 Directives require monitoring in order to predict the effects of a plan or project on an area or conservation feature, whereas the Water Framework, Natura 2000 and Marine Strategy Framework Directives requires monitoring to determine whether an area is in Good Ecological or Chemical Status, Favourable Conservation Status or Good Environmental Status respectively. 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.

We have to ensure that we have robust and defendable science to assess estuarine health and underpin estuarine management, hence be aware of the three aspects of science methodology – that we should define our Aims, as the big idea in the science, list our Objectives, as what we need to do to reach our Aims, and give our Hypotheses, as testable and scientifically rigorous questions. Following this, we can suggest there are three types of significance in our findings – firstly, and most easy to determine as long as we have sufficient data, is statistical significance. Secondly, and perhaps more importantly, is ecological or environmental significance, and thirdly we have the social significance of any change that we detect. For example, detecting the loss of a species amongst hundreds would be impossible statistically without a large and powerful statistical sampling design but that lost species could be ecologically relevant. Despite this, we might not be able to statistically or ecologically detect a change because of noise (inherent variability) in the system but if society thinks a change has occurred then it should have the highest significance (see Gray and Elliott 2009). If society thinks there is a problem then by definition there is one even if science cannot detect it. Consequently, the Ecosystem Approach relies on good and proportionate (fit-for-purpose) science to provide an ecosystem health assessment (or monitoring) programme consisting of four elements – (i) an analysis of main processes and structural characteristics of ecosystem; (ii) an identification of known or potential stressors; (iii) the development of hypotheses about how those stressors may affect each ecosystem; and (iv) the identification of measures of environmental quality and ecosystem health to test hypotheses.

7.1.2 Definitions and types of monitoring

In order to detect change then requires monitoring the system – when to assess and what to assess although we have further complicated this to result in 11 types of monitoring, many of which are identified explicitly or implicitly in EU Directives (adapted from Elliott 2011):

- Surveillance monitoring: a 'look-see' approach which begins without deciding what are the end-points followed by a post hoc detection (a posteriori) of trends and suggested management action.
- Trend monitoring: to follow patterns across spatial gradients or over time.
- Condition monitoring: used by nature conservation bodies to determine the present status of an area; it could be linked to biological valuation (e.g. Derous et al. 2007).
- Operational monitoring: used by industry for business reasons (e.g. for a dredging scheme linked to aims for management and to determine if an area requires further dredging).
- Compliance monitoring: used by industry and linked to licence (or permit/authorisation/consent) setting for effluent discharge, disposal at sea, etc.
- Self-monitoring: being carried out by the developer/industry under the 'polluter pays principle' but often sub-contracted to an independent and quality-assured/controlled laboratory.
- Check monitoring: where an Environmental Protection Agency checks self-monitoring to ensure that a developer is performing appropriate monitoring.
- Toxicity testing: as a predictive approach needed for licence setting, used by regulators to determine compliance of the licence conditions with required standards.

- Investigative monitoring: applied research on cause-and-effect, to explain any deviation from perceived or required quality.
- Diagnostic monitoring: determining effects but link to cause, synonymous with investigative monitoring.
- Feedback monitoring: real time analysis, linked to predetermined action; e.g. monitoring during dredging on condition that the activity is controlled/prevented/stopped if a deleterious change is observed; this relies on acceptance that any early-warning signal will be related to an ultimate affect (Gray and Elliott 2009).

These are then combined into 3 major groups:

1. Situation, condition and trend monitoring which implies an intensive programme to evaluate pressures and assess long term trends; this mainly focuses on system monitoring and may identify the consequences of pressures. Within the MONEOS monitoring plan (Scheldt estuary), the system monitoring refers to this kind of monitoring.
2. Operational, feedback, self-, check- and compliance monitoring implies monitoring the effects of activities and especially the success of implementing a programme of management measures, the success of development actions (such as a dredging campaign) or the monitoring required to determine whether or not a licence/permit/authorisation/consent has been met and that the monitoring is robust and legally defendable; this mainly focuses on effect monitoring, the consequences of actions at a place and thus an implied cause and effects link. Within MONEOS, these monitoring activities are grouped as project monitoring, because this monitoring is linked to specific (infrastructural) projects to assess their impact. The project monitoring is nested within the system monitoring, but can consist of additional parameters and a higher spatial and temporal resolution. Project monitoring is hwoever limited in space and time.
3. Investigative or diagnostic monitoring or toxicity testing 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; this allows cause-effect relationships to be interrogated. In the MONEOS programm, this is called research monitoring: an additional monitoring to fill knowledge gaps.

7.1.3 Properties of monitoring parameters and indicators

The system monitoring may be a long term monitoring programme to collect all necessary data to evaluate the functioning of the system or a wide-scale programme to define ecosystem structure. To evaluate the effects of individual management measures and the effect of natural and anthropogenic changes on human 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.

Each monitoring programme then should focus on a set of attributes to be monitored (e.g. the ecological and physico-chemical components) such that the information produced by the monitoring programme can be used in management (Table 7.1). More importantly that information has to be defendable especially in discussions between developers such as port authorities and statutory bodies charged with implementing EU Directives.

Most monitoring is required to determine what is the current situation in an area, how it changes through time and whether any parameter complies with or exceeds a threshold limit, a target or a baseline level. The latter may be regarded as indicators, e.g. an agreed change in the levels of SPM following dredging or the change in the ecological quality according to the WFD. Such indicators may be qualitative or quantitative but again to be used in robust monitoring and management they should have a set of properties (Table 7.1).

Table 7.1. The required properties of indicators and monitoring parameters for successful estuarine management (developed from Holl and Cairns 2002; McLusky and Elliott 2004; Gray and Elliott 2009; Elliott 2011).

Property	Explanation
Anticipatory	Sufficient to allow the defence of the precautionary principle, as an early warning of change, capable of indicating deviation from that expected before irreversible damage occurs.
Biologically important	Focuses on species, biotopes, communities, etc. important in maintaining a fully functioning ecological community.
Broadly applicable and integrative over space and time	Usable at many sites and over different time periods to give an holistic assessment which provides and summarises information from many environmental and biotic aspects; to allow comparisons with previous data to estimate variability and to define trends and breaches with guidelines or standards.
Concrete / results focussed	We require indicators for directly observable and measurable properties rather than those which can only be estimated indirectly; concrete indicators are more readily interpretable by diverse stakeholders who contribute to management decision-making.
Continuity over time and space	Capable of being measured over appropriate ecological and human time and space scales to show recovery and restoration.
Cost-effective	Indicators and measurements should be cost-effective (financially non-prohibitive) given limited monitoring resources, i.e. with an ease/economy of monitoring. Monitoring should provide the greatest and quickest benefits to scientific understanding and interpretation, to society and sustainable development. This should produce an optimum and defensible sampling strategy and the most information possible.
Grounded in theory / relevant and appropriate	Indicators should reflect features of ecosystems and human impacts relevant to achieving operational objectives; should be scientifically sound and defensible and based on well-defined and validated theory. They should be relevant and appropriate to management initiatives and understood by managers.

Interpretable	Indicators should reflect the concerns of, and be understood by stakeholders. Their understanding should be easy and equate to their technical meanings, especially for non-scientists and other users; some should have a general applicability and be capable of distinguishing acceptable from unacceptable conditions in a scientifically and legally defensive way.
Low redundancy	The indicators and monitoring should provides unique information compared to other measures.
Measurable	Indicators should be easily measurable in practice using existing instruments, monitoring programmes and analytical tools available in the relevant areas, to the required accuracy and precision, and on the time-scales needed to support management. They should have minimum or known bias (error), and the desired signal should be distinguishable from noise or at least the noise (inherent variability in the data) should be quantified and explained, i.e. have a high signal to noise ratio. They need to be capable of being updated regularly, being operationally defined and measured, with accepted methods and Analytical/Quality Control/Quality Assurance and with defined detection limits.
Non-destructive	Methods used should cause minimal and acceptable damage to the ecosystem and should be legally permissible.
Realistic / attainable (achievable)	Indicators should be realistic in their structure and measurement and should provide information on a 'need-to-know' basis rather than a 'nice-to-know' basis. They should be attainable (achievable) within the management framework.
Responsive feedback to management	Indicators should be responsive to effective management action and regulation and provide rapid and reliable feedback on the findings. Such feedback loops should be determined and defined prior to using the indicator.
Sensitive to a known stressor or stressors	The trends in the indicators should be sensitive to changes in the ecosystem properties or impacts, to a stressor or stressors which the indicator is intended to measure and also sensitive to a manageable human activity; they should be based on an underlying conceptual model, without an all-or-none response to extreme or natural variability, hence potential for use in a diagnostic capacity.
Socially relevant	Understandable to stakeholders and the wider society or at least predictive of, or a surrogate for, a change important to society.
Specific	Indicators should respond to the properties they are intended to measure rather than to other factors, and/or it should be possible to disentangle the effects of other factors from the observed response (hence having a high reliability/specificity of response and relevance to the endpoint).
Time-bounded	The date of attaining a threshold/standard should be indicated in advance. They are likely to be based on existing time-series data to help set objectives and also based on readily available data and those showing temporal trends.
Timely	The indicators should be appropriate to management decisions relating to human activities and therefore they should be linked to that activity; thus providing real-time information for feedback into management giving remedial action to prevent further deterioration and to indicate the results of or need for any change in strategy.

7.1.4 Monitoring regimes in case-estuaries

In this section, examples from the case estuaries are given.

7.1.4.1 Elbe

The management of the Elbe estuary forms a great challenge for the responsible authorities, because it is located at the intersection of the three federal states:

- Schleswig- Holstein (northern shore, Landesamt für Landwirtschaft, Umwelt und ländliche Räume (LLUR)),
- Lower Saxony (southern shore, Lower Saxony Water Management, Coastal Defence and Nature Conservation Agency (NLWKN)) and
- City of Hamburg, Department for Urban Development and Environment (BSU).

Each federal state is in charge of the monitoring activities of its territory. Furthermore the national state of Germany, represented by the Federal administration for Waterways and Navigation (WSV) belonging to the Ministry for Transport, Building and Urban Development and, for the area belonging to the City of Hamburg i.e. the area upstream and downstream of the port and within the port, Hamburg Port Authority (HPA) are responsible for the management of the shipping channel of the Elbe estuary. Due to the different uses lots of single/sectoral management plans exist, each with its own monitoring focused on a particular goal (e.g. good water quality for the Water Framework Directive WFD). A brief description of the most important monitoring programs is given, i.e. related to the EU legislation and system monitoring related to the fairway deepening. Specific investigative monitoring programs have been recently carried out, but they are not described here.

<u>Water Framework Directive</u>

The national surveillance program of the whole river Elbe implements the German part of the international measuring program set up by the International Commission for the Protection of the Elbe (IKSE). The aim of the measuring program is to be able to report once a year on the chemical and ecological state of the Elbe. The choice of the sampling frequency was chosen in order to safeguard a reasonable state of accuracy and reliability.

Until 2004 the ´Arbeitsgemeinschaft Elbe´ (ARGE) was responsible for the monitoring program. It was followed up by the Flussgebietsgemeinschaft Elbe ´FGG Elbe´, the coordinating group which consists of the national water management administrations of the 10 federal states in the catchment area of the Elbe river basin, working together with the IKSE. The national surveillance monitoring of the FGG Elbe is mainly related to the requirements of the WFD. Since 2010 the group has also been coordinating the Flood Risk Management Plan. The monitoring itself is carried out by responsible authorities of the different federal states asking for an agreement on monitoring parameters and methods.

The following sampling strategies are included in order to meet the requirements of the European directives:

- Continuous measurements
- Longitudinal transects

- Cross sections
- Special programs related to pollutants

A web-based database has been set up which contains not only all measured parameters for the whole Elbe river and its tributaries but also old reports of the former ´Arbeitsgemeinschaft Elbe´.

<u>Birds and Habitats Directives</u>

The main objective of the Birds and Habitats Directives is the conservation of biological diversity. Concerning the Elbe estuary the three federal states Lowe Saxony, Schleswig Holstein and the City of Hamburg are responsible for nature conservation. At the beginning of 2012 an integrated management plan was published by the three states as well as WSV and HPA that described the conservation objectives and measures to be taken in order to reach the aims in accordance with the various anthropogenic uses. According to article 11 of the Birds and Habitats Directives the state of preservation of the designed habitats and species has to be monitored by the three federal states and to be reported to the EU every six years (art. 17). Within the Elbe several areas are nominated for the Birds and/or Habitats Directive (Figure 7.1), which should form a coherent network of protected nature areas. The required parameters and the frequency of the monitoring for the various species and habitats are described in ´The state of preservation according the BfN method´ (BfN 2006).

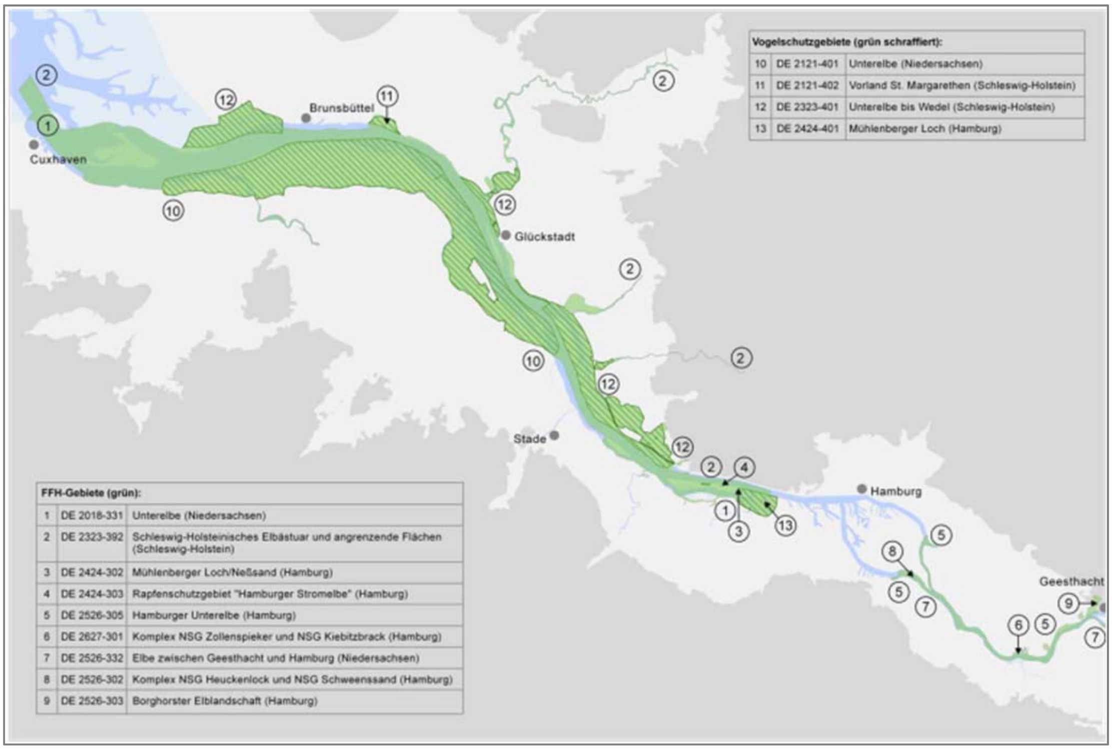

Figure 7.1. Areas of the Birds and Habitats Directives in the Elbe estuary.

System monitoring for navigation and ´Evidence monitoring´ related to the shipping channel deepening in 1999

The WSV and HPA have been carrying out continuous measurements in the water and on the shore until mthw level, related to maintenance dredging since .a long time, whereas HPA is responsible for the measurement in the area belonging to the city of Hamburg. In this context hydrological measurement (water levels, currents velocities, SPM, etc.) are carried out which are related to navigation, flood protection and water management, and other measurements related to ecological subjects.

Furthermore a program was set up in relation with the last deepening of the shipping channel in order to monitor the effects of the works of the dredging measure by HPA and the WSV (WSA Cuxhaven, WSA Hamburg and WSA Lauenburg). In the planning approval procedure it was determined to investigate whether the predicted effects described in the Environmental Impact Assessment would exceed during and after the works (1999 until 2015) and, if so whether further ecological compensation measures are necessary. The program is overlapping with the system monitoring described above (sampling stations and parameters) and includes further measurements, e.g. the development of tidal water and storm surge levels, conductivity/salinity, biotopes of the estuary as well as important flora and fauna.

Conclusion

In conclusion, many different monitoring programs and investigations exist. It is a challenge to coordinate different responsibilities and interests of the various responsible institutions, communication or data supply/exchange which is probably not always functioning as it should. These circumstances lead to the fact that the various monitoring programs have not been properly integrated; a number of important gaps remain. Another important challenge is the absence of a common database – e.g. in some cases the existence of data at one institute is not known by other institutions.

The fact that in the Elbe estuary several areas are nominated for the Birds and/or Habitats Directives (Figure 7.1), which should form a coherent network of protected nature areas leads to the effect that differences can appear between the monitoring program of the three states, i.e. every federal state is monitoring the species e.g. birds and habitats occurring at its own protected and nominated areas.

It is anticipated to improve the situation after the implementation of the Natura 2000 Management Plan. However concerning particular parameters such as water levels or oxygen content a good network for data exchange and multiple use already exists. Further the responsible authorities of the different federal states are working on coordinating the different monitoring programs related to a particular directive for practical and financial reasons. Also the performance of the single measurements, sampling techniques and reporting has been harmonised as much as possible.

7.1.4.2 Humber

The Environment Agency has a substantial historic data set on water quality, ecological, biological and chemical parameters within the Humber. A number of studies have been undertaken to data on the Humber, including LOIS (http://www.bodc.ac.uk/projects/uk/lois/), HARBASINS (http://www.harbasins.org), State of the Natural Environment (Environment Agency, 2011), and more recently TIDE (http://www.tide-toolbox.eu/). In more recent years, monitoring programmes have been reappraised to ensure that they are meeting the legislative drivers (EU Directives- Water Framework Directive, Habitats Directive, Bathing Water Directive) and have been pared down due to economic pressures. The Environment Agency has a WFD monitoring program that is used to undertake the WFD classification work within the estuary. The sampling sites are distributed between the three transitional water bodies according to the parameters being classified (Figure 7.2).

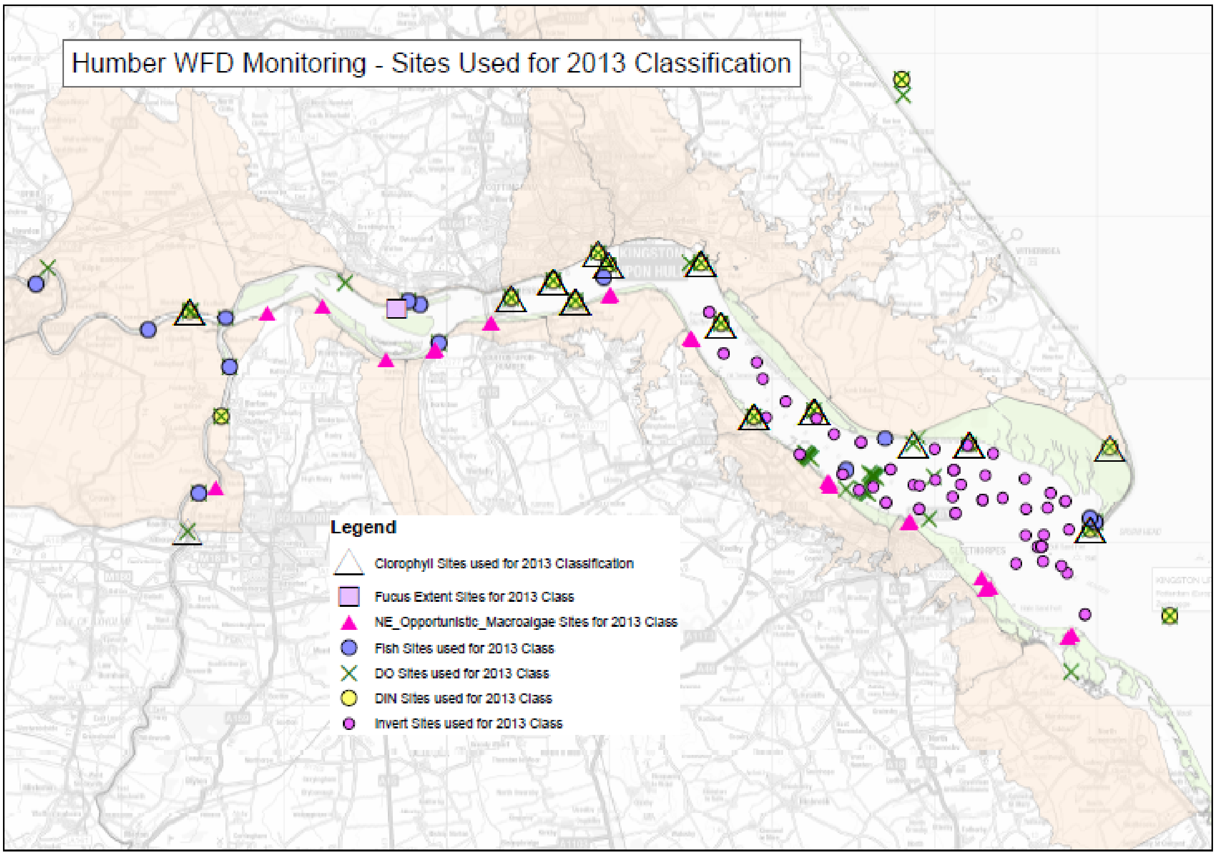

Figure 7.2. The Humber Estuary three transitional water bodies (Upper, Middle and Lower) showing the sampling site distribution for numerous parameters in the 2013 WFD classification monitoring program.

The Birds and Habitats Directives monitoring is undertaken by Natural England in the Humber, with the main objective being to ensure that the integrity of the Natura 2000 site is maintained. Natural England undertake condition survey within the estuary to ensure that we record the status of the habitat present and this is now combined with saltmarsh extent surveys on the estuary by the Environment Agency on a three yearly periodicity. Bird assemblages are surveyed under the voluntary WeBS scheme on a once per month basis 12 months per year. The surveys are undertaken for approximately two hours either side of high water on a sector basis (each sector is approximately 5-10km in length). The whole estuary is covered, but the tidal tributaries of the River Trent and River Ouse are not, and in some sectors the British Trust for Ornithology, who co-ordinate the WeBS counts, are struggling to secure sufficient volunteers to cover all the estuary sectors. In addition, approximately every five years a Low Water survey is undertaken on the same frequency and using the same sectors as the WeBS count. In addition, breeding bird success of Annex 1 species is monitored annually at key sites by the voluntary sector (RSPB, LWT, YWT, Spurn Bird Observatory), for example Marsh Harrier, Bittern, Avocet and Little Tern.

The Centre for Environment, Fisheries and Aquaculture Science (Cefas) undertake some monitoring within the estuary in terms of chemicals that are bound within sediments within the estuary and the dredge disposal sites. In addition Associated British Ports Humber Estuary Services (ABPHES) undertake bathymetric surveys to ensure a safe navigation channel can be maintained and in relation to the maintenance dredge program within the estuary. ABPHES also maintain a network of 16 tidal gauges within the estuary that monitor hydrological parameters (e.g. water levels, velocities) that they use for navigational purposes and to produce an annual bathymetric survey of the whole estuary.

There are numerous different monitoring programs and investigations that exist on the Humber. The next challenge that the estuary faces is to try to bring together the different responsible bodies to deliver a co-ordinated monitoring programme that will aid delivery of integrated estuary management. A positive step forward would be the creation of a centralized repository that all parties with a responsibility for estuary management could both contribute to and utilise the existing data. This would help deliver more effective and targeted monitoring and maximise the monitoring it is possible to deliver.

7.1.4.3 Weser

Also in the Weser different monitoring programs are carried out which relate to the different EU Directives but also to other international treaties or conventions, such as ASCOBANS. Table 7.2 presents an overview of the scope of different monitoring types and indicates the broad aspects such as morphology, water quality, etc. to which the monitoring relates as well as the connected policy framework.

Table 7.2. Compilation of measuring programs at the Weser estuary regarding various EU directives (Integrierter Bewirtschaftungsplan Weser 2012, altered).

