# River Engineering and sediment management concept for the tidal Elbe river

## Sediment relocation and river engineering measures of the RESMC seen from an estuary ecology perspective

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# Contents

# Summary

This report gives an assessment of the River engineering and sediment management plan for the Elbe estuary (HPA & WSV, 2008).

This assessment is made from the point of view of the ecological functioning of the estuarine system and does NOT take into account any aspect of legislation. It is not unlikely that some measures, although beneficial for the ecological functioning of the river, might be difficult to implement due to environmental legislation.

This assessment is based on the documents made available by HPA and WSV (see references) and other reports and publications found in the scientific literature and the internet. Although a lot of information is available on some aspects of the system (mainly dredging related) it is remarkable that very little information on the ecological aspects of the Elbe are present. Water quality data are available from the FGG Elbe site but other ecological information is very difficult to find and seems not to exists in a comprehensive way. This is a serious drawback for this evaluation. Another drawback is the very limited information on most of the proposed measures. The success of a measure will largely depend on the design of the project. As long as this information is not available, it is not possible to give a correct assessment of the measure. Therefore the overall approach is evaluated.

The ecological functioning can be subdivided into 3 main series of processes:

1. Maintenance of geomorphological processes
2. Maintenance of biogeochemical processes
3. Maintenance of ecological processes

These will be the major criteria used for evaluating the present situation and the proposed measured: how much do they contribute to the maintenance of these processes.

To make an evaluation, we must have a reference against which we have to refer to. As both historical and geographical references are not very useful it is argued that an approach based on ecosystem services (see TEEB, www.teebweb.org ) might be very helpful. Although there is no quantitative reference against which we can assess the present situation, the delivery of services and the human benefits related to this can be used as a reference. So measures or impacts that have negative influence on the production of fish populations, on the dissipation of tidal energy, on the possible volume of flood water that can be stored etc. will be assessed as negative.

## Assessment of the situation up to approx. 2005 (“initial situation”):

- ***What is the assessment of the influence exerted by past expansion, river engineering and dredging strategy on the present-day situation regarding estuary***

It is clear that the changing hydrodynamics (increasing tidal amplitude, increasing tidal asymmetry) in combination with the historical loss of habitat (due to different reasons) and possibly changes in sediment loads had a very important impact on the geomorphological development of the estuary and it is unlikely that tidal habitats, especially tidal marshes and flats, can be sustained without human interventions (like revetments), at least in a significant part of the estuary. This indicates that the **maintenance of geomorphological processes** is seriously hampered and human intervention is needed to maintain the structure of the habitats. This changes in hydrodynamics and geomorphological processes can also have an impact on the ecological quality of the marshes as evaluated by the vegetation communities. Information on other biota is lacking.

Also for the **maintenance of the biogeochemical processes** there seems to be still major problems. Oxygen patterns, certainly in the neighborhood of Hamburg harbor are a problem. Although the reasons for this oxygen sack in summer are still not really understood we believe, based on a detailed analysis of the data, that it is very likely that the problems are due to local phenomena within the estuary, rather than to the import from upstream. There are indications that local resuspension might be very important. This should be studied in more detail. The primary production in the Elbe is also rather low what could be attributed to an unfavorable Zm/Zp ratio (average mixing depth/photic depth) due to higher turbidity values and a high average depth. In overall conclusion, we can say that the ecological functioning of the system is certainly hampered and it is more than likely this is to a large extend due to the different measures taken in the past. As average depth, resuspension, current patterns and concentrations of suspended solids are all influenced by measures in the RESMC, the impact of the measures on ecological functioning should be studied and evaluated in detail.

**The maintenance of biodiversity and other important ecological processes** such as the food web, transfer of matter to higher trophic levels etc. is difficult to assess as information is too scattered, absent or not available at this stage.

It is clear that past measures have had a strong impact on ecological functioning. The geomorphology and hydrodynamics are not in equilibrium and further developments of the tidal amplitude towards even more tidal asymmetry and/or increase of tidal amplitude would be very negative for the system. The ecological functioning is also impacted but overall it is clear that still a lot of open questions exists. Especially understanding of how the system will further develop and whether or not some thresholds are reached leading the system to another state of the system is crucial.

## Assessment of the situation as of 2005 and with further implementation of the RESMC:

- ***What is the assessment of the objective "reducing tidal pumping" as a sediment management strategy from an estuary ecology perspective?***

Although tidal pumping is a natural phenomena, past river engineering measures have strongly increased tidal asymmetry and hence tidal pumping. As this results in a major increase in dredging activities the objective of reducing tidal pumping and hence less maintenance dredging, is seen as a positive and good objective. As will be mentioned later, this should be made more precise, to what degree tidal pumping should be reduced.

- ***What is the assessment of the river engineering measures envisaged for "reducing tidal pumping" from an estuary ecology perspective?***

A detailed assessment of the individual measures is not possible as this must be based on the detailed engineering design of each project as the individual design is crucial to the success. One measure can turn out to be extremely good or bad depending on the design AND the local conditions. Therefore only a general evaluation of the approach and types of measures can be given.

Reducing, or dissipating tidal energy is seen of utmost importance and it is clear that this cannot be achieved by one measure but that it will require a series of measures at very well selected sites along the estuary. All these measures will lead to a change in morphology. Successful measures should fulfill several criteria like, require as less as possible maintenance, trigger further "wanted" morphological developments, such as sedimentation or build up of intertidal areas. "Soft" measures are preferable over hard engineering and measures should be reversible. Indeed, the morphological development of estuaries is still poorly understood and even well designed measures may have unexpected negative consequences. Therefore it should be possible to adapt the measure according to the results and it is clear that adapting hard measures is more difficult. Reducing the cross section of the mouth is a potential measure that could reduce tidal energy. This seems to be a very sensible measure, but if this is realized by a hard structure it is likely to cause important unknown and possibly unwanted consequences. Therefore using a combination of dredged material with as little hard constructions as possible might be preferable. Experience with "morphological dredging" from the Westerschelde might be particularly useful. Dredged material is now used to maintain and/or build morphological structures in a soft way. Also the sand motor, being applied in the Netherlands is a useful concept that should be studied as this might be used in the mouth of the Elbe.

The basic idea of the different measures are sound and a correct implementation might improve the ecological functioning. Reconnecting Elbe branches is likely to be very successful, but as mentioned this will depend on the design. Especially the amount of sedimentation and hence the maintenance will determine the success. The creation of flooding areas is assessed as very positive however there might be a very important conflict between the efficiency for ecological functioning and the efficiency for hydrodynamics. The efficiency of the restoration site from a hydrodynamical point of view, is the bigger, the lesser the area dries out at low tide, however from an ecological point of view the gradient from rarely exposed to rarely flooded areas is important. Also the removal of sediments from tidal areas to increase the flooding frequency is likely to cause ecological problems. Therefore preference should be given to these measures where new intertidal areas are created by replacing dikes more landwards or removing sediments from sides that are not flooded any more. Creating flooding areas by removing sediments in harbor docks is seen as positive as their ecological role is limited. When creating new habitats special attention should be given to their morphological stability.

- ***What is the assessment of the current practice of using water injection in the Lower Elbe from an estuary ecology perspective? Are there comparative studies elsewhere?***

Very little information is available on the environmental impact of water injection dredging. Especially in very fine sediments it could cause some problems as organic matter, nutrients and pollutants could be released from the sediments into the water column. Although this might by less than during normal dredging operations it is advised to carry out some measurements campaigns to be sure the impact is minimal.

- ***What is the assessment of breaking dredging cycles as a priority sediment management strategy from an estuary ecology perspective?***

In general we can conclude that breaking up the sediment cycle is a very positive strategy but care must be taken that it is not just moving the problem from one place to another. In breaking the sediment cycle priority should be given to use natural areas for deposition, such as side branches, and make maximal use of high discharges to move the sediments downstream. When dredging, the disposal strategy should be optimized in a way the dredged material has as much as possible a beneficial use in the sense that the material is used to improve the morphology of the estuary, rather than just getting rid of the sediment. A sediment trap should be only a temporary measure until the whole project is realized.

- ***According to what criteria should relocation sites / disposal sites be selected?***

As already mentioned above, the disposal sites should be selected in such a way that the sediments play a role in the morphological development of the estuary. In doing so, it is important that resuspension of fine sediments is kept to a minimum as there is quite some evidence that resuspension might cause water quality problems. Local negative impacts should be weighed against larger benefits for the whole system. Of course, necessary attention should be paid to the quality of the sediments, but this is outside the scope of this review.

- ***What is the assessment of the removal of sediments from the Elbe estuary (disposal on land and in the North Sea in view of the long-term "solids balance" as well as consideration of the concerns of estuary protection, on the one hand, and those of marine protection, on the other hand?***

Removing the contaminated sediments from the system is a sensible management strategy. Although extremely expensive the processing of sediments in the Metha plant and the land disposal is evaluated as positive. The sea disposal might be a temporary solutions but given the large costs it is clearly unsustainable. The aim should be to keep the dredged sediments within the system. If too much sediment is imported from the catchments, measures should be taken there to reduce the amount of sediments transported to the estuary.