Aspect	Type of monitoring	Content / Scope	Directive/ convention										
			WFD	HD	OSPAR	TMAP	BD	MSFD	HELCOM	EMS	ASCOBANS	AEWA	other
Hydrology and morphology													
Morphology (Bathymetry/ Topography)	Surveillance	Recording of depth variations, topography, morphological changes with echo sounder (sublittoral) as well as terrestrial and laser scan investigations (eulittoral). *(Frequency spatially varying: every 1 to X years, all estuarine zones)*	x	x		x							x
Hydrology	Surveillance	Recording of water levels, tidal range, currents, sea state and discharge at a couple of stations. *(Continously, all estuarine zones)*	x	x	x								x
Morphology (substrate)	- Monitoring of distribution of mudflat types - Monitoring of border eulittoral – sublittoral	Investigations of sediment structure and characteristics at chosen stations with analysis of grain size and other physical soil parameters (water content, compaction) at other stations. Analysis of aerial photographs or satellite images. *(Every 6-12 years, mesosohaline + polyhaline zone)*	x	x		x							
Water quality													
Physico-chemical status	Monitoring to meet limit values	- Nutrients, organic carbon, pH. Stations: Farge Fahrwasser, Brake and Alte Weser - Nutrients, organic carbon, oxygen, etc. Stations: Farge Fahrwasser, Brake, Alte Weser, Hoher Weg and Leuchtturm Roter Sand *(Several times/year, all estuarine zones)*	x	x	x	x							x
Water quality	Monitoring to meet limit values	Yearly measurement at sampling sites with documentation of temperature, thermal conditions, ice conditions, salinity, oxygen concentration and saturation, suspended matter, visibility depth.			x								
	Pollutants in water	Stations: Brake, Farge Fahrwasser, weir Hemelingen. *(Several times/year, freshwater – oligohaline zone)*	x	x	x	x							

Aspect	Type of monitoring	Content / Scope	Directive/ convention										
			WFD	HD	OSPAR	TMAP	BD	MSFD	HELCOM	EMS	ASCOBANS	AEWA	other
	Pollutants in biota (blue mussels and fish)	The member states have to monitor the designated shellfish waters regarding halogenated organic substances every 6 years (minimum). *(Yearly, mesohaline + polyhaline zone)*	x [5]		x								
Typical habitat structures													
Mudflats and sandflats not covered by seawater at low tide (1140)	See hydrology and morphology	See hydrology and morphology											
	Pollutants in sediment	Stations/Profiles: Farge, Brake, Tettens and Hoher Weg, Cappel. *(Frequency spatially varying: minimum every 3 years, all estuarine zones)*		x	x	x							
Salicornia and other annuals colonising mud and sand (1310)	Stock monitoring	Area-wide recording based on aerial photographs with documentation of area size, vegetation, land use, drainage. *(Every 3-6 years, permanent plots for recording species and abundance every 1-3 years, mesohaline + polyhaline zone)*	x	x		x	x	x					
Spartina swards (*Spartinion maritimae*) (1320)	Stock monitoring	Area-wide recording based on aerial photographs with documentation of area size, vegetation, land use, drainage. *(Every 3-6 years, permanent plots for recording species and abundance every 1-3 years, mesohaline + polyhaline zone)*	x	x		x	x	x		x			
Atlantic salt meadows (Glauco-Puccinellietalia maritimae) (1330)	Stock monitoring	Area-wide recording based on aerial photographs with documentation of area size, vegetation, land use, drainage. (*Every 3-6 years, permanent plots for recording species and abundance every 1-3 years, mesohaline + polyhaline zone*)	x	x		x	x	x		x			
Reed / Foreland	Stock monitoring	Recording of foreland areas, percentage of habitats in favorable state, reed belt and vegetation structure. *(Every 6 (?) years, freshwater to oligohaline zone)*	x										

[5] The requirements of the Shellfish Waters Directive [79/923/EWG] are to be integrated in the Water Framework Directive (WFD).

Aspect	Type of monitoring	Content / Scope	Directive/ convention										
			WFD	HD	OSPAR	TMAP	BD	MSFD	HELCOM	EMS	ASCOBANS	AEWA	other
Vegetation and fauna													
Phytoplankton	Stock monitoring	Chl a, species and abundance. (*Several times/year, mesohaline/polyhaline zone at a couple of stations*)	x										
Opportunistic green algae	Stock monitoring	Green algae coverage of mud and sand flats. (*4-5 survey flights from May to September, mesohaline + polyhaline zone*)	x										
Seagrass	Stock monitoring of eulittoral seagrass populations	Area-wide recording by aerial survey connected with field investigation with documentation of extension (km²), position (GPS), coverage (%). *(Every 3-6 years, sampling of chosen seagrass beds at permanent sampling sites to validate aerial survey yearly, mesohaline + polyhaline zone)*	x	x	x	x							
Seagrass	Status quo survey sublittoral seagrass populations	Check benthic invertebrates samplings on appearance of seagrass in order to get hints regarding potential re-establishment of sublittoral seagrass. *(Occasionally/irregularly, mesohaline + polyhaline zone)*	x	x	x	x							
Benthic invertebrate fauna	Stock monitoring as an indicator for system changes	Species diversity, abundance at different stations (sublittoral and eulittoral, with various sediments and water depths). *(Every 1-6 years, couple of stations in all estuarine zones)*	x	x	x	x							
	Monitoring of neozoans	Stock monitoring and monitoring of distribution of neozoans. Need for research in terms of relevance of neozoans for the entire system (e.g. regarding crowding out effects). *(Partly recently started)*						x					
Blue mussel (*Mytilus edulis*)	Stock monitoring of eulittoral blue mussel beds	Area-wide aerial survey connected with investigations of permanent sampling sites. Abundance, live weight, shell length, biomass. *(Once a year, outer estuary)*	x	x	x	x							
Fish	Stock monitoring	Species composition and abundance. Fishing with stow net at 3 sampling sites. *(Every 3 years, freshwater, oligohaline and mesohaline zone)*	x	x	x								

Aspect	Type of monitoring	Content / Scope	Directive/ convention										
			WFD	HD	OSPAR	TMAP	BD	MSFD	HELCOM	EMS	ASCOBANS	AEWA	other
Harbour seal (Phoca vitulina)	Status quo survey	Abundance. *(Yearly, 5 survey flights from May to September within the meso- and polyhaline zone)*		x	x	x					x		
Breeding birds (Sea- and shorebirds)	Stock monitoring	- Recording of colonial breeding birds and chosen species. *(Yearly)* - Recording of remaining species of species list on sampling sites. *(Yearly, area-wide every 6 years)* - Measurement of breeding success at chosen breeding plots regarding indicator species - Investigation of population structure (bird ringing programs). *(Optional)*		x		x	x					x	
Migrant Birds (Sea- and shorebirds)	Stock monitoring	- Winter counting of sea- and shorebirds (species, abundance). *(Yearly, January, along the entire coast)* - Synchronously counting of geese and swans (species, abundance). *(Yearly, January and March, Lower Saxony-wide appointments, entire (?) estuary)* - Water and wading bird counting (species, abundance) on representative resting grounds at spring tide. *(Yearly, 26 recordings/year, all (?) estuarine zones)* - Species-specific additional recordings if required. *(Yearly).* - Airborne recording of seabirds at the German North Sea in winter. *(Twice in 6 years possibly synchronously to winter counting in January (?). Meso- and polyhaline zone)*		x		x	x					x	
Voluntary additional monitoring to map future significance regarding restoration objectives.													
Harbour Porpoise (*Phocoena phocoena*).	- Spatial-temporal distribution - Stock monitoring	- Documentation of incidental sightings - Monitoring of cadavers - Continuous documentation of ultrasound noises near the Weser fairway using click detectors (C-PODs)		x	x	x					x		

Legend for abbreviations:

Measuring Program	
WFD	Water Framework Directive
HD	Habitats Directive
OSPAR	Oslo-Paris-Commission (Convention for the Protection of the Marine Environment of the North East Atlantic)
TMAP	Trilateral Monitoring and Assessment Program
BD	Birds Directive
MSFD	Marine Strategy Framework Directive
HELCOM	Helsinki-Commission (Convention for the Protection of the Marine Environment in the Baltic Sea Area)
EMS	European Marine Strategy
ASCOBANS	Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas

A specific description of the monitoring of the species of Annex II of the Habitats Directive is listed in the following table. Additional investigations (orange) or planned investigations (green) are indicated.

Table 7.3. Monitoring of species according to Annex II of the Habitat Directive at the Weser estuary (Integrierter Bewirtschaftungsplan Weser 2012, altered).

Species	Monitoring Target	Content / Scope	Existing Measuring Program / Monitoring
Pond bat	Status quo survey and stock monitoring	Monitoring of usage of shore areas, especially of inland waters flowing into the Weser estuary and standing waters in the oligohaline zone	Open
Twaite shad	Stock monitoring	Until 2011: fishing every 2 years, then every 3 years	WFD
	Monitoring of abundance and age structure	Twice every 2 years: fishing with differentiation of age structure (juveniles, sub adults, adults) at 4 stations (stow net)	WFD
	Distribution of early development stages	Twice every 2 years: fish egg and larvae abundances at 4 stations (plankton net)	WFD (planned)
	Spawning ground	Monitoring of presence of adults at the breeding ground near Farge until 2010	Bremenports GmbH & Co. KG
	Spawning ground	To be continued: Monitoring of presence of adults at the breeding ground near Farge until 2010	WSA Bremerhaven
	Spawning ground	Monitoring of development of spawning population near Farge: According to approval decision on Lower Weser deepening monitoring over 10 years is required.	WSD Nordwest (responsible organisation)
	Water body structure/ Habitat mapping	Every 6 years at surveillance monitoring sites and operational monitoring sites	WFD

Species	Monitoring Target	Content / Scope	Existing Measuring Program / Monitoring
River and sea lampreys	Stock monitoring	Monitoring of upstream migration of adult lampreys at fish bypasses at Middle Weser and Lower Aller by means of fyke-nets (presumably 2 times within HD reporting period)	LAVES
	Stock monitoring / spawning habitats	Decentralised recording of anadromous lampreys in potential spawning waters upstream the Weser estuary (presumably 2 times within HD reporting period)	LAVES
	Functional and success monitoring	Functional monitoring of fish bypasses and success monitoring of renaturation measures (e.g. spawning grounds and larval habitats)	LAVES
	Water body structure / Habitat mapping	Every 6 years at surveillance monitoring sites and operational monitoring sites (according to LAVES (Meyer 2010)	WFD
	Water body structure / Habitat mapping	Expansion of existing (WFD-) monitoring: systematic mapping of river morphology	Open
	Transverse structures	Every 6 years at surveillance monitoring sites and at operational monitoring sites; according to LAVES (Meyer 2010) not very informative for bigger buildings/plants resp. for complex sites	WFD
	Transverse structures	Expansion of existing (WFD-) monitoring: Check existing transverse structures regarding passability	Open
	Stock monitoring	Monitoring of upstream migration of adult lampreys at fish bypasses at the weir Hemelingen (Weser) analogous to investigations at Middle Weser and Lower Aller (see above) by means of fyke nets	Open
Atlantic salmon (*Salmo salar)*	Stock monitoring	According to LAVES (Meyer 2010) stow net fishery in the frame of WFD monitoring are incidental and not relevant in view of stock development	WFD
	Stock monitoring	Decentralised recordings of returning spawning fish in inland waters upstream the Weser estuary where the species has been released	Decentralised recordings
	Stock monitoring	Recording at bottlenecks or potential spawning grounds	LAVES (planned)

Proposal for additional investigations regarding Habitats Directive
Planning (e.g. by the ´Niedersächsisches Landesamt für Verbraucherschutz und Lebensmittelsicherheit´(LAVES) resp. WSA Bremerhaven)

7.1.5 Opportunities for standardisation

In addition to the need to integrate policy and monitoring efforts, our inter-estuarine comparison revealed monitoring differences and hence the opportunities for monitoring standardisation. The study showed that while there are many monitoring schemes in all estuaries, these are often not coordinated across agencies, researchers or industries or for the places or ecological and physico-chemical attributes being monitored. Besides, suspended matter, a crucial parameter for interpreting sediment transport, turbidity, primary production, sedimentation, erosion and even water quality, is 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 monitoring programserves as an example to address the three main functions of estuaries namely accessibility (navigation), safety (against flooding) and naturalness (ecology).

7.1.6 Example of good practice: MONEOS monitoring program for the Scheldt estuary.

Before 2009, already a lot of monitoring efforts were done in the Scheldt estuary. This monitoring however, was not well coordinated: it consisted of several individual monitorings plans for different purposes, executed by different institutes. As a consequence, different methodologies, different timing, locations or frequencies were used resulting in a large but inconsistent database, often containing overlap, but also many gaps. Therefore an integrated monitoring framework has been set up, harmonizing all monitoring efforts in the Scheldt estuary. The new monitoring framework, MONEOS (Meire and Maris 2008, see report at www.tide-toolbox.eu), was approved by the Dutch and Flemish authorities in 2009, and gradually all existing monitoring programs were adapted to meet the MONEOS requirements.

Philosophy of the MONEOS program

Many policy frames are the driver for monitoring. However these policy frames are insufficient to establish a good monitoring program. Legal provisions for measuring a parameter thus cannot be the only criterion for including such a parameter in the present program.

After all, objectives follow from policy frames. And the monitoring requirements (Figure 7.3) are related to these objectives. However, in most cases, the objectives and/or monitoring requirements have not been elaborated in sufficient detail. For example, concentrations are determined in environmental regulations for various substances, but the nutrient ratios have not been included in these regulations. And yet it is precisely these ratios which determine the development of plankton, in combination with these concentrations. Species that should be monitored in the frame of nature conservation regulations are usually a selection of rare species. But the ecological function of the species is rarely taken into account in monitoring requirements. There are a number of species that play a very important role (e.g., system engineers), but these are not necessarily protected and thus there is no monitoring requirement; and yet these are precisely the species that may have a determining effect on the system's development.

Figure 7.3. Deducing monitoring requirements.

On the other hand several parameters are already being monitored, without any real policy frame. There are no legal grounds for conducting an area-wide bathymetry. Measuring discharge, sediment transport or water levels is clearly essential in the frame of the sound management of a waterway in terms of safety, naturalness and accessibility. However, there are no legal provisions as regards the number or frequency of these measurements. The policy frames are an insufficient framework for the monitoring program that needs to be conducted, especially if the aim is to use the obtained results to harmonise the current and future management of the waterway, i.e., to plan measures and implement them with a view to conserving the most important system characteristics, many of which have been enshrined in the policy frameworks.

The MONEOS monitoring framework is based on a system monitoring approach: the monitoring of those parameters that are required to characterise the entire system. In addition to the system monitoring there also is specific project monitoring. This involves a more detailed follow-up of certain interventions; it can be considered as effect monitoring, as described above. This specific project monitoring is embedded in this system monitoring (Figure 7.4). In other words: the system monitoring provides the general framework, describes the general status of the entire estuary at all relevant levels. Where necessary, monitoring efforts may be increased, in the frame of (additional) project monitoring but this monitoring is limited in time and space. After all, it is essential that a monitoring program is as cost-efficient as possible. On the other hand such a monitoring program must also allow us to effectively demonstrate trends within a reasonable period within which they occur; likewise it should allow us to establish causal relationships. The latter is essential as a basis for measures that may have to be taken.

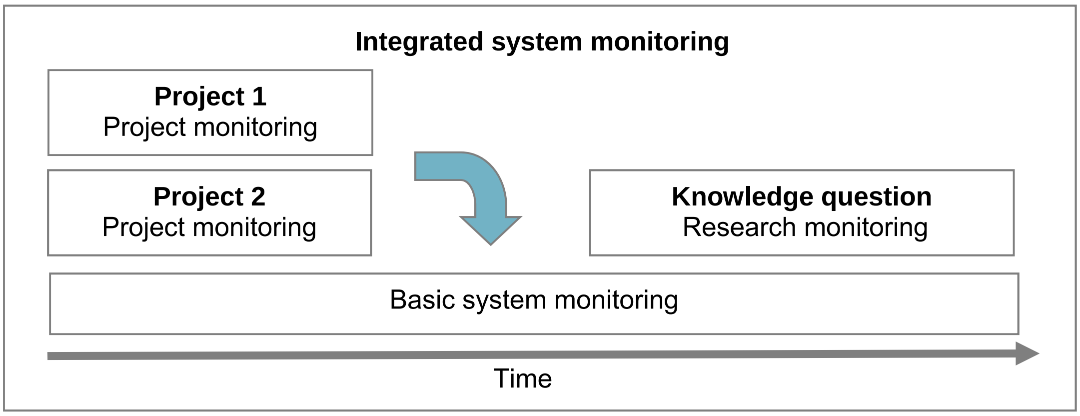

Figure 7.4. Relationship between project and system monitoring.

MONEOS does not wish to detract from the logical distinction between effect monitoring and system monitoring. However, in this proposal, the effect monitoring, which is included in the project monitoring, is subordinate to the system monitoring. System monitoring in this proposal not only is designed to monitor global trends; it also has to be able to uncover estuarine processes in order to be able to directly link effects to interventions. However, for the latter, the monitoring activity may have to be extended in order to capture the locally desired effects with a higher resolution. It is therefore recommended to formulate a very clear paradigm for the various elements (effect or project monitoring, system monitoring, etc.) with hypotheses about the potential developments (including effects). Depending on the evaluation that needs to be made, the relevant information can then be derived from the system monitoring, completed with information from project monitoring. The advantage of system monitoring is that it provides the best guarantee for maximum integration and optimisation of the used resources. One of the program's main principles after all should be its integrated character. At present, all too often related parameters are measured at different temporal and spatial scales, meaning that it is not always possible to associate these parameters with one another. We therefore strongly argue in favour of an integrated monitoring of the entire estuary, which may result in optimal synergies.

The system monitoring (with or without local detail through project monitoring) should then address some of the following aspects:

- Estuary-wide effects of the fairway deepening and of activities and maintenance work related to this deepening on the morphology, nature, ecology and water quality of the Scheldt Estuary.
- Effects of construction work of FCA (Flood Control Area), CRT (Controlled reduced Tide), managed realignment, wetland creation, dyke reinforcements on the estuary; also these naturalness measures have to be tested against the desired objectives.

- Signals on potential negative effects can be identified in a timely manner; effects that were predicted in the EIA can be verified.
- In case of negative effects, flanking measures can be developed based on the results
- In case conservation objectives are not achieved, additional/other measures can be developed using the conclusions of the system monitoring.

Next to this it is also very important that the monitoring provides the necessary information for the models. The use of models is after all essential for a proper interpretation of the results. On the other hand models are essential tools for planning new interventions. Both applications require good data, because the quality of the output of the models is directly proportional to the input. During the preparation of the EIA it became clear that there is absolute shortage of good data for the reliable use of some models. The system monitoring should provide such data.

Program strategy

The monitoring program mainly consists of a combination of two important approaches. First there is the area-wide information which should describe spatial (and depth) variations (Figure 7.5). The aim is to produce various map layers here, which facilitate the monitoring of the area's long-term morphological development. This includes the development of areas of specific habitats/ecotopes as well as volume changes and the spatial patterns of habitat/ecotopes.

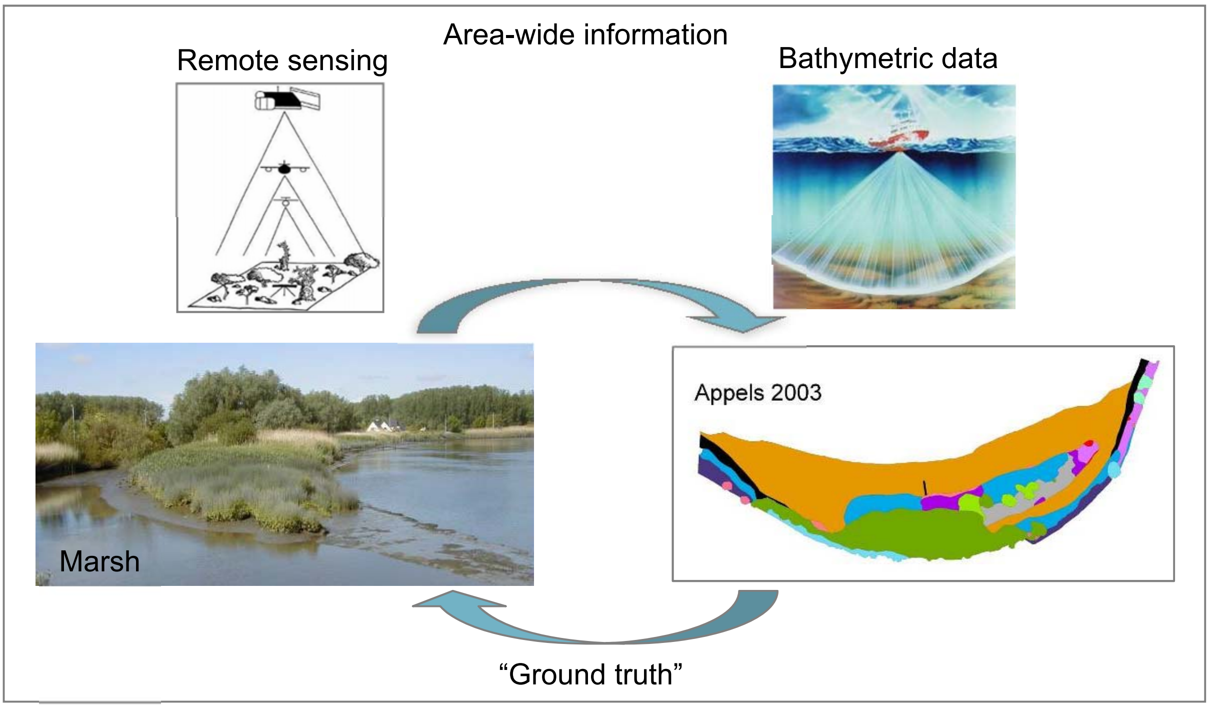

Figure 7.5. Area-wide information is gathered thanks to a combination of remote sensing, bathymetric data and ground truth measurements.

Various measurements, however, also require measurements of the "ground truth" in order to calibrate the information obtained from remote sensing or bathymetric data (e.g., recorded vegetation, soil samples etc.). This immediately establishes a link with the second part which consists of discrete measurements in given points and/or sections (Figure 7.6). Individual parameters are measured directly in the field and/or samples taken for lab analysis. These samples are often very labour-intensive. As a result, but even more because of the possibility to collate the data that were collected at one given time in the same location, the sampling for the various disciplines should be combined as much as possible. In the measure that it is possible these data should also be used as a "ground truth" for area-wide information.

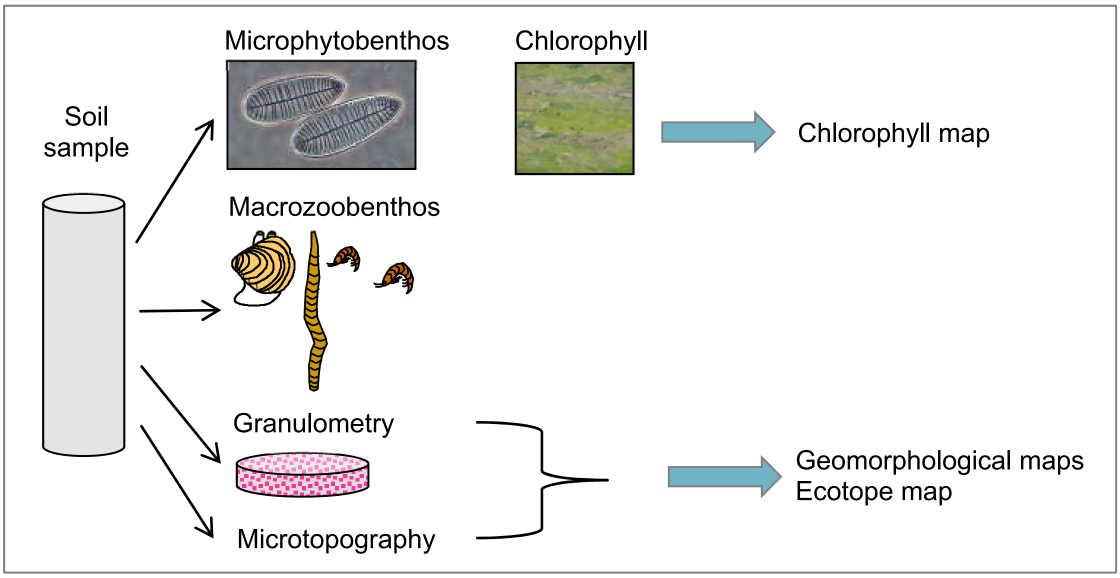

Figure 7.6. Overview of the integration of point measurements and link with area-wide information.

Both, the spatial resolution of the monitoring points and the sampling frequency in time have to be harmonised with the spatial scales and with the frequency of occurrence of certain phenomena in the estuary. In other words, the network of monitoring points should be close enough to be able to properly map all the important spatial phenomena, and the frequency high enough so that no important phenomena (such as a peaking algae population) are overlooked. Naturally the frequency does not have to be as high in all locations. The result is a monitoring program with a large spatial spread of points that are monitored on a regular basis, ranging from biweekly to every six years. A limited number of locations across the different zones in the estuary will be sampled more intensely, in order to identify any important short-term fluctuations. This should be done through continuous measurements. This monitoring network provides the data needed for scaling the parameters in space and time by linking the information to area maps (Figure 7.5) or to generate area-wide information (Figure 7.7).

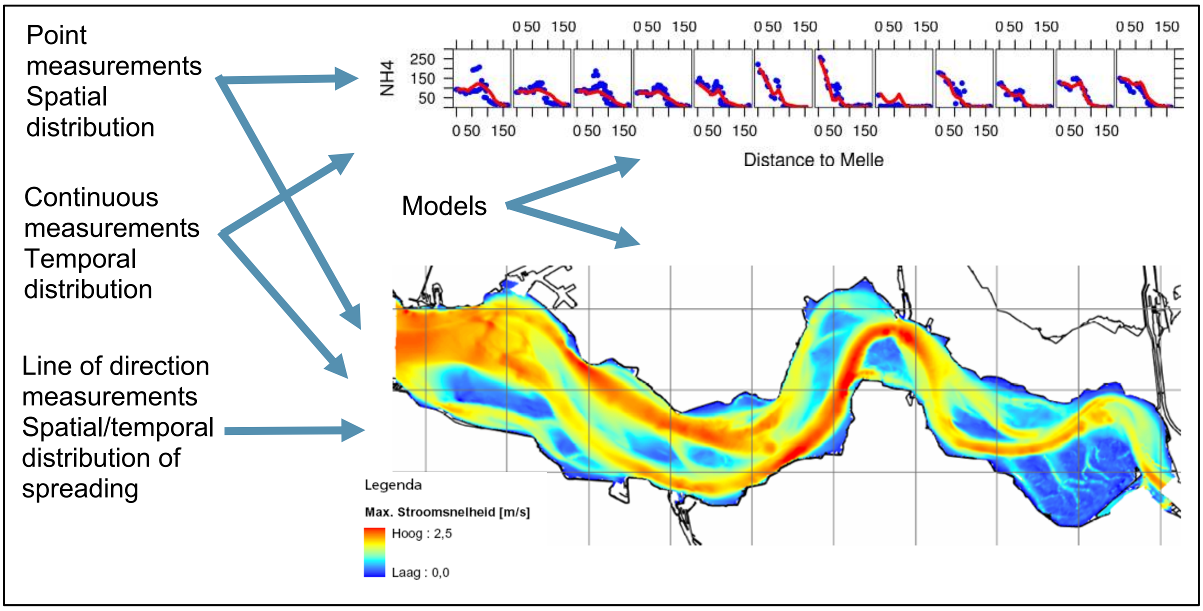

Figure 7.7. Overview of spatial and temporal scaling based on discrete measurements.

The estuary's boundary conditions are crucial to properly understand the entire system and to be able to properly model it. Until now these have not been given sufficient attention. The model output's resolution and quality can however not be better than the resolution and quality of the boundary measurements. That is why these points have to be sampled with the necessary attention.

The monitoring program is divided into several parts: hydrodynamics, morphodynamics, habitat diversity, physical chemistry, ecological functioning and safety. This division is mainly pragmatic, since the various components are strongly linked and therefore cannot be considered separately (Figure 7.8).

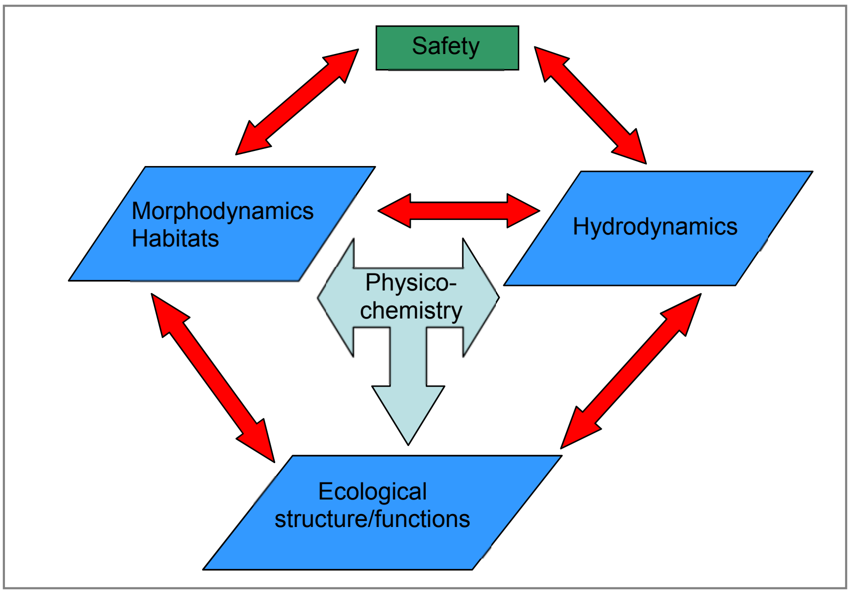

Figure 7.8. Overview of the interdependence of the monitoring program's various components.

7.1.7 The Pyramid Approach for evaluation

Adequate monitoring provides necessary information for communication and decision making. However, all these data do not provide a ready-made answer. A clear evaluation methodology for these monitoring data can improve both communication and 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 (Figure 7.9).

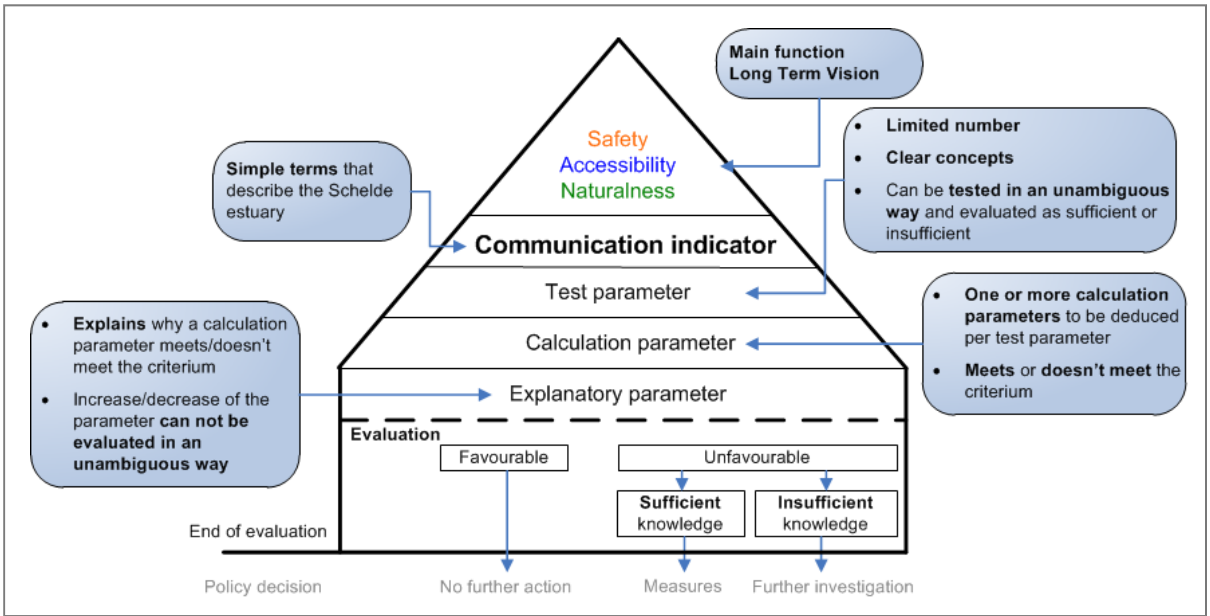

Figure 7.9. The Pyramid Approach for evaluation.

The top of the pyramid has 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.

7.1.8 Conclusion

The evaluation of single ecosystem services, the success of management measures as well as that of any management strategy depends on whether its outcome is monitored appropriately, i.e. the right parameters with spatial and temporal frequencies that are adapted to the frequencies of the phenomena to be monitored. An adequate monitoring is needed which allows us to have sufficient data which should be integrated so that they not only allow the evaluation of a management strategy or operational objective, but a true understanding of the functioning and development of the whole system.

We showed that while there are many monitoring schemes in all estuaries, these are often not coordinated. Further, if certain parameters are monitored differently in different estuaries, a comparison and exchange of knowledge becomes more difficult. Therefore, we propose a standard monitoring approach that can be used to cover all purposes with detailed, fully described methods.

The MONEOS program is such an approach: in the Scheldt estuary MONEOS provides a framework for all monitoring institutes to elaborate one common, comprehensive dataset. It is giving different monitoring levels 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 optimise the monitoring. It is based on a system monitoring approach: the monitoring of those parameters that are minimally required to characterise the overall functioning of the system. However, it is often necessary to answer specific question related to individual measures. Therefore, in addition to the system monitoring there also is specific project monitoring which involves a more detailed follow-up of certain interventions and is embedded in the system monitoring. The system monitoring gives insight in long term trends at the project site, project monitoring zooms in and gives more details. To achieve this, monitoring efforts can be increased (higher spatial or temporal frequency or additional parameters) in the frame of project monitoring but, to be cost effective, this monitoring is limited in time and space. Finally all monitoring efforts should be integrated and all results maintained in a common and widely-available database in order to avoid unnecessary costs and double works.

Additionally an adequate monitoring will provide necessary information for communication and decision making, but these data do not provide ready-made answers for management. A clear evaluation methodology for the monitoring data can improve both communication and decision-making (see Holzhauer et al. 2011 at www.tide-toolbox.eu). An evaluation methodology, using a limited set of indicators, was developed for the Scheldt.

Finally we can conclude that future monitoring in estuaries should be more integrated and collaborative, not only within but also between different estuaries, to ensure that all parties involved in estuary management have access to the best data and evaluation tools. When these are based on ecosystem services, this can improve understanding and management of estuaries.

7.2 Environmental assessment of development projects in estuaries

There are many uncertainties when investigating the environmental impact of a project in estuaries and hence there is the need to give advice on good practice to deal with these uncertainties when assessing the impact of a project. These recommendations are the result of a review of the national implementation methods and characteristics with regard to the Environmental impact Assessment[6] (EIA), the Strategic Environmental Assessment[7] (SEA), the Birds and the Habitats & Species Directives in different EU Member States. Also a case law analysis is performed in order to verify the conclusions of the above-mentioned analysis. In addition, the environmental assessment of 5 large port infrastructure projects has been analysed from Belgium, Germany, the Netherlands and the United Kingdom.

7.2.1 Uncertainties within environmental assessment

Coastal and estuarine areas attract a great variety of human activities, such as navigation, dredging, aggregate and sand extraction, fisheries, aquaculture, industry (including oil and gas extraction, wind farms), drainage of sewage and waste water, water extraction, flood protection, recreation (including bird watching and hunting), urbanisation, location for cables, pipes and tunnels, and military and research. All of these activities (while important for economic and social reasons), individually or in-combination, can potentially cause significant effects on the environmental and nature conservation objectives of estuaries and coastal zones as protected by the EU Directives.

[6] An environmental impact assessment (EIA) is an assessment of the possible impacts that a proposed project may have on the environment, consisting of the environmental, social and economic aspects. The purpose of the assessment is to ensure that decision makers consider the environmental impacts when deciding whether or not to proceed with a project.

[7] Strategic environmental assessment (SEA) is a systematic decision support process, aiming to ensure that environmental and possibly other sustainability aspects are considered effectively in policy, plan and programme making.

Not only within the EU but on a global scale, environmental assessment is an important tool for integrating environmental considerations into the authorisation of projects, and into the preparation and adoption of certain plans and programmes, which are likely to have significant environmental effects in the Member States. Environmental assessment ensures that such effects are taken into account during the preparation of projects and plans before their authorisation or adoption. The EIA and SEA Directives lay down an environmental assessment framework, which sets out broad principles for an environmental assessment regime. Where a SEA is by definition strategic and performed on a rather general level – not always related to a specific project, an EIA is focussed on one specific project and goes into much more detail. Member States are obliged to implement such an environmental assessment regime in their own jurisdictions. This is a minimum harmonisation measure, taking into account the principle of subsidiarity[8]. Consequently, the Member States (MS) enjoy discretionary powers to determine the environmental assessment mechanism and its details. While a MS must implement the directives at the level required, they can opt for implementing a much stricter system. Figure 7.10 shows the main obligations pursuant to the EIA and SEA Directives with which the environmental assessment mechanisms implemented by the Member States should comply.

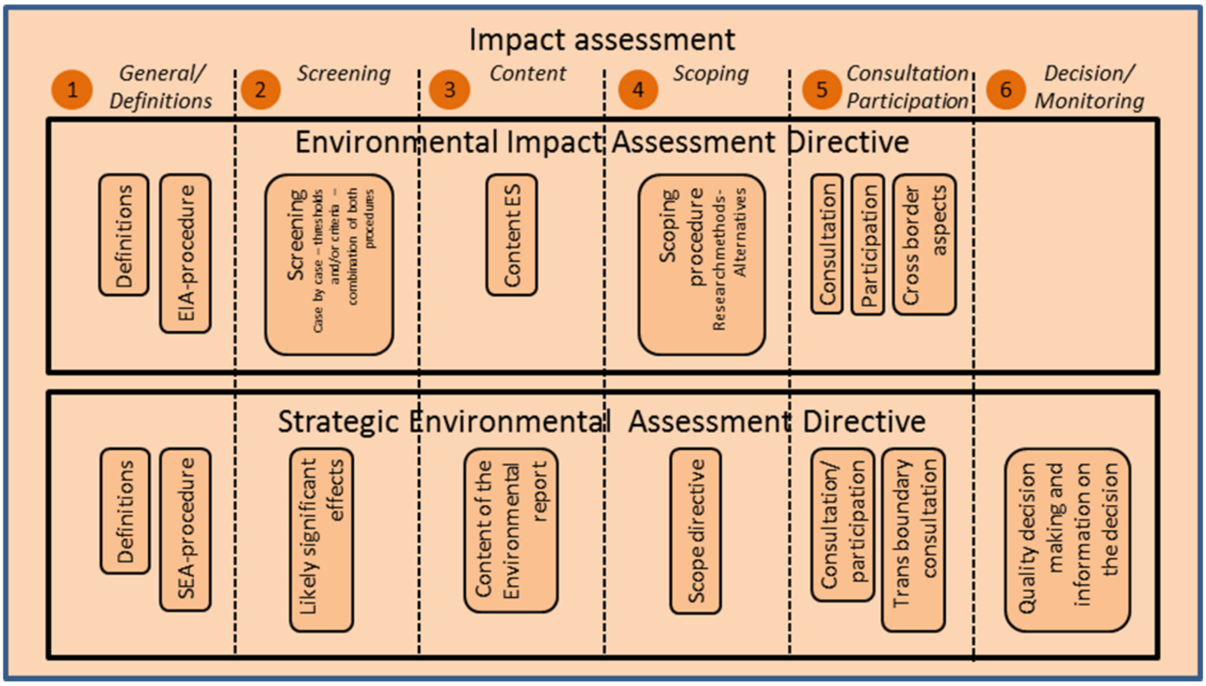

Figure 7.10. Overview requirements of Environmental Impact Assessment.

[8] The general aim of the principle of subsidiarity is to guarantee a degree of independence for a lower authority in relation to a higher body or for a local authority in respect of a central authority. It therefore involves the sharing of powers between several levels of authority, a principle which forms the institutional basis for federal States.

7.2.1.1 EIA: Screening

Annex I of the EIA Directive lists the projects for which EIA is mandatory[9]. For projects listed in Annex II of the Directive, the Member States have to determine if an EIA should be undertaken, based on the characteristics of the project; through a case-by-case examination and/or by setting thresholds or criteria[10]. In both ways the criteria of Annex III have to be taken into account, which are divided into three categories:

1. The characteristics of the project
2. The location of the project
3. The characteristics of the potential impact

This is known as the screening procedure. As a result of screening some projects might be deemed not to require EIA.

For estuaries, it must be noted that in Annex III the sensitivity of geographical areas likely to be affected by projects must be considered. This needs to have regard, in particular, to the absorption capacity of the surrounding environment, such as inter alia wetlands, coastal zones, areas classified or protected by the Birds and Habitats Directives, and areas that do not already meet the environmental quality standards laid down in Community legislation.

7.2.1.2 EIA: Content of the environmental statement

The Environmental Statement has to identify, describe and assess, in a consistent and objective manner, in the light of each individual case and in accordance with the other requirements of the EIA-Directive, the direct and indirect effects of a project on the following factors[11]:

- Human beings, fauna and flora
- Soil, water, air, climate and the landscape
- Material assets and the cultural heritage
- The interaction between the factors mentioned above

The EIA Directive does not explicitly determine the minimal content of the Environmental Statement. However, the required minimal content can be deduced from the provisions of the EIA Directive on the information that the developer is required to produce during the EIA process. The developer has to take care that he supplies the information specified in Annex IV of the Directive in an appropriate form. However, these requirements may differ in each country, because each Member State is allowed to consider which information is relevant to

[9] Article 4(1) EIA Directive

[10] Article 4(2) EIA Directive

[11] Article 3 EIA Directive

a given stage of the consent procedure, the specific characteristics of a particular project or type of project and of the environmental features likely to be affected. The Member States are also allowed to determine if a developer may reasonably be required to compile this information taking into account inter alia the current knowledge and generally accepted methods of assessment.

The developer needs to provide the following information in any case[12]:

- Description of the project comprising information on the site, design and size of the project
- Description of the measures envisaged in order to avoid, reduce and, if possible, remedy significant adverse effects
- The data required to identify and assess the main effects which the project is likely to have on the environment
- An outline of the main alternatives studied by the developer and an indication of the main reasons of his choice, taking into account the potential environmental effects
- Non-technical summary of the information described above

7.2.1.3 EIA: Scoping

Pursuant to Article 5(3) of the EIA Directive, the developer needs to provide an outline of the main alternatives that have been considered and an indication of the main reasons for the selection of the preferred option, taking into account the potential environmental effects. The EIA Directive does not contain specific provisions on how, when and by whom the scope of the actual EIA is to be determined. Each Member State is allowed to decide which alternatives are reasonably to be considered given the specific circumstances.

A developer can solicit a sort of optional scoping[13]. Member States must take the necessary measures to ensure that, if the developer so requests before submitting an application for development consent, the competent authority shall provide an opinion on the information to be supplied by the developer. The competent authority shall consult the developer and authorities likely to be concerned by the project because of their specific environmental responsibilities. The fact that an authority has given such an opinion does not preclude it from subsequently requiring the developer to submit further information.

7.2.1.4 EIA: Consultation and participation

Consultation

[12] Article 5(3) EIA Directive

[13] Article 5(2) EIA Directive

The EIA Directive compels Member States to ensure that the authorities likely to be concerned[14] by the project because of their specific environmental responsibilities are given an opportunity to express their opinion on the information supplied by the developer as well as on the application for development consent itself. The attribution of such competence to specific authorities may be stated in general terms or case-by-case. All information gathered pursuant to Article 5 shall be forwarded to these authorities and Member States should lay down detailed arrangements for consultation on the EIA.

Participation

Regarding participation, the EIA Directive distinguishes between “public” and the “public concerned” (see Section 7.2.4). The term public[15] means one or more natural or legal persons[16]. The public concerned[17] is defined as the public (likely to be) affected by, or having an interest in, the environmental decision making procedures. For the purpose of this definition, NGO’s promoting environmental protection and meeting any requirements under national law shall be deemed to have an interest[18]. The main difference is that the public must be informed and the public concerned[19] must be given early and effective opportunities to participate in the EIA as a part of the environmental decision making procedures and for that purpose be entitled to express comments and opinions while all options are still open before the consent is given by the competent authority[20].

Cross border aspects

The EIA Directive specifically focuses on cross border aspects. In these cases the public concerned must be supplied with the same information as the public of the country in which the project is realised.

If a project is likely to have significant effects on the environment in another Member State, or where a Member State likely to be significantly affected so requests, the Member State in whose territory the project is intended to be carried out has to send to the affected Member State as soon as possible, and no later than informing its own public, at least a description of the project, together with any available information on its possible trans boundary impact

[14] Article 6(1) EIA Directive

[15] Article 6(2) EIA Directive

[16] Depending on the national legislation or practice of the concerned Member State, this could also include associations, organisations or groups.

[17] Article 6(3) EIA Directive

[18] Article 1(2) EIA Directive

[19] Article 6(2) EIA directive

[20] Article 6(4) EIA Directive

and the information on the nature of the decision which may be taken. The other (possible affected) Member State also has to be given a reasonable time during which the public is able to indicate that it wants to participate in the EIA and the environmental decision making procedures.

If the affected Member State wants to participate, then the Member State in whose territory the project is intended to be carried out has to send all the available information on the EIA and environmental decision-making procedures. The affected Member State will then supply the information to their own public concerned and both Member States will permit the public concerned to participate effectively in the environmental decision-making procedures.

7.2.1.5 EIA: Decision making and monitoring

The EIA Directive demands[21] that projects likely to have significant effects on the environments are subject to development consent and that before consent is given an assessment with regard to their potential effects has been undertaken. The EIA Directive does not explicitly ask for a monitoring campaign after the granting of the development consent and during the execution and operation of the project.

The different requirements of an SEA (Figure 7.10) are slightly different and are explained in more detail below.

7.2.1.6 SEA: Screening

All plans and programmes that are prepared for a list of sectors[22] and which set a framework for future development consent for projects listed in Annexes I and II to the EIA Directive (Section 7.3.2); and all plans and programmes which require AA pursuant to the Habitats Directive (Section 7.4.3), are likely to have significant effects on the environment. As a rule these plans and programmes should be made subject to SEA.

When those plans or programmes determine the use of small areas at local level or are minor modifications to such existing plans or programmes, they should be assessed only when, and if, Member States determine they are likely to have significant effects on the environment[23].

Other plans and programmes that set the framework for future development consent of projects should be assessed only when, and if, Member States determine that they are likely to have such effects.

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[21] Article 2 EIA Directive

[22] Article 3 (2) SEA Directive: agriculture, forestry, fisheries, energy, industry, transport, waste management, telecommunications, tourism, town and country planning or land use.

[23] Article 3 (3) SEA Directive

The process of determining whether a plan or programme is likely to have significant effects is called the screening procedure.

7.2.1.7 SEA: Content of the environmental report

The Environmental Report (ER) should identify, describe and evaluate the likely significant effects on the environment of implementing the plan or programme, while taking into account any reasonable alternatives. The minimal requested information to be incorporated in the ER is indicated in Annex I of the SEA Directive, as follows:

- A outline of the contents, main objectives of the plan or programme and relationship with other relevant plans and programmes
- The relevant aspects of the current state of the environment and the likely evolution thereof without implementation of the plan or programme
- The environmental characteristics of areas likely to be significantly affected
- Any existing environmental problems which are relevant to the plan or programme including, in particular, those relating to any areas of a particular environmental importance, such as areas designated pursuant to Birds and Habitats Directives
- The environmental protection objectives, established at international, Community or Member State level, which are relevant to the plan or programme and the way those objectives and any environmental considerations have been taken into account during its preparation
- The likely significant effects on the environment, including on issues such as biodiversity, population, human health, fauna, flora, soil, water, air, climatic factors, material assets, cultural heritage including architectural and archaeological heritage, landscape and the interrelationship between the above factors
- The measures envisaged to prevent, reduce and as fully as possible offset any significant adverse effects on the environment of implementing the plan or programme
- An outline of the reasons for selecting the alternatives dealt with, and a description of how the assessment was undertaken including any difficulties (such as technical deficiencies or lack of know-how) encountered in compiling the required information
- A description of the measures envisaged concerning monitoring
- Non-technical summary of the information provided under the above headings

The ER shall include the information that may reasonably be required, taking into account current knowledge and methods of assessment, and the relevant facts of the plan or programme (level of detail, stage and earlier assessments). The authorities should be consulted about the scope and level of detail of the information in the ER.

7.2.1.8 SEA: Scoping

Pursuant to Article 5(1) of the SEA Directive, the ER needs to identify, describe and evaluate likely significant effects on the environment of implementing a plan or programme, and reasonable alternatives, taking into account the objectives and the geographical scope of the plan or programme.

The SEA Directive does not determine explicitly what these reasonable alternatives should be. The requested information in Annex I sub (h) requires only an outline of the reasons for selecting the chosen alternatives and a description of how the assessment was undertaken, including any difficulties (such as technical deficiencies or lack of know-how) encountered in compiling the required information.

On the other hand, according to Article 5(4) of the SEA Directive, each Member State should designate the authorities to be consulted when deciding on the scope and level of detail of the information to be presented in the ER. This includes information on the reasonable alternatives. Based on this provision, each Member State has developed a policy regarding the identification reasonable alternatives. The SEA Directive does not contain a clear cut scoping procedure.

7.2.1.9 SEA: Consultation and participation

Consultation

The draft plan or programme and ER, should be made available to the concerned authorities[24]. This also applies to the public, which has to be given an early and effective opportunity, within appropriate timeframes, to express their opinion on the draft plan or programme and ER. Pursuant to Articles 6(3) and (4), Member States should designate the authorities to be consulted and identify ‘the public concerned’, and determine detailed arrangements for the information and consultation of the authorities and the public.