- ***What is the assessment of the practice of sediment trapping for fine material management?***

The present sediment trap near Wedel has seemingly no impact on environmental parameters and hence on ecological functioning. The efficiency as sediment trap is outside the scope of this review. As it allows to concentrate the dredging activities to certain periods (and of course in space) this can be preferable to other dredging activities seen from an ecological point of view. However, I would strongly advice to study the options of installing sediment traps more upstream, both in the river, upstream Geesthacht and in the port area. Several possibilities exist to increase sedimentation in shallow areas. Using old docks in the harbor might be very efficient to capture polluted sediments before they are mixed with the cleaner marine sediments.

## Overall assessment:

- ***Are the objectives of the RESMC formulated in the work order sensible in your opinion, also in view of the situation in other European estuaries?***

Yes, the objectives are very sensible and in agreement with the situation in other estuaries although they need to be formulated much more precise. Although no really new concepts are described, the overall approach is certainly ahead of many other estuaries

- ***Do the measures outlined in the RESMC represent overall the right way to achieve the objectives? Are the aspects of nature conservation, water protection and marine protection given appropriate and equally weighted consideration?***

Yes the measures represent the right way to achieve the objectives although it are by now mainly building blocks. However the objectives are defined very narrow in relation to the dredging/sediment problems. In this respect the aspects of nature conservation, water protection and marine protection are not at all equally weighted. The aspects of nature conservation are just mentioned, there is no link at all to the conservation objectives related to EU-HD and ecological functioning is not really mentioned.

## Recommendations for the further development of the RESMC?

A crucial step is to integrated these RESMC into a broader overall management plan for the estuary. Indeed the measures proposed can have multiple benefits going far beyond the benefits for sediment management. Making these benefits clear might also be very helpful in creating a public acceptance for the plan. The concept of ecosystem services might be very helpful in this regard.

A crucial step is also the formulation of clear and measurable objectives. Now, the objectives are formulated in very broad and general terms like “reduce tidal pumping”, but this is very vague. Integrated objectives, taking into account different objectives is crucial. This would allow to evaluate the multiple benefits from the measures.

The success of the plan will also depend largely on the detailed planning and design of the projects and the right mix of the different projects at the different places within the estuary.

A very detailed an integrated monitoring should be set up. Now already large amounts of data are collected but there seems to be lacking some coordination in the monitoring and there is certainly a need for more integrated reporting of data. The problem of collecting data on birds and benthos is a clear example of this. There is also a clear need for more ecological data from the estuary.

When working out the concept in more detail, enough attention should be paid to the consequences of climate change,  not only the sea level rise, but also the expected changes in discharges and loads from the catchment.

If there is a conflict between objectives with N2000 sites, this should be situated in an overall approach and not on a site by site basis.

# Introduction

The Elbe, as many other estuaries, is impacted since a very long time by many different types of human activities. In recent years, it became clear that next to increased prosperity due to economic development as a result of these measures, some very negative developments occur as well. Increasing tidal amplitude, increased flood risks and increased dredging activities  are obvious signs. The need for a more integrated management strategy safeguarding the economic benefits of the estuary and in the mean time the characteristics of the estuary became prominent. The River Engineering and Sediment Management Concept (RESMC) is a step in that direction.
As part of an international peer review of this concept, this report deals with the impact on the general ecological functioning of the system. It is organized according to the questions formulated by Schuchardt & Beilfuss (2010).

In this report I do not take into account the legislative aspects, it is entirely based on an assessement of the ecological, hydrodynamic and morphological functioning of the estuary as shown in fig. 1.