Cross border aspects

If a Member State considers that the implementation of a plan or programme is likely to have significant effects on the environment in another Member State, the Member State in whose territory the plan or programme is being prepared shall, before its adoption or submission to legislative procedure, forward a copy of the draft plan or programme and ER to the other Member State. The other Member State shall indicate whether it wishes to enter into consultation regarding the likely trans-boundary potential environmental effects and the measures envisaged to reduce or eliminate such effects. In such cases, the Member States

[24] Article 6(3) SEA Directive

shall agree on detailed arrangements to ensure that authorities and public concerned are informed and given an opportunity to forward their opinion within a reasonable timeframe.

7.2.1.10 SEA: Decision making and monitoring

During the preparation of the plan or programme the ER in the sense of Article 5, the opinions expressed pursuant to Article 6 and the results of any trans-boundary consultations entered into pursuant to Article 7 shall be taken into account prior to the adoption of the plan or programme or submission to the legislative procedure.

After the decision making process, the Member States are obliged to monitor the significant environmental effects of the implementation of plans and programmes pursuant to Article 10 in order, inter alia, to identify at an early stage unforeseen adverse effects, and be able to undertake appropriate remedial action.

An EIA is a process which results in a document the Environmental statement. An EIA is a precise process – in essence 'what is the impact of this activity, performed at this place and this time, using these methods and degree of mitigation or compensation and communicated in this way'. It is not an assessment of every aspect of an area in an uncritical manner. The development of activities in estuaries and coastal zones in compliance with the aforementioned EU Directives inevitably entails a certain amount of uncertainty. Six categories of uncertainties have been identified, regarding:

A.

1) Baseline conditions: Which conditions should be used as the reference state: the current physical conditions or the legal/permitted status or another standard?
   Does an accurate understanding of the baseline conditions exist? In environmental assessments, baseline environmental conditions should be established for the current situation and projected into the future to represent the "do minimum" scenario. Baseline information gathering is usually a combination of a desk study (to collate available information from existing sources) and sampling or survey to collect new data. Measurements might have limited precision and accuracy due to limitations of the measuring equipment. Human error can also contribute to this kind of uncertainty.
2) Autonomous development and cumulative effects: What are the processes for managing uncertainty associated with the autonomous development of the system and (the accumulation of) other plans/projects which are not (yet) final?
3) Proposed activity and its alternatives: What are the nature, characteristics and scope of the proposed activity and what alternatives need to be examined?

Uncertainty in environmental assessment can arise from a lack of specificity in proposals, such as the locations, size and design of developments and the particular activities that will take place there. A lack of specificity represents a lack of knowledge of the source of any potential impacts, which will translate into a lack of knowledge and consequent uncertainty in predicted effects. Imprecise wording and unclear terminology may also contribute to a lack of proposal specificity.

4) Effects of the proposed activity and its alternatives: Are the (described or calculated) effects significant or not?

Ecosystems may be complex by virtue of their size and quantity of relevant detail, and by the quantity, sensitivity and natural variation of interactions between system components. There may be a lack of knowledge or scientific agreement about cause-effect relationships, contributing to uncertainty in predictions of impacts related to such a system. Uncertainty arises from assessing impacts in systems that are sufficiently complex that existing knowledge does not adequately describe them, such as estuarine ecosystems. As a complicating factor, estuaries are inherently more variable than other systems (Elliott and Whitfield 2011) and hence anthropogenic variability may be more difficult to detect over and above that natural variability (Elliott and Quintino 2006).

Translation of the baseline data, knowledge of the proposed development and understanding of the relevant systems into predicted impacts is also difficult. Practical limitations exist in representing those aspects in a suitable medium (such as a simulation model, photomontages or maps) to enable projection, contributing to predicted uncertainty. The inability of models to represent complex systems, for whatever reason, can lead to uncertainty in EIA.

Uncertainty is also involved in assessing the significance of impacts. In some case standards and criteria exist that guide the determination of significance (e.g. environmental quality standards); however, for the majority of assessments, significance relies upon a degree of expert judgement and, therefore, may be considered subjective.

In any assessment there are 3 types of significance (Elliott 2011) – firstly, and most easy to determine as long as we have sufficient data, is statistical significance. Secondly, and perhaps more importantly, is ecological or environmental significance, and thirdly we have the social significance of any change that we detect. For example, detecting the loss of a species amongst hundreds would be impossible statistically without a large and powerful statistical sampling design but that lost species could be ecologically relevant. Despite this, we might not be able to statistically or ecologically detect a change because of noise (inherent variability) in the system (i.e. the signal to noise ratio) but if society thinks a change has occurred then it should have the highest significance (see Gray and Elliott 2009). If society thinks there is a problem then by definition there is one even if science cannot detect it (Elliott 2011). Additionally there are also problems in the need to translate uncertainty that may be inherent in dynamic systems which have considerable 'noise' into a legal consenting process that effectively requires 'yes' or 'no' answers, and where uncertainty would entail 'precaution' and 'precaution' might then entail rejection of a proposaed development plan, or at best a considerable additive cost in terms of over compensation/mitigation in order to ensure any 'uncertainty' is covered.

B. Lack of knowledge (modelling, gaps in knowhow): Uncertainty relating to: research tools and methods, calibration/validation of models, (the accumulation of) uncertainty margins in figures and formulae, especially when the outcome is input for other calculations, gaps in data on certain species and habitats and gaps in scientific knowledge on inter alia doses-effect relations, the effect of emergencies and the ecological effect of mitigation and/or compensation measures.

   Existing information may be absent, not up to date, not from appropriate locations or not collected over a suitable timescale, which leads to increased uncertainty when applied in EIA. Data collection may suffer additional uncertainties due to project budget and timescale limitations, causing new data to be subject to similar uncertainties as existing data.

C. Changing legislation and policy: Which legislation and regulations are applicable, how long is the transitional period and change in administrative settings and government policy?

   Impact uncertainty is increased by unknowable and uncontrollable factors that affect an impact pathway. Typically these factors relate to future decisions, or future impacts of past decisions, such as the effects of future technological innovation, but also changes in legislation and policy. Assessment of impacts over longer time-scales, such as in SEA, increases the uncertainty from unknowable factors.

Each of these categories plays a predominant role in a different phase in the life cycle of the activity. The following life cycle phases have been distinguished:

- Current situation: the phase prior to the project or plan without the proposed activity
- Project assessment: the phase in which the possible effects of the proposed activity are analysed by an environmental impact assessment or appropriate assessment
- Permits and derogation: the phase of the decision making process on the assessed activity and other required permits
- Monitoring and evaluation: the phase after the implementation of the activity

The distribution of the different types of uncertainties across each phase are graphically presented in Figure 7.11. This figure indicates that:

- Uncertainty issues regarding the baseline conditions (A1) arise mainly at the start of the project and the required assessments.
- In the phase prior to the decision making (on EIA/SEA and Appropriate Assessment (AA)) the uncertainty issues are mainly related to the autonomous development and cumulative effects (A2), the effect of the proposed activity and its alternatives (A3/A4) and/or lack of knowledge (B).
- Uncertainty issues in the decision making process mainly focus on the scope of the proposed activity (A3) and its effects (A4) and/or lack of knowledge (B).
- After realisation of the activity, uncertainty issues can arise due to the differences between the predictions in the EIA/SEA and/or AA and the monitoring observations (A4) or to a lack of knowledge (B) and the consequences thereof.
- Changing legislation (C) is a particular source of uncertainty. Due to the long term development of port related activities, the risk of a possible intermediate change of the regulatory framework or governmental policy is always present.

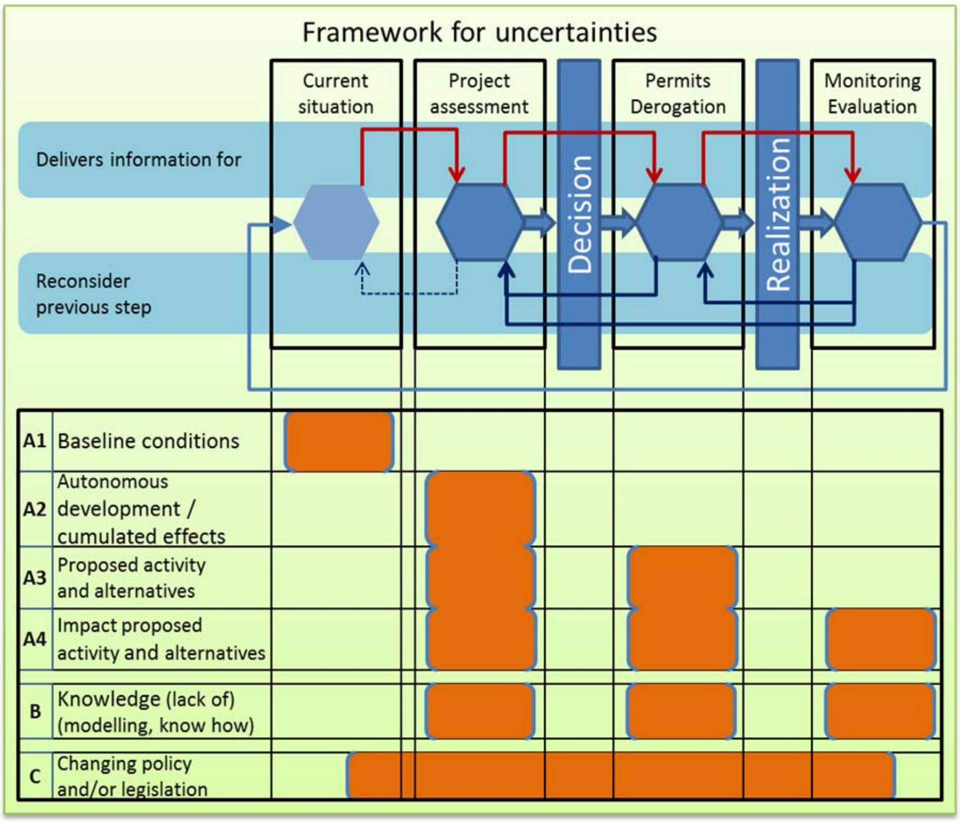

Figure 7.11. Uncertainties in the life cycle of projects.

7.2.2 Difference in national implementation of EU Directives

Where the Birds and Habitats Directives, the Water Framework Directive, the EIA and SEA Directives, all cornerstones of the EU environmental policy, lay out the broad lines on how to deal with plans and projects situated in an estuary, it is the responsibility of the different European Member States to implement these directives in their national law (i.e. enabling legislation). This national implementation can differ from Member State to Member State – both in the legislative framework and in the decision-making process – resulting in a different way to deal with the aforementioned uncertainties.

Each of the Member States included in this study has implemented the EU Directives into national (and sometimes also into federal or regional) law. Considering the discretionary margins of Member States when implementing the EU Directives, the environmental assessment and appropriate assessment regimes in Belgium (Flanders), Germany (Federal state of Bremen), the Netherlands and the UK (England and Wales) are quite similar. The existence of uncertainties in EIA/SEA and Appropriate Assessment, and permitting procedures is acknowledged in the legal provisions, guidance documents, permits and in case law. In each Member State competent authorities, consultees, NGOs and port authorities have developed different ways to overcome problems caused by these uncertainties.

In Belgium the regions are responsible for the approval of EIA, SEA and AA. In Flanders the EIA Unit, which is a governmental body part the Flemish department of Environment, Nature and Energy, is involved in every EIA and SEA and therefore has an large amount of expertise in environmental assessments, which is obviously an advantage in dealing with uncertainties. In addition, this permit granting authority has the right to demand special permit conditions (for instance emission thresholds, noise control methods and a phasing over time).

In Germany the environmental assessment and the appropriate assessment obligations have been integrated into existing project procedures. Therefore, in Germany the competent authority varies according to the law that is applicable to the project or plan concerned and the territory in which the project is located or the plan applied, rather than attributing a substantial role to a specialised central authority, like in Belgium. Instead the competent authorities have drafted an exhaustive set of guidance documents (Leitfaden) and a legal instrument on mitigation and compensation (the Eingriffsregelung).

With regard to uncertainties, it can be concluded that in the Netherlands, although legislation does not give a definition of significance, national guidelines provide information on how to manage uncertainties, for instance on the interpretation of baseline conditions and autonomous situation. Also the Netherlands Commission for Environmental Assessment plays an important role in providing (mandatory) advice to the competent authorities on content and quality of the SEA/EIA. Our analysis of the Dutch case law shows that an adaptive approach can be a useful instrument for avoiding significant adverse effects.

In the United Kingdom considerable guidance exists on the application of the EU Directives both from central government and from statutory bodies. This provides a standardised approach to the application of EIA/SEA and Appropriate Assessment in port projects (which are, in general, centrally regulated). Following permission being granted, licence conditions will be imposed on the developer by the statutory bodies and these conditions may include compensation, mitigation and monitoring commitments. Harbour Empowerment Orders and Harbour Revision Orders, granted by the Marine Management Organisation, can also impose conditions based on the environmental impacts of the estuary activities.

To summarize: in each Member State, mechanisms to manage uncertainties have been developed. These mechanisms are often crucial in giving the regulators and consultees comfort that a project can be consented in light of these uncertainties.

7.2.3 Analysis of case studies

In order to see the way in which uncertainties are now accommodated in environmental assessment studies, five recent case studies have been analysed. Hereby special focus is on the tools and methodologies applied in EIA and Appropriate Assessments and how uncertainty and risks are dealt with and managed in practice. It should be noted that the scope of the analysis is limited to the subjects of flora and fauna (marine and estuarine), soil (marine sediments) and water. In terms of fauna, the focus is on the potential effects on biological communities through direct impact of the project (e.g. land-claim), effects on water quality and effects on habitats (e.g. through changes to the hydrodynamic and sedimentary regime). Disturbance effects (e.g. construction noise) were excluded from this project as being outside the scope of the project .

The following five case studies have been studied:

- Enlargement of the navigation channel in the outer Ems estuary (access to Emshaven)
- Dredging of the approach channel to the Immingham Oil Terminal in the Humber estuary
- Enlargement of the navigation channel in the Scheldt estuary
- A series of major port development and capital dredging projects in the Stour and Orwell estuaries

- Construction of Container Terminal 4 in the Weser estuary (Bremerhaven)

This analysis resulted in the following findings concerning how it is coped with uncertainties in the different phases of the case studies.

7.2.3.1 Approach to the EIA and AA studies

Application of SEA

For the Scheldt case study, a SEA was undertaken on a development plan the so-called ´Scheldt Estuary Development Outline 2010´ (http://www.vnsc.eu/publicaties/vnsc-publicaties/100-ontwikkelingsschets-2010-schelde-estuarium.html) that stemmed from the long term vision for the Scheldt estuary (established in 2001). The vision comprised the following three pillars and was known as the 'package deal':

1. Conservation of the physical characteristics of the estuary (naturalness)
2. Maximum safety against flooding
3. Optimal accessibility for the ports

Through applying the above approach, uncertainty regarding the likely acceptability of the project can be reduced as the potential environmental impact can be understood earlier during the planning stages and there is an opportunity for designing mitigation measures into the overall project. The EIA that is subsequently required for the project itself is therefore based on the earlier consideration that has been given to the project through the SEA process. This approach also has other potential benefits, such as the EIA being able to better demonstrate that alternative approaches (e.g. project design, design of mitigation) have been considered through the SEA process.

Expert review of EIA

For the Scheldt and Ems case studies, a formal review body ('EIA commission') was established to assess the quality and the results of the EIA. For the Ems case study, the advice of the EIA commission was also important in informing the conditions for the permit that is issued by the regulatory authorities.

For both of the UK case studies there was no formal EIA commission established, and this approach is not a standard procedure in the UK generally. However, there is a Planning Inspectorate which can have a judicial hearing to hear both sides. Is this particular case an application the formal consultation that is undertaken by the regulator when the application (supported by the Environmental Statement) is submitted effectively constitutes a similar process. During this process, the organisations that are consulted by the regulator review the findings of the EIA and provide their opinion on the quality of the Environmental Statement, its findings, their view on the acceptability of the project and any recommendations for conditions that should be included in the licence (permit). If there are objections then the process goes to a Planning Inquiry and the Planning Inspector makes a final judgement.

For the Weser case study, the process was similar to that described for the UK case studies. There was no formal EIA commission established. Instead the consultation process had been implemented together with the Wasser- und Schifffahrtsdirektion Nordwest (decision-making authority) and the Senator für Bau und Umwelt (Environmental/Nature Conservation Agency). The consultation process and the processing of the remarks of consulted parties are similar to that described for the UK case studies.

7.2.3.2 Sources of uncertainty

Numerical modelling

In all case studies, numerical modelling was used as a tool to predict the potential impacts on estuarine habitats. It was recognised that all modelling has some degree of error which will always represent a source of uncertainty, and this was acknowledged in all case studies but not necessarily possible to quantify. This is a key aspect for all case studies because the implications of the projects on designated estuarine habitats are the main issue of concern to relevant consultees.

One common theme that emerges from the analysis of the case studies is that the Environmental/Nature Conservation Agency that is consulted during the EIA often require the predictions made by numerical modelling to be quantified precisely. This approach can be misleading in that whilst modelling can provide a quantitative prediction (e.g. predictions of annual rate of intertidal erosion), there is a tendency to place too much reliance on such numbers when defining what constitutes a significant effect within the estuarine system. For example, a prediction can be well within the margin of error of the model but, when quantified, it is often taken as an absolute effect which is then used to define mitigation and compensation measures. More reliance should be placed on the interpretation of modelling results by experts in the field when considering whether or not an effect is significant. It was considered that interpretation of the results of the modelling by an expert who understands the functioning of the estuary system is as important as the quantitative predictions made through numerical modelling when determining what represents a significant effect.

Consideration of significance

When considering the question of what constitutes a significant effect, there are no universally accepted limits or thresholds (e.g. a change greater than X% is significant). This would be a very difficult mechanism to develop because the definition of what constitutes a significant effect has to be made on a case by case basis given that particular environmental characteristics prevail in different estuaries. What constitutes a significant effect (´significant´ in terms of the Birds and Habitat Directive) in one estuary may not be significant in another. Even within an estuary system, an impact that may be considered significant at one point in time may not be significant at another time due to, for example, environmental changes or changes in regulatory or management policy.

For the UK case studies, thresholds were not defined in an attempt to conclude whether or not an effect was considered significant. The approach adopted was to quantify, as far as possible, the predicted effects on habitats within the estuary system and then to develop a strategy to mitigate potential impact. In this sense, any potential effect could therefore be considered a significant effect despite the fact that the effects were predicted to be small in the context of the estuary system (particularly for the Humber case study).

For the Ems case, the opinion of the NGOs (represented by the Wadden Vereniging (WV)) was that no activity should be allowed as their view was that the Ems-Dollard system is currently in a poor condition. The WV considered that there is a lack of understanding of the functioning of the ecosystem and that studies are needed to understand what needs to be done to resolve any existing problems in the system. The view was that these issues needed to be resolved before any new activity should be allowed.

Uncertainty related to success of mitigation

An area of uncertainty for the Stour and Orwell estuaries and Scheldt case studies was the likelihood of success of mitigation measures. Although mitigation measures were implemented for the project in the Ems and Weser, there were no specific uncertainties defined related to the success of such measures.

For the Stour and Orwell case study, one significant area of uncertainty was related to the success of mitigation measures (i.e. the programme of sediment replacement) proposed as part of the 1998-2000 Approach Channel Deepening. Maintenance dredgings are discharged from the dredger at certain defined disposal locations within the estuary system adjacent to intertidal areas. Disposals are made under specific tidal conditions that encourage material to disperse over the intertidal areas. This represents a novel approach and whilst this technique has since been proven successful, there were uncertainties regarding the likely success of this approach when it was first proposed as it was untested. Similarly, in the Scheldt case study, there was also uncertainty regarding the effects of the proposed disposal strategy for dredged material.

7.2.3.3 Approaches to deal with uncertainties

The case studies show that several mechanisms have been identified to deal with uncertainties. These mechanisms address both uncertainties that are associated with the prediction of potential impacts and also uncertainties associated with the success of mitigation and compensation measures that are proposed to address predicted negative effects. These mechanisms are described with the various case studies and are summarised below.

All of the approaches to deal with uncertainties described below were effective in the context of the projects for which they were proposed. In other words, the approaches described are fit for purpose for the particular project and it is not possible to conclude whether one approach is better than another. The principles described below could, however, be adopted and used for projects in other areas, but it is likely that the approach would need to be adapted to the particular circumstances of the project in question.

Incorporating a project into a wider package of measures

This approach was adopted in the Scheldt project. The proposed dredging-disposal strategy to improve the accessibility of the Scheldt navigation channel was part of a wider package agreed on by the Flemish and Dutch government including safety and naturalness of the estuary. The fact that the enlargement of the navigation channel was thus counterbalanced by the improvement of the ecological quality of the estuary, ensured that (initially) there was broad support for the project. Subsequently the naturalness part of the package was excluded due to disagreement of the Dutch politicians and, therefore, the applicant of the project (the Flemish Maritime Access Division together with the Dutch Rijkswaterstaat, which is part of the Ministry of Transport) had to try to ensure that the project was independent of the naturalness part by ensuring no negative effects. A new disposal strategy was adopted creating a positive effect on habitat development (though creation of low-dynamic intertidal and shallow water area) to mitigate the minor negative effects of the project. This strategy also dealt with the uncertainty/error in modelling predictions.

Implementing precautionary compensation

For the 1998-2000 Approach Channel Deepening project in the Stour and Orwell estuary, precautionary compensatory habitat was required in order to deal with the uncertainty associated with sediment replacement into the estuary system that was proposed as mitigation for the predicted increase in rate of intertidal erosion. The area of compensatory habitat allowed for an assumed 5 years of failure of mitigation.

Compensatory habitat

In cases where an adverse effect on the integrity of a Natura 2000 site is predicted to occur, it is necessary to implement compensatory measures. As with most compensatory habitat schemes, there is an element of uncertainty with regard to the quality of habitat that will be created and, therefore, whether or not the scheme would deliver sufficient compensatory measures. Given this uncertainty, in determining the compensatory habitat requirement for the Bathside Bay container terminal project in the Stour and Orwell estuaries, a risk-based approach was adopted and a compensatory habitat ratio of approximately 2:1 (compensatory habitat area: habitat area claimed for harbour project) was required in light of the predicted impact. This contrasts with the Weser case study where the compensation measures (habitat creation) were progressed on a 1:1 basis.

Legal agreements

One of the key mechanisms for dealing with uncertainty in the Stour and Orwell case studies was the use of legal agreements between the applicant and other organisations, such as Natural England and the Royal Society for the Protection of Birds (e.g. Compensation, Mitigation and Monitoring Agreements). Such agreements were seen as crucial as they develop mitigation and monitoring commitments that are enforceable, together with a Regulators Group which has the authority to make decisions regarding the refinement of the mitigation and monitoring programme.

Through the mitigation and monitoring commitments, nature conservation bodies were able to ensure that ‘safeguards’ were built into the mitigation and compensation proposals and this was especially important in providing certainty that the commitments were deliverable. For example, mitigation could be adjusted (scaled up or down) if necessary depending on the results of the monitoring.

Part of the three stage rocket approach, that was developed for the Scheldt case study (see Section 7.2.4 for details) included commitments built into the permit to enforce the undertaking of necessary measures to counteract any negative effects of the project and, potentially, to stop the project. In this sense, the Scheldt case study also made use of a legal agreement to deal with uncertainty.

Dredging and disposal strategy

The Dredging and Disposal Strategy developed for the Immingham Oil Terminal Approach Channel Deepening project in the Humber was a key component of mitigation outlined in the EIA. The measures set out in the strategy would mitigate the potential effect of the increased maintenance dredging commitment on designated habitats by aiming to distribute material throughout the estuary to supplement sediment supply.

This strategy is referred to separately to the legal agreements (above) because in itself it was not a signed legal document. However, the licence that was granted for the project included a condition that the dredging and disposal operation must be carried out in accordance with the agreed Dredging and Disposal Strategy and, therefore, the strategy was enforceable via the licence.

The flexible disposal strategy developed for the Scheldt case study is a similar mechanism to deal with uncertainty in relation to prediction of potential impact of the project. Here a flexibility of the disposal strategy, based on the outcomes of the monitoring, is foreseen in the license.

Applying knowledge from past experience

One issue that is apparent from the case studies is that past experience is often crucial in gaining acceptance to a project. The proposed use of a mitigation technique (e.g. sediment management as a measure to mitigate predicted adverse impacts on estuarine habitats) is more easily accepted if it has been previously applied for other projects and has been demonstrated to be successful (or if no adverse impact has been noted as a consequence of the implementation of the project). This has been important in both the Stour and Orwell estuary system and the Humber estuary where evidence from previous projects has been used to demonstrate the effectiveness of a mitigation technique. This minimises the risk and uncertainty for the regulator, and acceptance of the continuation of the technique (with modification if necessary) for subsequent developments has been critical in gaining approval for projects.

Monitoring programmes

Monitoring programmes were established for all of the projects discussed in the case studies. The main purpose of the monitoring is to verify the predictions made within the EIA process and, importantly, to verify whether the mitigation and compensation measures proposed were effective in meeting their objectives. Monitoring was also required during the EIA to obtain data for the baseline conditions given in the Environmental Statements.

The establishment of monitoring programmes forms an important part of managing uncertainty. Such programmes, together with a mechanism to report the findings of the monitoring and make adjustments to mitigation and compensation measures, are important in enabling nature conservation bodies to accept a degree of risk.

Future estuarine management

It is of note that in the Stour and Orwell estuarine system, habitat enhancement schemes were constructed on the intertidal areas at Shotley and Trimley in the lower Orwell estuary.

The areas of land behind the seawalls at Shotley and Trimley are designated as Sites of Special Scientific Interest (SSSI) for freshwater habitats and the regulators recognised that, in the longer term, it may not be sustainable to maintain seawalls and, therefore, maintain the freshwater habitats. As a consequence, there is uncertainty regarding what the future policy may be for the management of the aforementioned mitigation measures (regarding flood defence and habitats) in the longer term.

Given the above, the regulators (Marine and Fisheries Agency and Department of Transport) stated that it was important that the habitat creation schemes should not be considered to be permanent structures and that they should be designed to evolve and erode over time. This was considered desirable as the habitat enhancement schemes would not constrain future options for the sustainable management of flood defences and habitats in the estuarine system.

7.2.3.4 Approaches to consultation

For the case studies included in this project, one notable difference was the way in which the consultees were organised. In the Scheldt, Ems and Weser case studies the main environmental organisations formed a coalition and consultation was undertaken with this coalition, rather than on an individual basis. This did not occur for the UK case studies, and consultation was on an individual basis. These different approaches did not seem to have significant impact with regard to uncertainty in the EIA processes or how these were addressed. In EIA, in the UK, scoping is required to identify the main areas of concern based on discussions with consultees, both statutory and non statutory (Glasson et al. 2012).

7.2.4 Case study: enlargement of the navigation channel in the Scheldt estuary as a good example to cope with uncertainties

The Scheldt estuary is the maritime access to several ports in Flanders and the Netherlands, the largest being the Port of Antwerp located at some 100km from the open sea. The Western Scheldt – the part of the estuary between Vlissingen and the Dutch-Belgian border – is a typical multiple channel system. Up-estuary the Dutch-Belgian border, the estuary evolves to a meandering single channel system (Figure 7.12).

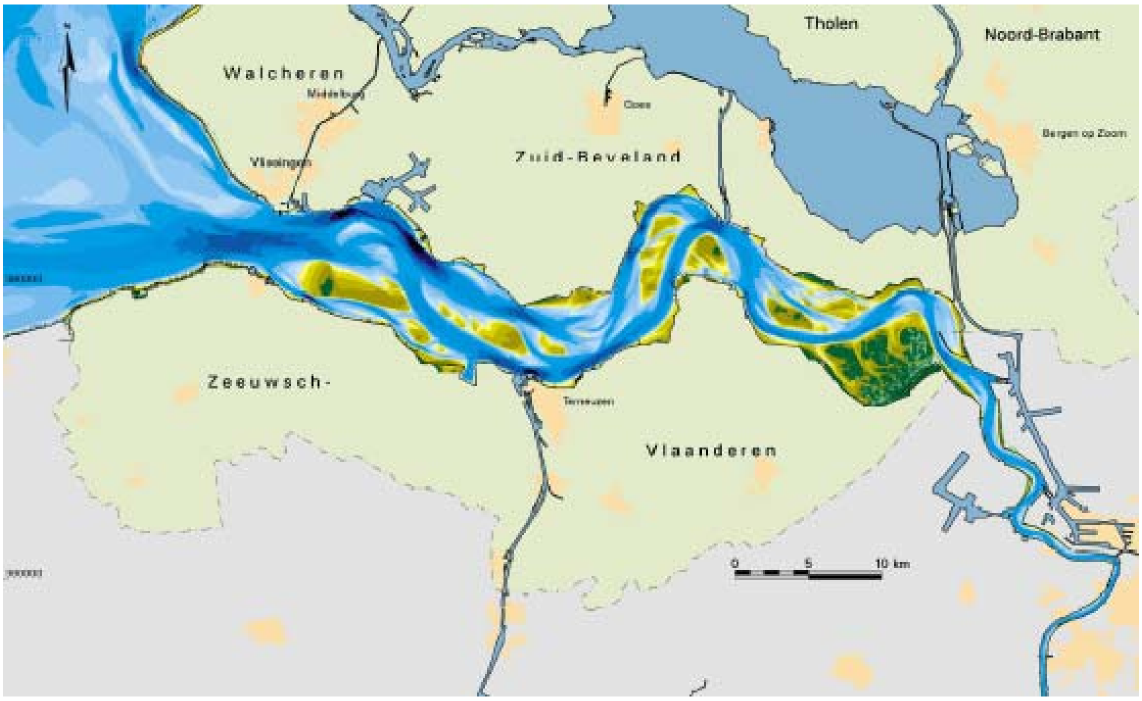

Figure 7.12. The Scheldt estuary.

In 1999 Flanders and the Netherlands agreed to set up a common strategy for managing the Scheldt estuary. In 2001, both parties signed a memorandum of understanding in which was defined a Long Term Vision (LTV) strategy and its objectives (see also Section 1.4). The government of both countries adopted this overall target and already in 2002 the drawing up of the Development Outline 2010 for the Scheldt estuary had started. The aim of the Scheldt Estuary Development Outline 2010 was to define those projects and measures which, in a first stage, must be started up no later than 2010 to ensure the realisation of the LTV in 2030. Already in March 2005 the execution of the Scheldt Estuary Development Outline 2010 was decided on, setting a management strategy to combine the safety against flooding, the accessibility of the ports and the naturalness of the estuary. One of the projects included in the Scheldt Estuary Development Outline 2010 was the deepening and widening of the navigation channel to the port of Antwerp.

In order to cope with the global economics of scale in the container shipping industry, the Antwerp Port Authority asked for such an enlargement of the navigation channel. This project should enable the accessibility to the port of ships with a draft of 13.10 m independent from the tide. After the SEA which was finished in 2004, an EIA including an AA was finished in 2007. Where the traditional disposal strategy involves disposing material in secondary channels, a new disposal strategy which had been investigated from 2002 on was also included as a project alternative. This disposal strategy aims at creating low dynamic intertidal and shallow water area, ecological valuable area that is desired in the Scheldt estuary. In this way the positive effect of disposal of dredged material from the capital dredging works was seen as a mitigating measure. The alternative including the new disposal strategy along sandbars was seen as the most environmental friendly alternative, in fact creating ecological valuable area by capital dredging works.

Despite the fact that state-of-the-art tools had been used, as well as expert judgment to interpret the results of the models, despite intensive monitoring after the previous deepening campaign in the estuary as well as focused monitoring in the field to increase insight in local physical processes, uncertainties still occurred in the results of the environmental assessment. In order to cope with these uncertainties, a specific approach (the so-called three rocket approach) has been followed in order to exclude the occurrence of unexpected negative effects during and after implementation of the project.

- Stage 1: use of most friendly alternative as determined through the SEA.
- Stage 2: use of a flexible disposal strategy. Within the permit a flexibility for the disposal strategy is foreseen. Based on comparison of the continuous monitoring results of the effects of the project to predefined thresholds, the "flexible disposal project group" decides on when and how to adapt the disposal strategy. Every 2 year a report on the monitoring results is made. A team of cross border experts (the so-called Western Scheldt Monitoring Commission) will review these reports and give recommendations to the responsible government, including a possible change of the disposal strategy, change of the monitoring program or additional research.
- Stage 3: in case negative effects would occur, the license includes the possibility to stop the project and even remove the disposed sediments if necessary.

7.2.5 Recommendations and good practices

Based on the findings of this study, some recommendations on good practice and innovative solutions are formulated here, especially regarding the way to deal with uncertainty and/or other research issues within national legislation, assessment procedures and decision-making. The recommendations are grouped per phase in the lifecycle of a project as defined in the blue part of the scheme (see Figure 7.11).

However, also the preparatory work undertaken prior to the phases in the lifecycle of a project (see Figure 7.11) is of crucial importance to the attempt of avoiding uncertainties during the assessment and permitting phases. The more the conception of a project has been based on research and the more detailed (the scope and concept of) a project or plan is defined, the slimmer the chance of uncertainties arising in a later phase. During this preparatory work more specifically the proponent should try to prevent negative effects likely to be caused by this project. Negative effects should be avoided by choosing a project concept and implementation strategy that are based on sound eco-morphological insight in the estuarine system and that do not work against nature and the morphological evolution of the estuarine system. This approach has been followed in the widening and deepening of the Western Scheldt (e.g. the sediment disposal strategy along sandbars in the Western Scheldt).

Nevertheless, assessing the environmental impacts of port developments in estuaries can prove to be very challenging, due to the dynamic nature of the estuary and the uncertainty associated with cause and effect of development on the physical and biological environments. Consequently, the underlying idea for all these recommendations are the observations in the relevant literature that port authorities, regulators, EIA/SEA professionals and all other stakeholders in the process should accept the fact that EIAs and AAs (and, even more, SEAs, given their 'strategic nature') will always contain aspects that for several reasons could remain unexamined and unexplained and as a result need to be based on value assumptions instead.

7.2.5.1 Prediction uncertainties concerning the current situation

The available scientific knowledge and past experiences are often crucial in gaining acceptability of a project.

- Detailed investigation of the physical processes and morphological evolution of the specific estuaries by the proponent, preferably in close collaboration with the national or federal government, in connexion with the monitoring and research obligations pursuant to the Water Framework Directive, the Birds and Habitats Directives. This investigation should lead to a clear scientific view on the current situation and the baseline conditions that are to be used in assessing new plans and projects.
- The best available and most sound scientific knowledge regarding these components should also be established and used by the competent authorities and ports as a basis for the establishment of the environmental and nature conservation objectives for such ecosystems. When and if uncertainties or lack of knowledge on physical, morphological or biological processes still exist, these should be minimized as much as possible by additional research, but it has to acknowledged that sometimes this might not be possible.
- As the acceptance of certain mitigation techniques for subsequent developments is critical in gaining approval for projects, ports and competent authorities should collaborate in establishing a more systematic approach towards monitoring, so that new evidence about previous mitigation measures can be fed back into the scientific knowledge system and – if necessary – also be used for refining numerical models.

- The ultimate standard for determining whether an effect on a Natura 2000 site (according to the Birds and Habitat Directives) or a water body (according to the Water Framework Directive) caused by a project or a plan will be significant or not, is its relation to the nature conservation objectives adopted for the area. Therefore, the responsible authorities should be consulted early on the development and implementation of conservation and improvement measures for the relevant area. In the management plan of these sites, economic, social and cultural requirements and regional and local characteristics such as the actual situation in ports and the expected future economic developments, could be taken into account with the simultaneous aim of not jeopardizing the contribution of the respective site to achieving the overall objective and coherence of the Natura 2000 network.

7.2.5.2 Uncertainties concerning the project assessment

- In this phase developer and consenting authorities should communicate extensively and consistently with all stakeholders on the scope and the effects of the plan or project, the assessment principles and process and on the (remaining) uncertainties. This should go further than what the EU Directives and national regulations require (e.g. public enquiries, scoping procedures, etc.). Good stakeholder management is often crucial to a smooth implementation of the project.
- Authors of EIAs, SEAs and AAs should carefully consider how and where to convey the information concerning uncertainty issues in their reports. Information should be progressively disclosed depending on its relevance to target audiences. Crucial information on how the report deals with uncertainties should be openly revealed in the textual parts, preferably not in appendices.
- In reporting on the environmental assessment or AA, the author will have to characterise the environment and put it into context with respect to its ecological ‘value’ and its vulnerability to the relevant impacts. It has to be proven if development targets according the specific Natura 2000 site or waterbody might be hampered or slowed down. The EIA/SEA professionals are required to identify, label, weigh and rank uncertainties. For each individual uncertainty the report should indicate whether it is policy relevant or not. This can be done in a separate risk assessment memo, containing a synthetic risk matrix.
- The EIA, SEA or AA documentation should undergo an independent review in order to control the quality and adequacy of the information prior to the decision being made.

7.2.5.3 Uncertainties concerning permits and derogations

- In case of any remaining (minor) scientific uncertainty with regard to the effects of a plan or project or the related mitigation or compensatory measures, the consenting authority always has the possibility to grant its consent under special conditions (integrated in the consent decision itself).
- These conditions could impose an adaptive strategy. Such a strategy may result in a phasing in time of the proposed project or the duty to work with a pilot project. In this phasing process, sequencing could be integrated that only allows the following phase to start after meeting certain goals or conditions.
- Such special conditions should also include a pre-defined and validated scheme to monitor the actual impacts as well as a framework to adapt the mitigation and compensation measures regarding the actual impacts. Monitoring schemes should be established to monitor short and long term evolution, such as morphological dynamics and sediment circulation/re-distribution.
- The EIA, SEA and AA, although being different in purpose, can be helpful in setting up such an adaptive strategy, by following the next steps:
    1. Determination of the bandwidth of effects, fixed uncertainty margins or calculation of a favourable and an unfavourable scenario;
    2. Questioning: What is the probability of the impact scenarios (especially the worst-case scenario)? What is the probability that the best or worst-case scenario is occurring? This insight into the reality of the scenario can help the authorities in the decision-making process;
    3. Determination of the importance of the uncertainties for the comparison of alternatives. This is relatively straightforward by comparing similar alternatives which will have usually similar effects, but a statistical test may be needed to compare dissimilar alternatives to determine whether or not alternatives significantly differ from each other;
    4. Determination of the probability of exceeding limits. In statistics the true value often lies somewhere in the interval of the calculated value plus or minus half of the uncertainty margin. On this basis, the probability of exceeding the limits can be estimated.
    5. Prepare possible management measures in order to be ready when needed. These measures, and when and by whom they are to be conducted, must be determined in advance. It is important to establish which measures are conceivable, what effects they may have, how the actual effects are

monitored, based on which criteria, when and in what order the measures will be taken and who is responsible for funding and and implementation.

- An adaptive strategy requires also the implementation of a long term forum with stakeholders for reporting results or any other vigorous follow-up mechanism (e.g. a combination of competent public bodies) that is authorised to implement changes to a programme of mitigation or compensation and to take additional (predetermined) compensatory measures on the basis of the results of monitoring programmes (flexible approach).
- In order to achieve this, financial warranties or any other financial safeguards should be put in place that can guarantee long-term implementation and protection.
- The special conditions imposing an adaptive strategy could be accompanied by one or more separate legal agreements committing an applicant to take corrective measures, following certain timescales or in the event that mitigation and/or compensation measures do not meet the objectives set, stop the project.

7.2.5.4 Uncertainties concerning monitoring and evaluation

- An adaptive strategy is also useful in order to overcome knowledge gaps. Instead of extensive research prior to the consent, the estuarine situation might also be monitored in a later stage. If this procedure is feasible depends on the specific project and its boundary conditions. New evidence and current scientific information should then be fed back into the management plan and into assessments for new projects or plans.
- As soon as the monitoring data reveals deterioration of the estuarine environment, a set of (predetermined) measures is applied in order to adapt mitigation and compensation measures regarding to the actual impacts. Moreover, on the basis of trends measured during the monitoring, the conservation objectives and management measures may be revisited where and whenever necessary.

7.3 Considerations in delivering a management plan

One of the primary considerations in delivering a management plan is to ensure a coordinated approach to the management of the estuary and its hinterlands including planning for the future. This requires the need for collaboration between a wide range of stakeholders (business, NGO's, Statutory Bodies, local and national government, and research organisations) to ensure an estuary is managed as a single entity when it has a lot of competing and complementary pressures exerted upon it.

There are many different issues that arise within an estuary, including but not limited to, environmental issues, ecological change, ports, modifications to natural process, climate change and recreation. Strategic management and planning within estuaries seeks to identify a framework that enshrines sustainability. Any management initiative must address the issues of:

- Long-term change,
- Physical, chemical and biological interactions, and
- System response (including socio-economic interactions)

whilst ensuring compliance with the law is adhered to. Of the many issues (sectors) within estuaries, each is often likely to have a management plan or management framework operated by a particular body (Figure 7.13). Such sectoral plans are often in conflict with each other, for example a port management plan may conflict with a nature conservation management plan. The aim of an integrated and holistic estuarine management plan is to harmonise the different sectoral management plans (Table 7.4).

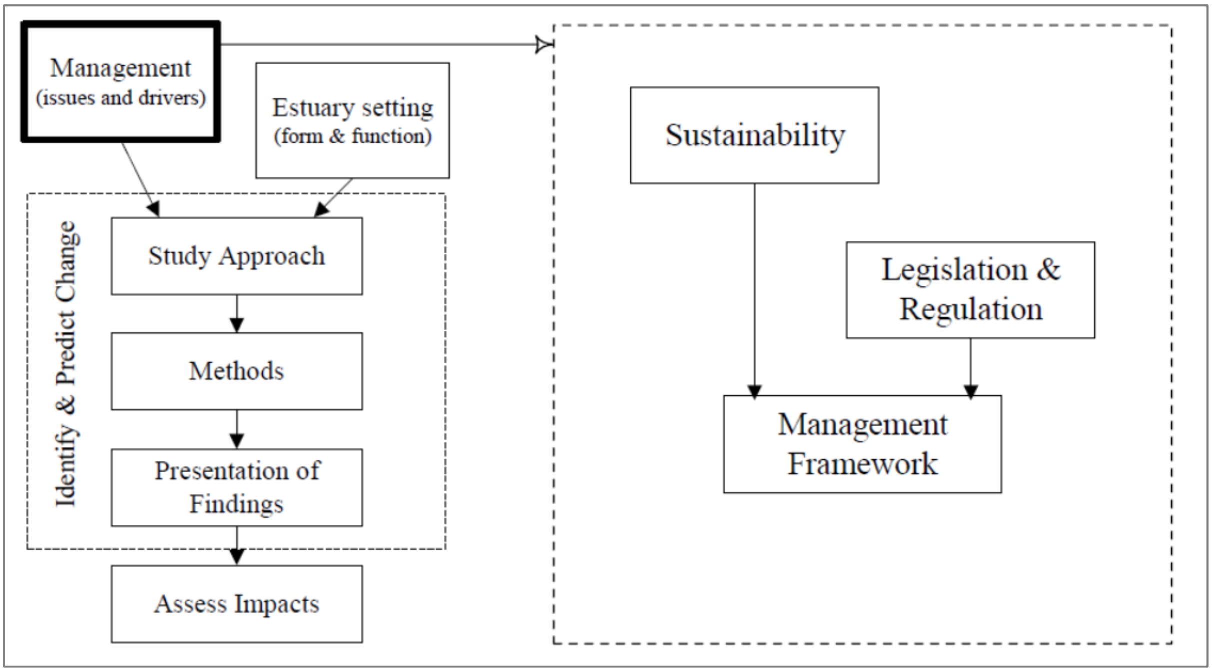

Figure 7.13 Flow diagram illustrating the process of estuarine management. Source: Department for Environment, Food and Rural Affairs (Defra) (UK), 2011.

Table 7.4 Aspects within an estuary to be managed (and by whom).

Aspect of Estuary	Who to manage
Habitats	Nature Conservation Agencies
Environmental quality	EPA-type organisations
Water space usage	Port authorities
Navigation	Port authorities
Infrastucture	Municipalities/ federal state
Energy extraction	Private companies
Biological extractions	Fisheries bodies
Estuarine water extraction	Private energy companies
Upstream water abstraction	Water supply companies
Land space usage	Municipalities/ federal state
Erosion and flooding control	EPA, municipalities etc
Industry	EPA and private companies
Recreation and tourism	Agencies

7.3.1 Examples of management plans in the North Sea Region

7.3.1.1 The Humber

The Humber Estuary has been described previously (see Section 1.4) and is a highly dynamic system with complex interactions between physical, chemical, geomorphological and biological factors. It is thought to be in a state of dynamic equilibrium and responds to the natural physical variables such as freshwater inflow, tidal range, salinity and sediment characteristics (Townend and Whitehead 2003). As such the approach to estuary management is extremely important (Environment Agency 2013).

Humber Management Scheme and the Humber Flood Risk Management Strategy

Partnership working on the Humber has been developing over a number of years. This was initiated by the Humber Estuary Management Strategy (HEMS) and a subsequent Action Plan, published in 1998, which was a collaboration between the Environment Agency, Local Authorities, Associated British Ports, English Nature (now Natural England) and industrial and agricultural representatives, land owners and conservation and recreation bodies. The draft consultation plan was published in 1996 (HEMS 1997). This initial Action Plan led to the creation of the Humber Management Scheme (HMS).

Humber Management Scheme

The Humber Management Scheme was set up in 1999 and has over 30 relevant authority members (Humber Management Scheme. http://www.humberems.co.uk/humber/, Accessed 2013). The HMS published its first plan for the Estuary in 1999 (Humber Management

Scheme. http://www.humberems.co.uk/humber/, Accessed 2013), which served the management of the European Marine Site well. However, changes in legislation and drivers by the HMS to focus upon the areas that didn't currently have adequate management strategies in place led to the revision of the Action Plan for the Estuary during 2011-12. The new Action Plan was published in 2012 will the specific Objectives as outlined below (Humber Management Scheme. http://www.humberems.co.uk/humber/, Accessed 2013):

1. To manage the estuary to meet the requirements of the conservation objectives
2. To bring people and organisations together to deliver the sustainable management of the Humber Estuary European Marine Site
3. To raise awareness and educate stakeholders about the Humber Estuary European Marine Site and increase participation in its management
4. To identify information gaps and research requirements and to promote sharing and availability of data for the management of the Humber Estuary European Marine Site
5. To ensure a coordinated approach to the management of the estuary and its hinterlands including planning for the future in respect to the features of the Humber Estuary European Marine Site

<u>Humber Flood Risk Management Strategy</u>

The Environment Agency has responsibility for managing flooding from "main rivers" and from tidal flooding in England, hence the Agency manages risk around the Humber Estuary.

In 2000, the Humber Estuary Shoreline Management Plan (HESMP) was produced (Environment Agency 2000). The HESMP identified a long-term policy plan for managing the flood defences surrounding the Humber Estuary, including the lower, tidal reaches of the Rivers Ouse and Trent. Further studies have included the development of the Strategy, published in March 2008, which outlines how the policies in the HESMP will be implemented over the next 100 years. The first 25 years of the Strategy has been approved by the Department for Environment, Food and Rural Affairs (Defra), and it will be refreshed through a 5-year rolling programme of reviews. The first packages of work under the Strategy are underway and some schemes have already been completed including managed realignment/habitat creation schemes at Alkborough and Paull Holme Strays, which contribute to compensatory habitat provision for anticipated coastal squeeze (and direct) losses in the estuary.

It is part of the Humber Flood Risk Management Strategy (HFRMS) (Environment Agency 2008) compensation plan to address coastal squeeze in the estuary as required by the EU Habitat Directive. In the UK, the EU Habitats and Birds Directives were transposed into UK law in 1994, and as such reference here on in to Habitat Regulations is reference to the UK law, where reference is made to the to Habitat Directive, this is reference to the EU legislation rather than the UK law. Part of the Defra) approval of the HFRMS was made on the requirement that there will be no loss in the ‘integrity of sites’ designated for their European conservation importance (i.e. the Humber Estuary Special Protection Area (SPA), Special Area of Conservation (SAC) and Ramsar site) under the Habitats Regulations 1994 as amended to Habitats Directive. This was based on an shadow Appropriate Assessment, as required by the Habitats Directive, which was submitted with the Strategy. At the time the Strategy was submitted this was not a legal requirement. Subsequently following approval of the HFRMS a full Habitat Regulations Assessment has been submitted and approved by Defra (Environment Agency 2011).

The Humber SPA/SAC/Ramsar site could be affected by the footprint of any FCRM works (a direct loss) or by coastal squeeze associated with sea level rise against existing hard defences which prevent the natural roll back of these habitats and subsequent loss of their area. Compensation for direct losses needs to be met by the organisation carrying out the works, but on the Humber, where the whole of the estuary is subject to European habitat designations, the Environment Agency has a legal duty to maintain the integrity of the desinganted sites and hence to compensate all losses arising from coastal squeeze.

7.3.1.2 The Weser

Integrated Management Plan Weser

An integrated management plan for the Weser estuary, the Unterweser and the Lesum (NLWKN and SUBV 2012) has involved an intensive participatory process involving all major stakeholders. The plan is to form a basis for sustainable river area management and a balancing of the various interests. The project aim has been to alleviate current conflicts between users and to generate a greater willingness to actively support the enhancement of the ecological situation. This plan brings together economic, social, infrastructural and regional aspects, as well as the conservation guidelines and specialised objectives. Interdisciplinary planning groups with representatives from administration, industry and associations have been set up for this purpose at the Lower Saxon State Office for Water Management, Coastal Protection and Conservation (NLWKN), as well as with the Bremen Senator for the Environment, City Development and Europe (SUBV). This Integrated Management Plan is to serve as a guideline for national activities. It offers a great variety of options for action and for development of the Tideweser region and is intended to increase planning reliability. The plan also seeks to reach a negotiated agreement between all stakeholders regarding the preservation and consistent development of the ecological network Natura 2000. The plan has required the agreement of the states Lower Saxony and Bremen and the Federal Waterways Administration to devise a joint IMP Weser, with a not legally binding agreement having been signed in 2008. The parties are pursuing the aim of reconciling ecological and economical claims including those of shipping when implementing the European Habitats, Birds, and Water Framework Directives (http://www.efre-bremen.de/, 2013). The agreement (signed in 2008) included provision for the development of an Integrated Management Plan by the end of 2010 in accordance with the EU Fauna-Flora-Habitat guidelines and legally underpinned by Article 6 (i) of the Habitat Directive. Article 6 (i) requires EU member States to specify the measures necessary in order to achieve a favourable state of conservation for habitat type and/ or species (http://www.efre-bremen.de/, 2013).

The Weser Integrated Management Plan includes the habitats and bird reserves of the Tideweser extending from downstream of Hemelingen dam to the mouth of the Weser. This is an ecologically important area, with 90% of its water and flood banks part of the Natura 2000 network. Successful integrated management in the Tideweser will need to balance the high conservation value and its requirements with the economic demands of northern Germany and the Weser ports, including industrial production, agriculture, tourism and flood and coastal protection (www.tide-project.eu).

7.3.1.3 The Elbe

<u>Integrated Management Plan Elbe estuary (IMP)</u>

The integrated management plan (Arbeitsgruppe Elbeästuar 2012) for the Elbe estuary was set up for the implementation of Natura 2000 (according Article 6 (i) of the Habitat Directive) at the Elbe estuary which is almost entirely designated as Natura 2000 sites while at the same time on of the world's most frequented shipping routes with the Port of Hamburg situated on the upper end of the estuary, 120 km inland. Its aim is to draw an authoritative framework for human activities within the Elbe estuary while ensuring that the requirements of the Birds- and Habitat Directive are thoroughly met. Allthough the IMP is clearly a plan for nature conservation it is quite remarkable as all the other aspects and uses are considered and integrated through a broad participation process and by this the accepted basis for any future activities with the potential of affecting Natura 2000 objectives. The plan has been set up under the direction of a steering committee consisting of high ranking representatives of the nature and economy ministries of the three federal states Hamburg, Schleswig-Holstein and Lower Saxony, as well as the Federal Waterways Administration and Hamburg Port Authority. The actual work has been coordinated by a working group and the involvement of all relevant stakeholders has been ensured through two planning groups. Based on comprehensive technical reports for all relevant themes (nature conservation, navigation, agriculture, tourism etc.) the actual IMP has been drafted, focussing on the identification of conflicts and synergies between the different issues. Following this, an extensive set of possible measures aiming at improving the conservation status has been derived. The measures have been discussed again with all the stakeholders and consensus has been found on a set of roughly 230 possible measures.

Many management measures have been identified with high synergetic potential such as most important all the measures that aim at improving the hydro-morphological regime of the Elbe estuary. Measures like the creation of new tidal volume are highly beneficial to both nature conservation and navigation as they create new valuable habitat while at the same time stabilising the sedimentation processes. Subsequently, 30 ha new tidal area at the location of Kreetsand in the vicinity of the city of Hamburg (see also www.tide-toolbox.eu) is currently being constructed by order of the Hamburg Port Authority. This realignment project is considered as a pilot project to improve the tidal regime and should thus result in benefiting maintenance dredging while at the same time it is one of the largest management measures of the IMP for the creation of estuarine habitat.

The IMP was considered a good practise by the EU and within DeltaNet, despite being a sectoral plan (nature conservation). It is a good example of how sectoral plans can be beneficial to many other groups and issues. Key was the early involvement of all relevant groups and the identification of potential win-wins. However, the Birds and Habitats Directive functioned as a clear and powerful driver, mandating the cooperation in first place. Figure 7.14 shows the general structure of the planning process which took from 2008- 2012.

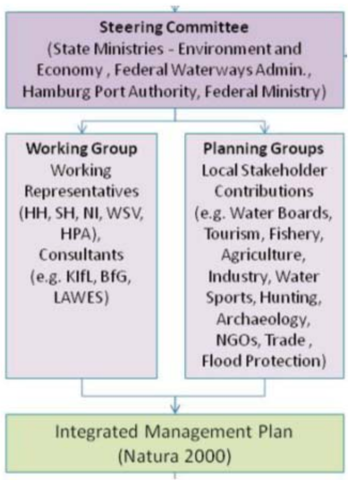

Figure 7.14. A summay of the structure of the Elbe Integrated Management Plan, including the working parties involved to ensure the plan is successful in implementation (Arbeitsgruppe Elbeästuar 2012).

Figure 7.15 gives an illustrative example of how different aspects within a section of the estuary are taken into account and how they can be combined into management strategies seeking multi beneficial effects. For further information see www.natura2000-unterelbe.de.

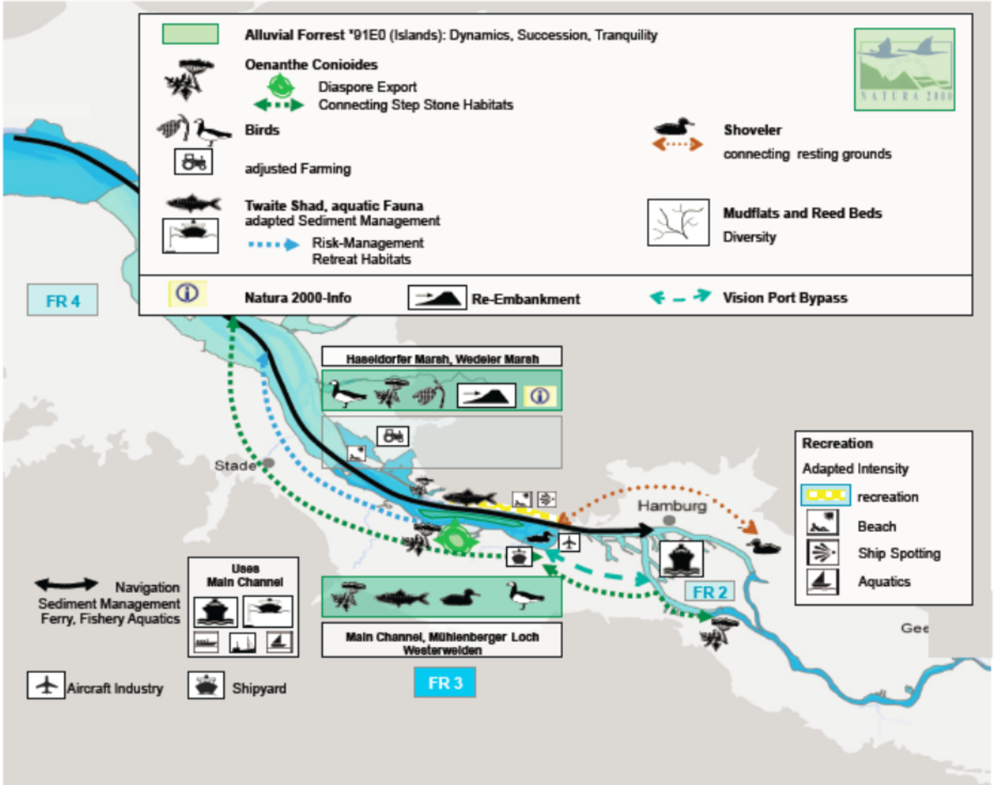

Figure 7.15. An example of integrated management at a unit level on a functional basis (Arbeitsgruppe Elbeästuar 2012).

7.3.1.4 The Scheldt

<u>Nature Development Plan (Long Term Vision for the Scheldt Estuary)</u>

The Scheldt estuary has long been a source of conflict between the Netherlands and Belgium/Flanders. Between 1585 and 1792 the Schelde was closed by the Dutch and no sea ships could reach Antwerp. In 1863 a treaty between Belgium and the Netherlands guaranteed the free access for vessels to the port of Antwerp, but adaptation of the fairway to the increasing ship size was always a matter of discussion between both countries. The request of Flanders for a new deepening could again lead to long negotiations between both countries. To avoid this and to work towards more integrated management in the future, the Dutch and Flemish government agreed in 1999 to set up a common strategy for the sustainable management of the Scheldt, with goals to achieve by 2030: the so called “Long Term Vision for the Scheldt estuary” (LTV). This vision should integrate the characteristic functions of the system and lead to "the development of a healthy and multifunctional estuarine system, which can support human needs in a sustainable way".

Further both countries have been victims to several severe floodings which caused a high number of casualties; safety against flooding is still an important issue in both countries. In Flanders, the Updated Sigma Plan aims at this. Safety along the Belgian ´Sea Scheldt´ should be increased by establishing controlled inundation areas no later than 2030. Where space for inundation areas was lacking, such as in urban areas and industrial areas, the heights of the dykes should be increased. In order to create ´win-win´ situations, a new natural multifunctional environment should be established, e.g. the areas should provide opportunities for combining nature with other objectives such as safety, agriculture, marine aquaculture, recreation, and residential/employment initiatives.

Therefore, three key functions were selected for the set-up of the vision in order to address the two aspects described above plus meeting the conservation goals of the European nature legislation:

- Safety against flooding (implementation of the updated Sigmaplan in Flanders)
- Accessibility (fairway deepening and widening that allows ships with a draught of 13.1 meters to sail to the port of Antwerp regardless of the tide)
- Nature conservation

The Flemish-Dutch Scheldt Commission (VNSC), as the successor of the common Technical Scheldt Commission (TSC) which was founded in 1948, should implement these common objectives by setting up:

- Integrated and common vision with stakeholder involvement
- Guidelines for policy making in both countries
- Technical and scientific approach
- Emphasis on joint fact finding and transboundary cooperation

As a first step a project organisation called ProSes was set up to define a joint development plan with a time horizon of 2010, the ´Scheldt Estuary Development Outline 2010´ (´Ontwikkelingsschets 2010´). The main projects and measures of the ´Scheldt Estuary Development Outline 2010´ were formalised in a Treaty of December 21, 2005 that contains dozens of resolutions regarding how the two governments intend to reach the ambitious goal. Within a period of 2 years several studies were carried out by a consortium of scientists and public authorities to set up a comprehensive package of projects and measures.

In order to create the anticipated ´win-win´situations a innovative measure has been applied: the construction of a Flood Control Area with Controlled Reduced Tide (FCA-CRT).The Ecosystem Services Approach (at that time referred to as the goods and services of the estuary) provided the bases this integrated Sigma Plan. By combining functions, and by taking all functions into account in a societal cost benefit analysis, an approach with the construction of several FCA-CRT appeared to be the most cost effect one, better than only dyke strengthening of the construction of a storm surge barrier.

This pilotproject at Lippenbroek in the Zeeschelde is a good example for a ´win-win´ situation (safety and nature) (Cox et al. 2006). The aim was to combine water storage during extreme high tides and estuarine wetland restoration. Lippenbroek, a polder area with low elevation is separated from the estuary by a lowered overflow dyke. During storm surges, on average once a year, water can overtop this dyke and be stored in the area. To restore an estuarine ecosystem in this same area, a limited but daily exchange of water with the estuary is essential. A well designed sluice system introduces a tidal wave with clear spring tide neap tide variation, thus providing a wide range of inundation frequencies in this embanked site to restore estuarine functions and habitat. Lippenbroek is the first FCA-CRT system worldwide and acts as a pilot project in terms of habitat development for other flood control areas to come (e.g. Kruibeke-Bazel-Rupelmonde). By creating the correct conditions (primarily a correct tidal regime), the aim is to develop a sustainable freshwater tidal marsh habitat on a lowered rural site with nature itself as the primary steering factor.

A crucial aspect of the Long Term Vision was that at all times the unique morphological and ecological characteristics of the system have to be preserved and maintained. One of these characteristics is the preservation of the so-called “multi-channel system” in the Westerschelde which consists of a dynamic flood and ebb channel network.

Studies that have been conducted during this process, have for example shown that deepening the channel would have little effect on the vitality and natural environment of the Scheldt estuary, under the condition that the existing disposal strategy is modified and ecological development takes place. In 2001, an expert team stated the need for morphological management, which aimed at steering the estuarine morphology in the sense that the sediment deriving from dredging works should be used to reshape eroded sandbars where needed in order to maintain the multiple channels. Within this new strategy, dredged material should be used to create ecological valuable ecotopes, i.e. subtidal and intertidal areas with low currents (“working for nature”) and mitigate at the same time uncertainties surrounding the effects of the channel deepening on the long term. So several decisions were taken, amongst which the application of the new adaptive disposal strategy (see also the report on ´Morphological management of estuaries´ (APA 2013 at www.tide-toolbox.eu). Additionally, further measures should be taken to restore natural vitality e.g. constructing or removing groynes, excavating old salt marshes, and either increasing or decreasing the depths of different parts of the channels. Finally both countries agreed on a joint monitoring of the evolution of the estuary and the effects of the implemented projects.

Since 2002, the effects of the new disposal strategy are being studied in a pilot project on the Walsoorden sandbar in the Western Scheldt. In 2004 as well as in 2006, 500,000 m³ of sand was disposed in relatively shallow water at the Walsoorden sandbar. Thorough morphological and ecological monitoring led to the conclusion that from morphological viewpoint the test was a success. The ecological monitoring revealed no significant negative changes in trends due to the disposal test. The monitoring was evaluated by an independent expert group that should advice – if appropriate – on potential adaptations of the disposal strategy.

7.3.1.5 The Seine

The Seine-Normandy Basin district in the north-west of France covers an area of about 97,000 square kilometres (km^2), nearly 18 percent of the country's total surface area. It is composed of the drainage basins of the Seine River and its tributaries, the Oise, Marne and Yonne, and those of Normandy's coastal rivers. Work has been ongoing over a number of years to work towards an integrated approach to management in the Seine Aval region of the Seine Basin. In 1995 a research programme was set up and in 2003 it became a GIP (Group in the Interest of the Public, see http://seine-aval.crihan.fr/web/) Seine Aval. The GIP has become a tool for decision making, but which has an operational component. It enables dissemination to both the scientific community and the estuary stakeholders, including the public. This co-operative approach enables the best scientific information to be made available to inform all of the decision makers and managers involved in estuary management in the region.

The current aspiration of the partnership is to work towards a multi-parameter approach to achieve good ecological status which will account for ecological, economic and societal needs. This approach is already delivering in terms of interlinking multiple processes, efforts and investments that are currently underway.

7.3.1.6 Best practice from the North Sea Region

Different integrated management plans for estuary management exist across Europe in response to the European Commission's Integrated Coastal Zone Management demonstration programme, which consisted of thirty-five demonstration projects between 1996 and 1999 representing a range of ecological, economic and social situations that exist in European coasts. Evidence from the Elbe, Humber, Schedlt and Weser shows that development of integrated management plans requires the investment of time, resources and a large number of stakeholders (Boyes et al. 2013), if a successful outcome is to be achieved. Successful integrated management plans manage to bridge the apparent gaps between the different groups with disparate interests and seek synergies between the natural environment and socio-economic requirements (Boyes et al. 2013). The Ecosystem Services Approach (see 1.3.2) is an ideal tool to integrate management plan and to build bridges between stakeholders: it shows in an objective way the importance of all components of the system for the economy, ecology and human well-being.

It is not always necessary for integrated management plans to have a legal basis, non-statutory plans can also deliver successful outcomes, but it is necessary to minimise overlap between plans to avoid conflicts and deliver a harmonised plan (Boyes et al. 2013). One example of this is the move from the Humber Estuary Shoreline Management Plan (Environment Agency 2000) being incorporated and embedded into the Flood Risk Management Strategy in 2007 (Environment Agency 2008).

In order to further promote sustainable development of coastal zones, the European Commission adopted in March 2013 a draft proposal for a Directive establishing a framework for maritime spatial planning and integrated coastal management. The adoption of this Directive should allow the knowledge on integrated estuary management gained during the TIDE project (www.tide-toolbox.eu) to be examined and implemented within the wider European context.

7.3.2 Management measures: Benefits

Raising awareness of the economic value of the ecosystems created by managed realignment schemes can only benefit the promotion of managed realignment projects in estuaries around the North Sea Region, including on the Humber Estuary. However, it is recommended that the approach should only be applied in the correct circumstances and at an appropriate scale with full acknowledgement of practical limitations. It is recommended that detailed ES valuations should only be considered where additional project appraisal is justifiable, necessary and useful (Environment Agency 2012). This level of appraisal is likely to be useful when there is a significant risk of delays and objections arising from a proposed scheme locally – which is the case in almost all managed realignment projects in the Humber Estuary, and more widely within the UK. In these cases, the role of Ecosystem Services (ES) valuation would be twofold:

- To potentially provide a more balanced evidence base for the relative merits of the project with stakeholders, councillors and the planning authority, and
- To support the business case by proving an enhanced statement of the economic benefits of legal compliance projects, as required by Defra for all cost-effectiveness analyses (Environment Agency 2012).

However it should be noted that the complex and site specific nature of ES assessments mean that there is not likely to be a one size fits all guide or approach, and that this work is still in its infancy in mainstream estuary management and planning.

Caution is advised when carrying out site specific ES assessments, particularly with regard to benefits which when considered in isolation on smaller sites may appear insignificant or minor. Such ES benefits may be significant in the wider context. For example if this were to be deployed on the Humber, it may be more appropriate to undertake a more strategic Humber-wide approach to capture these benefits and give a wider appreciation of tipping points when impacts on ES become significant (Environment Agency 2012). It is likely that valuation gaps and uncertainties may preclude meaningful monetary valuation of all ES benefits that a managed realignment would provide, but that indicative valuations would be possible for the large, significant benefits and that the investment required to understand all ES would not be prudent in the short-term, for the additional value that they would deliver. It is vital that these research gaps are identified at the local, national and international scale to enable co-operation and collaboration to fill these evidence gaps in the medium term.

The complexity of estuaries means that an integrated management approach will have the best chance of success when based on the Ecosystem Service Approach which is aimed at preserving the natural functioning of the system and recognising humans as an integral component of the ecosystem (Jacobs et al. 2013). The ecosystem service approach can be used as a common denominator between the economic, ecological and social system (Jacobs et al. 2013). Our understanding of the dependency between the delivery of these services and on the functioning of the system delivering the services has been enhanced (Jacobs et al. 2013). Services were not valued, but a methodology was developed to enable economic valuation of ecosystem services, resulting in a database of values for different processes and functions (Jacobs et al. 2013).

- Management plans which engage all users and uses of the estuary - Although non-statutory in nature, successful plans have been implemented in many estuaries (Elbe, Humber, Scheldt and Weser) to ensure that the habitats and species within the estuaries maintain their favourable condition (Boyes et al. 2013). 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.
- Creation of unified management decisions and avoidance of overlapping plans - The Coastal Defence for 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 (Boyes et al. 2013). In response to the Flood Risk Management Directive, estuaries within Europe have developed comprehensive flood risk management plans. Many of 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 (Boyes et al. 2013).

- Open communication between statutory authorities, stakeholders and users within an estuary will lead to common goals being met - development of plans should involve stakeholder and advisory networks if they are to demonstrate good practice, for example the River Basin Management Plans (RBMPs) and other programmes of measures as required under the Water Framework Directive (Boyes et al. 2013). 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 (Boyes et al. 2013).

A SWOT analysis (Strengths, Weaknesses, Opportunities and Threats) can be undertaken on exisiting management plans to identify best practice for the development of new integrated plans, or to enhance exisiting plans. Although the most successful plans are of a statutory nature, it is possible to develop successful plans that do not have a legislative underpinning, such at the Integrated Management Plan Elbe (Boyes et al. 2013). It is also important to identify the necessary financial underpinning to ensure the successful implementation of plans, but where this is not possible, strong governance may be able to compensate for this (Figure 7.16)

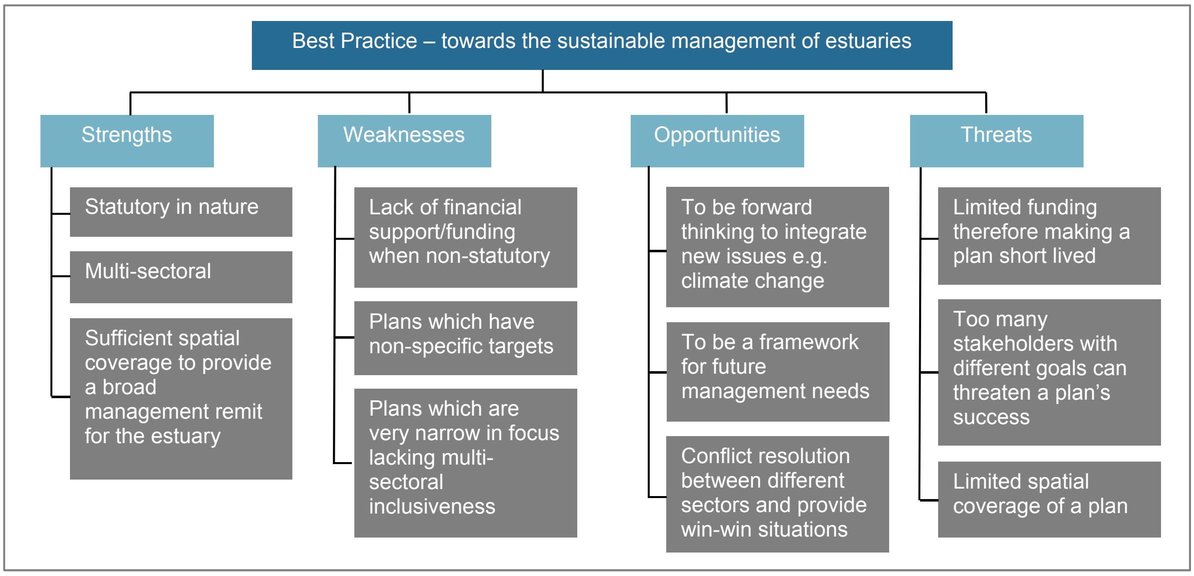

Figure 7.16. Common strengths, weaknesses, opportunities and threats identified within the management plans of the Elbe, Humber, Scheldt and Weser (Boyes et al. 2013).

<u>Integrated management</u>

Successful management requires us to understand both the dynamics and functioning of estuaries in relation to natural and anthropogenic features and to disseminate this knowledge to all those involved in estuary management. Estuaries have responded to natural and anthropogenic change over time. Anthropogenic influences have included land for settlement, agricultural production, industrial use (including ports and navigation).

Estuaries often cross national and regional borders resulting in a complicated pattern of governance which can lead to conflict between the multiple uses (Boyes et al. 2013). However, there are commonalities between estuaries, despite these differences, in terms of process, structure and demand (Boyes et al. 2013). This complicated matrix indicates that a strategic approach to estuary management must consider the estuary as a whole, managed within the spatial context of the river/ estuary/ sea interactions (ABPmer and HR Wallingford 2007).

An important part of successful integrated estuary management is the recognition that an estuary will adjust to any imposed constraints (natural and anthropogenic). As such it is not sensible to define a "natural" estuary system, but that the central question for estuary management is whether any imposed changes will alter a particular estuary feature that society values in a way that society will consider unacceptable (ABPmer and HR Wallingford 2007).

If this is the fundamental question for estuary management to seek to address, it is important that there is an agreement as to what sustainability constitutes and what society is seeking to sustain. The guiding principle as stated in the Bruntland Commission's report succinctly encapsulates the ultimate objective (WCED 1987): "We must meet the needs of the present generation without compromising the ability of future generations to meet their own needs".

There are many different perspectives on the best way to achieve this in an estuarine environment, and this forms part of the debate of developing estuary management plans. Defining the different view points in terms of ecology, society and economic systems (Steeley 1995) enables us to work towards the ecosystem systems approach to defining integrated estuary management as previously defined (see Section 1.4.1). The main aim of integrated estuary management is to ensure that the natural system is maintained and protected whilst delivery societal benefits (Elliott 2013). The ten tenets of sustainable management provide a means to define the main considerations that involve all stakeholders within the current regulatory framework at the time at which any decision is to be taken (Elliott 2013).

Each of the three different facets (ecological, economic and social) makes use of the wider environmental systems and consumes inherent resources from the environment (Defra 2011). As such there is a complex web of inter-linkages and feedback loops both within individual systems and between systems (Defra 2011). Where these overlaps between systems occur, are the potential shared objectives that feed into the formulation of an integrated management plan that will seek to maximise sustainability by maximising the degree of overlap and synergistic benefits within the system.

Recognition of the need for evolution in integrated estuary management is likely to result in a more successful and deliverable plan. Sustainability is one aspect of an integrated management plan, and just as sustainable development has expanded from economic viability, technological feasibility and environmental sustainability to the 10 tenets now considered in sustainable management (Elliott 2013, see also Section 1.4.1), integrated management needs to be able to evolve and respond to the changing needs of an estuary.

An important aspect of successful estuary management is the recognition that long-term survival of certain aspects of the system is not the same as sustainability. It is important to accept that there are a range of spatial and temporal scales at which both ecosystems and societies exist and a successful integrated estuary management plan will reflect this.

7.3.3 Conclusions

An integrated management approach should include the following (Boyes et al. 2013):

7.3.3.1 System-wide perspectives

Estuaries are a continuum from coast to freshwater, acting as the interface between these two different systems. Different functions, natural and anthropogenic uses exist along this continuum and these differences must be an explicit consideration in the development of any plan for estuary management taking account of the whole system. Taking a system-wide approach enables a more sustainable outcome and reduces conflict. For example, adopting a Natura 2000 management plan which recognises the demands of society is already approaching a holistic approach (Boyes et al. 2013).

Attempts have been made over many years to manage the Humber estuary on a holistic basis. The Humber Estuary Management Strategy (Environment Agency 1998) was initiated by the Environment Agency (UK) in 1996, and was a useful initial process, but it lacked the necessary high-level and formal agreements with key organisations and regulators. The recent introduction by the Government of Local Enterprise Partnerships may make a fundamental difference however. These public and private partnerships are for the first time bringing all of the key players together to tackle common problems (achieving economic growth is the main objective), but this is also resulting in the regulators working in a much more unified way, and all parties identifying common objectives. There is the opportunity now for ecosystem services approaches to genuine influence estuary management for the first time. A key difference in this approach is that different administrative regions, political and economic drivers are being forced to be united with the estuary at the heart of the debate. This gives a real opportunity for integrated sustainable approaches to estuary management to be agreed. We also consider the implementation of the integrated management plans for the Elbe and Weser as well as the Long Term Vision for the Scheldt estuary as good examples for this approach.

7.3.3.2 Adaptive management

Estuaries are by their very nature dynamic systems, and as such they need an adaptive management approach. Adaptive management ensures that management changes and responds to changes beyond the bounds of the management plan, such as changes in legislation, or changes to economic circumstances. Such an approach needs to accommodate natural processes and anthropogenic demands and changes. TIDE (Boyes et al. 2013) emphasises that any management which cannot accommodate such changes will eventually either be costly or may have limited success.

An example of an adaptive approach is the Humber Flood Risk Management Strategy (Environment Agency 2008) which was initially published in 2008, but that is now being updated in response to legislative changes in both the UK and EU, policy changes by the UK Government, and new understandings of estuary functioning. As the update is taking place, the project team is taking the opportunity to seek formal agreements with all of the Local Authorities regarding future funding, and to build the broadest involvement in future management. Delivery of flood risk management is still at the heart of the update process, but this is integrating the Water Framework Directive and ecosystem services into the updated Strategy, in addition to the existing inclusion of the Habitats and Birds Directives (via the Habitat Regulations). The final product will have sustainability (economic, environmental and social) at its centre.

7.3.3.3 Monitoring and evaluative monitoring

Monitoring programs need to be established (and maintained) to understand the morphological and other changes at appropriate scales, but in addition it is necessary to assess the success of any management strategy. This requires that the outcomes are monitored appropriately. It is therefore necessary to decide on key success measures and then ensure that the relevant parameters are monitored. It is important that monitoring programmes are cost-effective and fit-for-purpose. Monitoring programmes should be integrated to enable both the evaluation of a management strategy or operational objective, and to enhance understanding of the functioning and development of the whole estuarine system (Saathoff et al. 2013).

It may be beneficial if future monitoring within estuaries can be more integrated and collaborative to ensure that all parties involved in estuary management have access to the best data. This approach was used in the Schelde estuary within the MONEOS framework for monitoring (described in more detail in 7.1.6). It has also been one of the drivers in the

GIP Seine Aval programme (Ducrotoy 2013), and Natural England in the UK has recently undertaken a piece of work looking into the potential for statutory conservation bodies and industry for joined up data collection and monitoring (Natural England 2013). This latter piece of work aimed to identify opportunities for closer collaboration between Statutory Nature Conservation Bodies, Marine Regulators, and industry undertaking licensable activities in areas where joint monitoring of Marine Protection Areas could be of mutual benefit in English Waters. It identified five protocols that could be used where there is potential for joint monitoring and data collection. These protocols fall within two groups:

- Protocols to enhance within sector monitoring foundations- these would help lay the foundations for joint monitoring
- Protocols to establish methods for joint monitoring and data collection- these are specifically related to joint monitoring practice and measures that could be implemented to facilitate this.

These five protocols are identified below, with further information to be found at (Natural England 2013).

- Improve information exchange on monitoring activity
- Improve information exchange on existing data
- Enhance guidance and standardisation on monitoring and data processing/handling
- Draw on existing examples of site monitoring and data collection
- Focus on strategic monitoring and data collection.

This is a serious attempt to improve monitoring and evaluation by providing a protocol for integrated monitoring and data collection to provide both efficiencies and economies of scale, whilst ensuring that integrated management is a more viable goal due to all parties having access to the same data sets and information to inform decision making.

7.4 Stakeholder communication

As shown earlier (Section 5.2 and 5.4), estuaries are subject to many often competing and conflicting uses and users. While high level management needs are the same across most north-west European estuaries, namely 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. Therefore management needs to reflect this and should be targeted to estuary specific and local issues within one estuary.

In particular – and most obviously, the need for conservation protection arising from (inter)national legislation as well as from the ethical conviction of (some parts of) the society raises several management conflicts with other uses, including the ports industry, flood protection requirements and recreational access to the estuary and vice versa. As such, successful implementation of management plans and measures requires an appropriate communication strategy, in order to be accepted by the public and stakeholders (Boyes et al. 2013), or at least providing substantial knowledge to the public and stakeholders, in order to reach their acceptance.

Mechanisms and methodologies are necessary to assist in stakeholder inclusion and conflict resolution as part of a wider integrative management strategy. 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. Doing so, the most successful strategy is searching for a win-win-situation for the involved stakeholders as well as residents by trying to combine ecological restoration with socio-economic growth (RAE newsletter 2011; Van den Abele et al. 2008).

Integrated estuary management covers the full cycle of information collection, planning, decision-making, management and monitoring of implementation. It is important to involve all stakeholders across the different sectors to ensure broad support for the implementation of management strategies.

Additionally to the conflicts with regard to content the way of communicating and handling the process can be a source of conflicts, because very often decisions on the implementation of management measures or development plans made by authorities are perceived as non-transparent, short-term and interest-based by the public (Ratter and Weig 2012 at www.tide-toolbox.eu). Quite often authorities and the public do not seem to speak the same language. Besides a good information flow a common language is essential in building up trust and establishing a high level of cooperation. Often the technical terms used by authority staff and scientists in their everyday work are unknown to ordinary people. Apart from the linguistic challenge of finding a common language, it is also important to understand local problem awareness. Acceptance and active support of decisions made by authorities is probably easier to come by if residents understand how compromises were reached and what alternatives were abandoned for which reasons. From a questionnaire conducted at the Elbe estuary (Ratter and Weig 2012) it appeared that it is useful to raise public awareness of the region and the challenges it is faced with now and in the future in order to actively involve the public in regional planning and management processes. Therefore it might be necessary to educate people – at least to a certain level. Furthermore, as estuaries cover a broad area they cannot be seen as a uniform region, as for example its rural and urban parts can differ in manifold ways. Therefore is helpful to be aware of differences in the local perception (Ratter and Weig 2012). Stronger regional identity in both rural and urban parts of the region could reinforce people's intrinsic motivation for becoming involved, as other studies and literature show (Ratter and Weig 2012).

Therefore an appropriate communication strategy should include:

- Indicating the technical basis for any decisions (but doing that in ways that are suitable for non-technical audiences);
- Involving the concerned parties as early as possible;
- Considering regional and cultural differences;
- Increasing awareness of existing conflicts between various uses;
- Finding synergies;
- Adapting the communication and its language to the targeted audience and the media used.

In the following sections two examples of good practise will be presented, one example for estuarine wide and crossborder communication and another for communication on a smaller scale.

7.4.1 Scheldt Estuary (The Netherlands and Belgium)

An extensive communication program has formed an important part in the process of setting up the ´Long Term Vision for the Scheldt estuary´ (LTV) and the 'Scheldt Esturay Development Outline 2010'. Flanders and the Netherlands consulted various parties, including the involved governments, official bodies and interested parties. They joined to form the 'Consultative Committee of Advisory Parties (OAP)'. On significant occasions, the OAP issued independent advice on individual topics before decisions were taken. The OAP also issued a unanimous recommendation in favour of the draft 'Scheldt Estuary Development Outline 2010'. The earler mentioned project organisation ProSes held several public hearings, e.g. regarding the results of the strategic environmental impact report, the social cost/benefit analysis and the draft version of the 'Scheldt Estuary Development Outline 2010'. The results were explained in informational meetings. The responses from the public hearings were compiled and published, and they were used in formulating the final version of the 'Scheldt Estuary Development Outline 2010'. During the preparation of the 'Scheldt Estuary Development Outline 2010', interested parties made contributions during working meetings and in other manners. Such contributions could take the form of 'joint conceptualisation', 'joint knowledge', or 'joint participation'. Interested parties were regularly informed of the state of affairs via brochures, newsletters and the website, among other means.

7.4.2 Kreetsand/Spadenlander Busch (Elbe Estuary, Germany)

The Hamburg Port Authority (HPA) and the Federal Waterways and Shipping Administration (WSV) set up a new approach to sustainably develop the Elbe estuary ("River Engineering and Sediment Management Concept for the Tidal River Elbe" and the "Tidal River Elbe Concept"). In order to reduce the upstream sediment transport and to decrease tidal energy tidal shallow water areas should be created which are suited to moderate the tidal action. The area ´Spadenlander Busch / Kreetsand´ which is located upstream of the city of Hamburg was chosen as a first project to be implemented (see also www.tide-toolbox.eu, management database). The area outside the dyke is being transformed as a tidal shallow water area in order to meet the overall objective of dissipating tidal energy and to create valuable nature area being suited as a habitat for diverse fish and bird species and the protected endemic plant Elbe waterdropwort (*Oenanthe conioides*). Hence the project anticipated a ´win-win´ situation for nature and river engineering aspects.

In order to get most possible acceptance of the project amongst the stakeholders e.g. nature protection groups as well as the residents, the communication concept included a transparent and as early as possible dialog with all interested parties and the locals in order to involve them already in the planning process and to inform them on the project´s overall background. Therefore the following points have been considered:

- Presentation of the overall management targets and potential synergies with nature conservation and flood protection to the residents.
- Explanation of general reasoning of the plan and in particular the chances for local recreation.
- Presentation of all planning steps, design of the new area, and the results of the assessment of alternative designs and subsequent discussion BEFORE the start of the planning approval procedure.
- Explanation of overall project details and design to the NGO's and request for their approval - BEFORE they had to be consulted anyway - which is normally unusual in actual planning approval processes.

During the whole process the choice of an understandable language, i.e. the avoidance of technical terms in all forms of communication such as information events, newsletters or individual mail, appeared to be very important. For obtaining acceptance it was useful to explain the choices made. The presentation of potential conflicts and subsequent mediated discussion between conflicting parties and development of potential solutions was also helpful.

Additionally a hut, the so-called ´Deichbude´, has been built on the dyke at the start of the construction works. The hut should provide a place to people passing by for observing the construction works, but it also provides an exhibition which explains the philosophy of the "Tidal Elbe Concept" and gives further information about related subjects such as flood control and the surrounding marshland.

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8 Conclusions, Recommendations and Tools for Management

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8.1 Recommendations for managing the functioning of the estuaries and delivering Ecosystem services

8.1.1 Basic considerations

In the introduction we described that the big challenge of estuarine management is to maintain and protect existing estuarine natural structure and functions, to rectify historical damage and the negative impacts of human actions which led to socio-economic problems (inundation, siltation and eutrophication) and to guarantee at the same time future economic development. At the same time it is widely accepted by scientists as well as those tasked with making and implementing estuarine policy that the only way to overcome the challenge is to apply a multidisciplinary and functional, holistic approach. Although it does not apply to transitional water bodies such as estuaries, this thinking is exemplified by the European Marine Strategy Framework Directive (2008/56/EC) which is based on the idea of an ecosystem based approach clearly demonstrates that for example European nature protection policy has evolved from the application of a deconstructing, structural management approach to a functional, holistic approach (Borja et al. 2010). This new way of thinking acknowledges the functioning of the marine and estuarine system as a whole, although different zones exist which have different functions, ecology and anthropogenic uses, some of which cannot be properly managed by sectoral and occasionally spatially constrained plans. The main management deficiencies lie in the co-ordination and integration of the different management approaches which are often not well co-ordinated or unknown or unavailable to stakeholders. This general situation is also true for estuaries.

8.1.2 Contribution to the 10-tenets of successful and sustainable estuarine management

Elliott (2013) suggested that in order to deliver successful and sustainable marine management, i.e. the implementation of the Ecosystem Approach, an interlinked set of tenets is required. In the following section we will demonstrate how the application of our research approach within TIDE addresses this *10 tenets* approach. We also provide considerations and recommendations related to each of the single tenets, where appropriate.

As mentioned earlier in text, it is widely acknowledged that a functional, holistic approach is the most appropriate way to deliver successful management of complex ecosystems such as estuaries. This is not only important for societal/ethical reasons which require the assurance that current uses will still deliver a healthy natural system for future generations, but also because it will eventually reduce management costs and increase benefits for the current society by the avoidance of unnecessary conflicts between different interests (tenets: economically viable and ethically defensible, i.e. morally correct). We have applied the Concept of Ecosystem Services as a strategy for the integrated management of estuaries as it promotes conservation and sustainable use in an equitable way. Furthermore, it recognises that humans are an integral component of ecosystems, leading to the provision of benefits for ecology, economy and society. Applying the Ecosystem Services Approach requires us to identify societal benefits being delivered by ecosystem services, and the TIDE project has demonstrated how and which ecosystem services are delivered within spatially variable estuaries, among habitats and between the different case estuaries (Chapter 4).

A precondition of this approach is a detailed understanding of the system functioning in relation to both natural and anthropogenic features, as well as its translation to actions by the responsible estuarine policy-makers and implementers. In addition, 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 are necessary. We have contributed to the understanding of estuarine processes, structures and functions (tenet: ecologically sustainable) as a basis for the delivery of ecosystem services by using appropriate techniques for comparing the four case estuaries, such as detailed data analyses, different modelling techniques (Chapter 2 and 3), and the use of matrices for e.g. the analysis of conflicts between estuarine users (Chapter 5) (tenet: technologically feasible). We have also used the existing knowledge of regional working groups and tested new approaches e.g. for assessing the efficacy of management measures. In doing so, we have considered interactions between morphology, hydrology, ecology and human uses and users and demonstrated that although having basic structures and processes in common, each estuary has unique functional characteristics.

Based on our analyses of the case study estuaries, i.e. water quality parameters and the occurrence of waterbirds, we have highlighted the fact that the connectivity of estuarine systems, both with adjacent areas and with a network of habitats at a larger spatial scale, is of major importance in ensuring that the estuarine functions are fulfilled (Elliott and Whitfield 2011). Estuarine ecosystems do not only provide local processes but also sustain biodiversity at a wider scale, e.g. via the net export of energy (as faunal biomass) to other ecosystems (Carleton Ray 2005), or the input from the catchment and transport of nutrients or pollutants to the sea. This is an important element in the management of these systems both for compliance with EU directives (tenet: legally permissible), but also for wider estuarine health and function.

As mentioned earlier, estuaries are not only exposed to internal (endogenic) pressures of which the causes and consequences of change can be managed, such as the installation of a power plant or river engineering works which can be managed by design and licensing, but they are also exposed to unmanaged exogenic pressures e.g. climate change or sea level rise which we cannot control on a local scale but whose consequences have to be addressed by management, for example by constructing higher dykes (Figure 8.1). It is therefore recommended that before setting up a management plan, the origin of a certain pressure needs to be identified in order to decide whether or not its cause can be controlled or whether only other management measures can be employed to mitigate the issue and address the consequences (Elliott 2011). The DPSIR approach (Atkins et al. 2011, and Section 1.4.3) delivers a framework for assessing the causes, consequences and responses to changes in a holistic way. It includes societal demands (D), which in turn create physico-chemical pressures (P), which in turn cause physico-chemical and biological state changes (S), which can then create socioeconomic impacts (I), leading to the requirement for management responses (R).

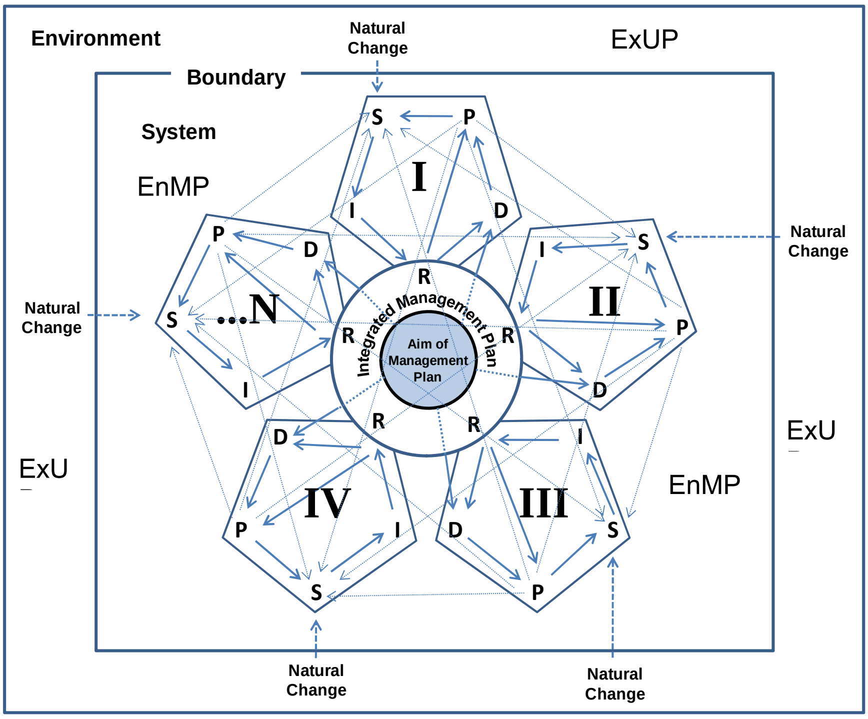

Figure 8.1. DPSIR Approach showing DPSIR cycles for each sector (Endogenic Managed Pressures) within a boundary for management and subject to Exogenic Unmanaged Pressures from outside

In addition, the concept of connectivity is fundamental to the functioning of estuaries (Basset et al. 2013) and also plays a role in both the identification of potential user conflict scenarios but also in the identification of suitable and effective mitigation and compensation measures. Hence the DPSIR framework for the estuary has to be assessed in view of the inter-linkages between the estuary and the adjacent coastal and marine areas, the river and lake system in its catchment (Figure 7.2).

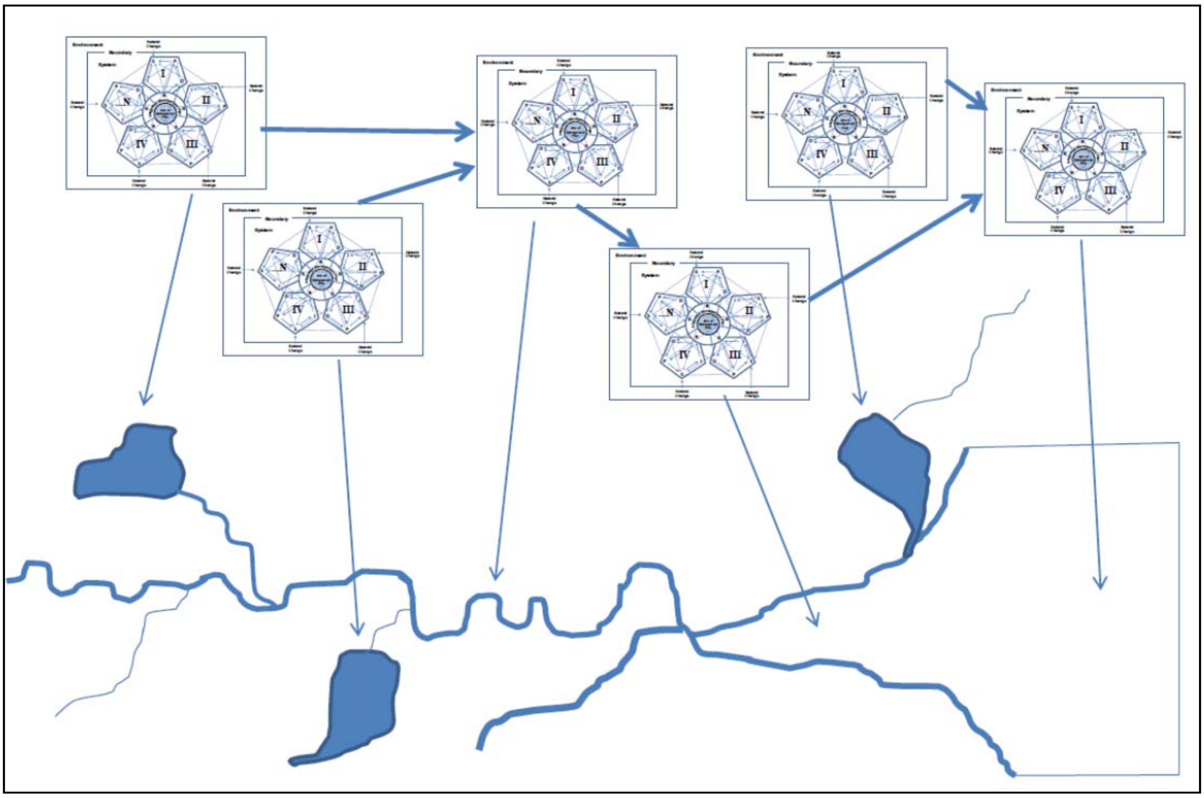

Figure 8.2. Linking nested DPSIRs across aquatic systems (freshwater, estuarine, coastal and marine) (after Atkins et al. 2011)

For the assessment of management measures being carried out in the four case estuaries, the Ecosystem Services Approach has been applied as one criterion (Section 4.2, Chapter 6). By applying this approach it has been possible to demonstrate that, for example, managed realignment measures often (in addition to their main goal to create, restore or conserve estuarine habitats) have positive impacts on several ecosystem services, for example on those related to recreation or flood protection which can improve their acceptance by the wider stakeholder audience (tenet: effectively communicable). A 10-step approach (Liekens et al. 2013 at www.tide-toolbox.eu) has been developed to evaluate the impact of a particular potential management measure and how to use the results in the decision making process for the application of a broad management approach. Based on the collected data (the surface area involved, habitat types, recreational users, bio-physical data and monetary data per service), the impact of the management measure on the different estuarine services can be calculated both in bio-physical and in monetary terms through the use of literature-based data (Section 4.5 and 4.6).

However, for many services it is not easy to determine a specific value or importance. As Maris and Bechet (2010) point out, values are contextual, relative to a certain place, a certain time, and a certain view of people to whom e.g. a particular landscape, is very valuable. However, when it comes to making choices, very often an economic approach may be requested by the decision makers and stakeholders. The concept of valuation which is thus more anthropocentric in nature, can be considered as a promising approach to highlight the relevance of ecosystem services to society and the economy. Furthermore it may serve as an element in the development of cost-effective policy instruments for the restoration and management of natural systems and for use in impact assessments in cost-benefit analysis. Economic valuation usually attempts to measure something in monetary terms, in order to provide a common metric. However, related to the valuation of ecosystem services it does not mean that only monetary costs, or only services that generate monetary benefits, are taken into consideration (Costanza and Folke 1997; Liekens et al. 2013). Not all benefits provided by the services are fully translatable into economic terms, e.g. some ecological values such as the value of one species to the survival of another species. At the time of writing, robust valuation methods are still under development and much more research is needed. However, the application of the Ecosystem Services Concept is considered to be of value, at least in the visualisation and demonstration of the sustainability and fairness of management issues/problems, and this is often sufficient to inform and improve current resource management policies. Despite this, we emphasise the anthropocentric nature of the Ecosystem Services and Societal Benefits approach (Atkins et al. 2011) and that we also require to consider the intrinsic nature conservation aspects of the estuaries.

The evaluation of the development of single services, the success of management measures, as well as any management strategy, depends on whether its outcome is monitored appropriately, i.e. the right amount of assessment of the right parameters at the right location. There are different types of monitoring: condition monitoring to determine the present status or the overall health of the system, e.g. whether or not the ecology is in Good Ecological Status as required by the respective European Directive (tenet: legally permissible), surveillance monitoring (´look-see´ approach without defined purpose), or – most common – compliance or operational monitoring, e.g. to ensure a navigational route remains open or that industries comply with licences to operate in an environmentally safe manner (Elliott 2011). In times of financial constraint, it is important that monitoring programmes are cost-effective, i.e. focus on what do we ´need to know´ instead of what is ´nice to know´, whilst remaining fit-for-purpose (Borja and Elliott 2013). The latter includes the consideration that the chosen indicators should be ecologically relevant, but also be understandable and interpretable by non-scientists, and reflect the changes against the system´s natural variability. It means that we require sufficient data which should be integrated so that they not only allow the evaluation of a management strategy or operational objective, but provide a true understanding of the functioning and development of the whole system (tenet: technologically feasible). Finally all data should be maintained in a common and widely-available database in order to avoid unnecessary costs and duplication of work (tenet: economically viable). A comprehensive overview of required properties of indicators and monitoring parameters is given by Elliott (2011). Within TIDE we have shown that while there are many monitoring schemes in all estuaries, these are usually not co-ordinated across different federal states, agencies, researchers or industries or for the places or ecological and physico-chemical attributes being monitored (Section 7.1). For example, for the Elbe it is a challenge to coordinate responsibilities and interests of the various responsible institutions of several federal states (tenet: administratively achievable). Thus the communication or data supply/exchange is probably not always functioning as it should. Furthermore, if certain parameters such as suspended matter, which is an especially important parameter for interpreting sediment transport, turbidity, primary production, sedimentation, erosion and water quality – as shown for the Humber - are monitored differently in different estuaries, a comparison and exchange of knowledge becomes even more difficult. Therefore, we propose a standard monitoring approach that can be used to cover all purposes with detailed, fully described methods: the Pyramid approach (Section 7.1). 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 (tenet: economically viable**)**. Furthermore, this example shows that monitoring results can improve communication and decision-making criteria through a limited set of communication indicators which are built up in a pyramid approach (tenet: effectively communicable).

Finally we conclude that future monitoring within estuaries should be more integrated and collaborative to ensure that all parties involved in estuary management have access to the best data and that the methods are fit-for-purpose. This has been one of the drivers in the GIP Seine Aval programme (see http://seine-aval.crihan.fr/web/), and Natural England in the UK has recently undertaken a piece of work looking into the potential for statutory conservation bodies and industry for joined up data collection and monitoring (Natural England 2013). This latter piece of work aimed to identify opportunities for closer collaboration between the Statutory Nature Conservation Bodies, Marine Regulators, and industry undertaking licensable activities in areas where joint monitoring of Marine Protection Areas could be of mutual benefit in English Waters.

It is evident in heavily used systems such as estuaries, that multiple conflicts between different users occur and that the implementation of a management measure or an intervention relating to economic development, even if it seems very reasonable, can fail or be delayed because it will interfere with other user interests. North-west European estuaries are multi-user environments, and they require an appropriate management approach to ensure the best and most equitable use of resources amongst the variety of legitimate stakeholders. However, whilst many high level management needs are generic across these estuaries, there are clear differences in priorities for specific management actions (tenet: socially desirable/tolerable), and these will vary both between estuaries and, as the usage potential is not uniform, also along an individual estuarine system (Chapter 5). This means that for key sectoral interactions between users, there may often be several spatial hot-spots, whilst sector interactions will develop in different areas. As such, a uniform management approach may not be the most effective use of resources and needs to reflect spatial and sectoral interaction variability and with management initiatives thus often requiring a quite specific spatial focus.

The TIDE project has developed a typology of estuarine user interaction conflicts and synergisms and this provides a generic priority list of management topics for estuaries, as well as indicating areas where beneficial outcomes may occur. Estuary-specific surveys which identify stakeholder issues (Chapter 5) are therefore considered a valuable tool to confirm key areas of conflict, and incorporate local variations in both spatial and sectoral severity. They also have the potential to identify areas where wider public participation and education may assist the integration process. Such methods, i.e. the ´Conflict Matrix Approach´ can include aspects of the Ecosystem Services Approach which allows a value-based comparison of differing services (and thus uses), including those with no readily evident economic value such as aspects of nature conservation, heritage and landscape. Furthermore, the application of the Ecosystem Services and Conflict Analysis Approaches employed here have the potential to be combined to assist in effective management, particularly when used in combination with targeted measures.

Due to the dynamic nature of estuaries, an adaptive management approach is needed which accommodates natural development and anthropogenic demands and changes. We emphasise that any management which cannot accommodate such changes will eventually either be costly or even unsuccessful. An adaptive strategy also requires the implementation of a long-term stakeholder forum through which management results are assessed and any follow-up mechanism implemented e.g. a combination of competent public bodies (tenet: socially desirable/tolerable) that is authorised to implement changes to a programme of mitigation or compensation and to take additional (usually pre-determined) compensatory measures on the basis of the results of monitoring programmes (flexible approach). Therefore with the agreement of stakeholders but against a background of fitting within legal and economic (business) constraints, developers can achieve sustainable management actions. In order to achieve this, financial warranties or other similar financial safeguards should be put in place that can guarantee long-term implementation and protection even after a developer has completed the development and moved away from the area. The specific conditions requiring such an adaptive strategy could be accompanied by one or more separate legal agreements committing an applicant to take corrective measures, following certain timescales or in the event that mitigation and/or compensation measures do not meet the objectives set, stop the project (tenet: politically expedient; administratively achievable).Furthermore, all parties are required to consider the timescale of compensation schemes which may be required for many years.

Evidence from the Elbe, Humber, Scheldt and Weser shows that the development of integrated management plans requires the investment of time, resources and the participation of a large number of stakeholders (Section 5.3) if a successful outcome is to be achieved. Successful integrated management plans must be able to bridge the apparent gaps between the different groups with disparate interests and seek to identify synergies between the natural environment and socio-economic requirements (tenet: socially desirable/tolerable). It is not always necessary for integrated management plans to have a legal basis, as non-statutory plans can also deliver successful outcomes, but it is necessary to minimise overlap between plans to avoid conflicts. One example of this is the move from a stand-alone Humber Estuary Shoreline Management Plan (Environment Agency 2000) to its incorporation into the Humber Flood Risk Management Strategy developed in 2007 (Environment Agency 2008).

Additionally we emphasise that estuarine management and resulting management plans should be preferably based on, or related to, the ´working with Nature´ concept as presented by the PIANC organisation (http://www.pianc.org/workingwithnature.php) or as introduced by the Dutch Delta commission (2008). Experience, e.g. from the Scheldt, shows that planning should be based on an analysis of conflicts, benefits and co-benefits leading to the development of potential synergies and a better understanding of the main conflicts, as well as how aspects of regional variability might affect the chances of success (tenets: culturally inclusive; socially tolerable/desirable; ethically defensible). Furthermore the use of conditions on development permits, especially for remedial actions, could be a solution for dealing with scientific uncertainty.

8.1.3 Good examples

The comparison of a range of relevant data, issues and measures from the case study estuaries has identified clear differences in estuary management needs, and thus it is emphasised that estuary-specific management strategies and the implementation of specific measures are necessary. This management approach not only has to be considered at an individual estuary level, but management practice within each estuary has to be adapted to a series of changing boundary conditions e.g. requirements based on changes to environmental legislation, natural and anthropogenic hydrogeomorphological change, developments in public opinion or the current financial situation.

Given that all EU Directives aim to achieve economic development while protecting the natural system, it is recommended that the adoption of a management plan based around all the relevant EU Directives but especially the Natura 2000 EU legislation requirements, i.e. the inclusion of an estuary within the Natura 2000 network, which recognises the demands of society as well as ecological aspects, will help to deliver a holistic management approach in order to achieve the most sustainable management outcome and to avoid conflicts between different uses. In the meantime integrated management plans of several estuaries are available, e.g. for the German estuaries Elbe (Arbeitsgruppe Elbeästuar 2012) and Weser (NLWKN and SUBV (2012).

It is of note that around 15 years ago the Scheldt estuary identified that the co-operation between interdisciplinary research, governmental institutions and involved stakeholders could lead to a successful and sustainable estuarine management approach, achieving the goals of ´nature conservation, safety against flooding, accessibility of the port´ (Long term vision Scheldt estuary, 2001) and thus a ´triple win´ situation for ecology, economy and society. This plan also includes an adaptive management strategy. Governmental institutions and scientists have developed a new approach of disposing dredged material on tidal shallows which could have positive effects on Natura 2000 goals (Section 7.2). The effects of applying this approach have been intensely monitored in order to learn from its outcomes and adapt the strategy if necessary.

Another example is the extension of the port of Le Havre in the Seine, known as Port 2000, which led to the establishment of a management plan which aimed at favouring economic diversification (port development, logistics, fishing activities and tourism promotion) as well as the conservation and restoration of the natural functioning of the estuary (Ducrotoy 2010). The port construction was used by managers and politicians as an opportunity to emphasise the importance of research as well as the balance of the development of economic objectives and the protection of the natural environment which eventually led towards the implementation of integrated estuarine management.

8.1.4 An integrated framework for managing estuaries

The aspects considered and detailed here can be combined into a holistic, adaptive marine and estuarine management framework (Figure 8.3). This shows that while addressing the exogenic unmanaged and endogenic managed pressures, we are required to accommodate the vertical integration of agreements and legislation across geopolitical levels that range from the global to the local. These include the implementation of European Directives and the enabling local agreements required by these Directives. The approach has to accommodate all the stakeholders ranging for those who wish to place materials into the estuarine system (such as dredged material, cooling water, infrastructure, etc) and extract materials and space from the system (such as again cooling water, aggregates, fish and shellfish), those who regulate these activities (the administrative bodies) and those affected by these activities (society and other users). The system in turn has to include those who can influence the outcomes, such as the policy-makers and the NGOs and of course those benefitting from the uses and users of the system.

The management of this system is then included within the DPSIR framework which includes the 10-tenets, conflict resolution, the polluter pays principle (PPP) and the precautionary principle (PP), Environmental Impact Assessments (EIA) and the associated Appropriate Assessments. It also includes tools such as Cost Benefit Analysis (CBA), Multi-Criteria Analysis (MCA) and Local Policy Impacts (LPI) and Environmental Integrative Indicators (EII). This integrated management system then aims to protect the natural structure and functioning and fundamental processes while producing the ecosystem services and societal benefits required by society (*sensu stricto* the Ecosystem Approach).

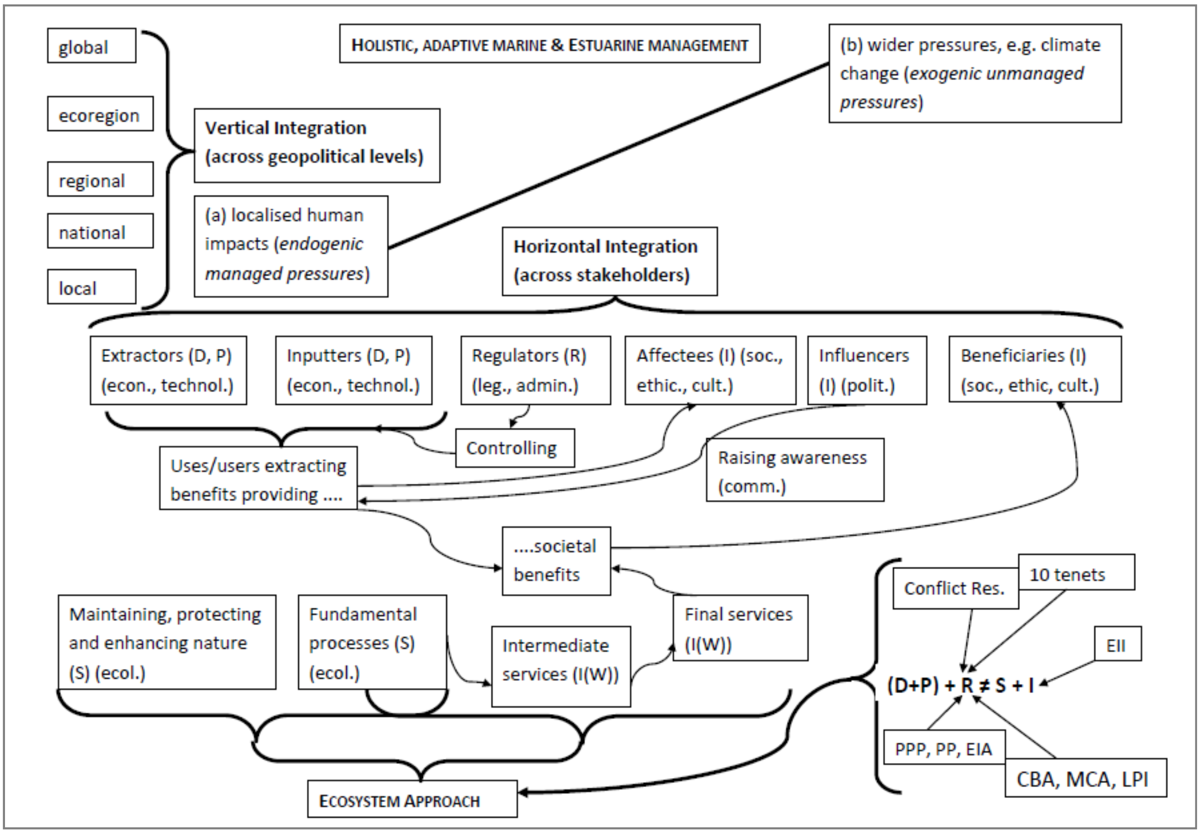

Figure 8.3. An adaptive, holistic marine and estuarine management framework which encompasses the concepts present here (Elliott, unpublished; see text for abbreviations and explanation)

8.2 A toolbox for sustainable and effective integrated management of estuaries

The wide range of aspects and interests of estuarine management may lead to different ways of approaching the challenges of estuarine management and may require one or more particular tools to be used. Much valuable information related to the application of integrated estuarine management has become available in recent years from a variety of media, e.g. books (McLusky & Elliott 2004), articles (Elliott 2011, Van Buuren et al. 2008), newsletters (http://www.eucc-d.de/) and websites (http://www.natura2000exchange.eu/, http://www.vnsc.eu/, http://www.estuary-guide.net/).

As part of the TIDE project, we take the view that the ´TIDE toolbox´ (www.tide-toolbox.eu) augments this established body of information. The toolbox (Figure 8.4) presents the outcomes of the EU INTERREG IV B project TIDE (Tidal River Development), which cover broad aspects of estuarine functioning, governance and management measures and are, amongst others, meant to support estuarine managers in their work. In particular, the TIDE project provides a series of tools that are considered necessary and of value to assist in the development of the integrated management process in estuaries.

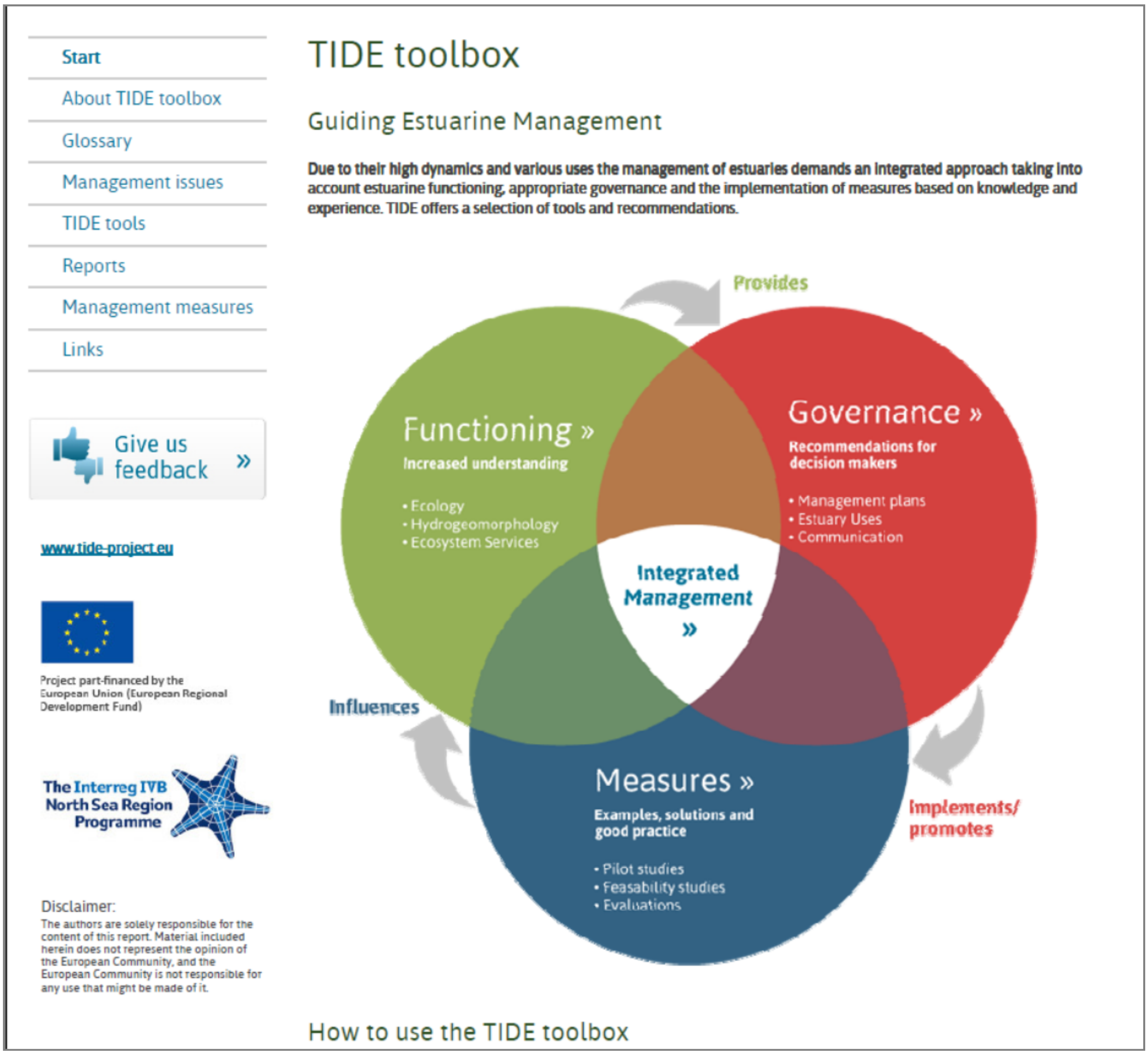

Figure 8.4. Screenshot of toolbox website

The website provides useful and interesting information for a broad range of stakeholders, e.g. managers; policy makers and implementers; as well as estuarine users, residents, students, communication personnel, and other interested parties. The toolbox user is able not only to find information on the historical evolution of the four case estuaries, their functioning and the delivery of ecosystem services, but also practical tools to assist in aspects of estuary management (Fig. 8.5). For instance, the toolbox contains a smartphone app that provides a tool to assess the severity of waterbird disturbance from a development along with potential mitigation measures as well as templates which can be downloaded to assist managers in their daily work.

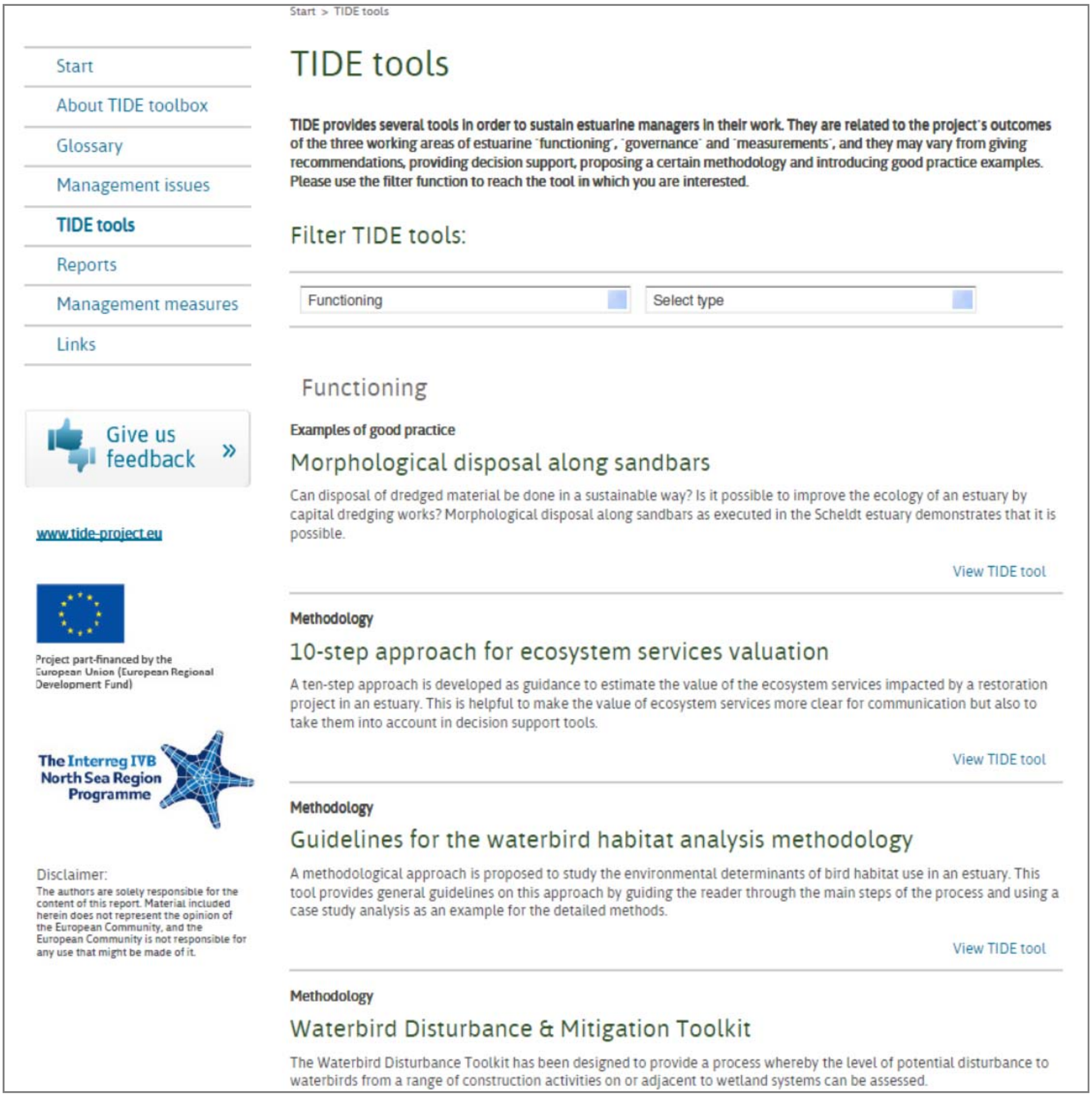

Figure 8.5. Example of tools presented in the TIDE toolbox

Further experiences and recommendations relating to the implementation of management plans and measures are presented, together with a range of assessment methodologies covering topics such as hydrogeomorphology and the analysis of estuarine user conflicts. The user can also find examples of good practice in the communication and implementation of management measures, whilst in order to gain a better understanding of the initial requirements when setting up an integrated management plan or carrying out an environmental assessment study, it is recommended that the planning support scheme is looked at. This area of the toolbox also contains the instructions for performing an Environmental Impact Assessment and an Estuarine Planning Support System (EPSS) framework to assist plan development.

Estuary managers will have differing management needs based on their sectoral focus, differing levels of knowledge, and different ways of approaching a challenge and as such may be interested in only one particular or a combination of TIDE management products. As such, the toolbox provides several ways to access the diverse products in an easy way. As the estuarine system is very complex, diverse aspects of one issue or one research question have to be taken into account by a manager, or the issue has to be approached by several ways in order to implement integrated estuarine management. The toolbox allows for this by presenting related links, for example one keyword or management issue which may guide the user to several inter-connected reports, tools or links.

The user is able to navigate to a desired report of interest by searching via a keyword, a management issue or a measure, or immediately go to the list of associated tools. Those reading a report summary may become interested in learning more on a topic and subsequently can interrogate the subject through accessing one or more reports. Within the toolbox website it is possible to scroll down in a document and enlarge graphs and tables, however the products can also be downloaded as pdf documents for subsequent use or output. Of course this summary report can also be found within the toolbox.

Although TIDE focuses on the Ecosystem Approach and the application of integrated estuarine management as the most appropriate way of delivering sustainable estuarine management, within the toolbox different TIDE products are related to the main chapter's ´Functioning´, Governance´ and ´Measures´ in order to provide a better overview of the wider topic.

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