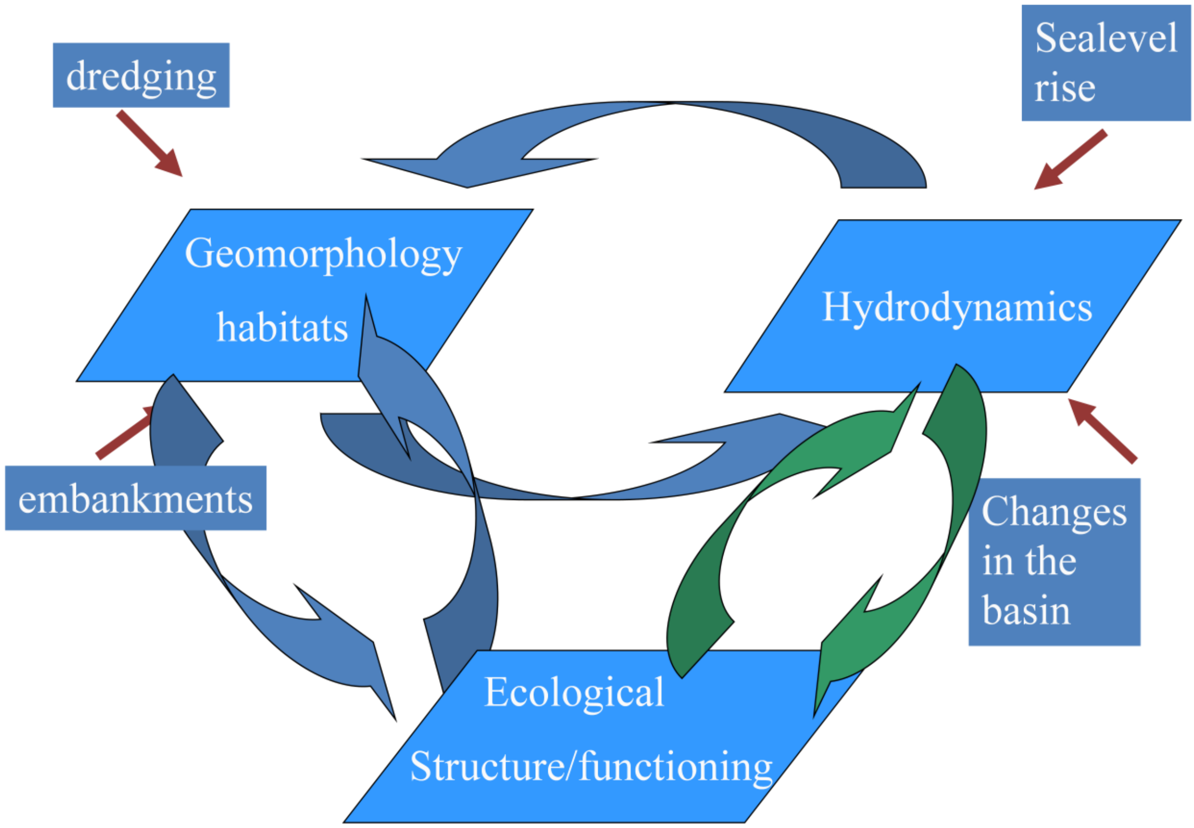


*Figure 1 Interlinkages between hydrodynamics, morphodynamics and ecological functioning.*

It is clear that the overall functioning of the system is not only dependent on local activities such as dredging and embankments, but to a large degree also to external factors such as changes in the catchment and in the coastal sea. Changes in the catchment consists of changes in water quality; this covers the classical pollutants but also nutrients, plankton populations etc. Also the amount of suspended solids reaching the estuary is to a very large degree dependent on the (mis)management in the catchment. However not only what and how much is transported from the catchment to the estuary changed over time, also the discharges themselves changed. In the coastal sea, both major morphological changes can occur impacting currents and sediment transport and changes in sea level. The last one is crucial as the tidal wave is amplified in the estuary and climate change is likely to result in a further significant rise in sea level. The emphasis of this report is on the ecological functioning but as shown this is not independent of other changes. The evaluation of the proposed measures is done against this background and it may well be that what is perceived as a useful measure might be very difficult to implement due to the current environmental legislation.

This review is based on a snapshot of the present situation as is described in the reports made available to us and on additional references found on the internet. A full list of documents used can be found in the reference section. Already here I want to stress that for several aspects of the system the information is scarce or even lacking. Some information could not be collected within the time frame of this review.

# Assessment

The assessment follows the questions given in the document of Schuchardt & Beilfuss (2010).

## 1 Assessment of the situation up to approx. 2005 (“initial situation”):

### 1.1 What is the assessment of the influence exerted by past expansion, river engineering and dredging strategy on the present-day situation regarding estuary ecology?

#### 1.1.1 What measures were taken?

The estuary has been subjected to an enormous amount of small to very large scale measures, such as small scale embankments, management of marshes up to the construction of storm surge barriers at the tributaries, channel deepening and the construction of the harbor of Hamburg and others. As already indicated in the introduction, not only measures within the estuary but also changes in the catchment and the coastal sea impact the estuary. As an estuary is a complex system, see fig. 1, it is not only clear that different measures will impact different parts of the system and their impact can be both antagonistic or synergistic, but also that the timescale on which several processes act must be taken into account.

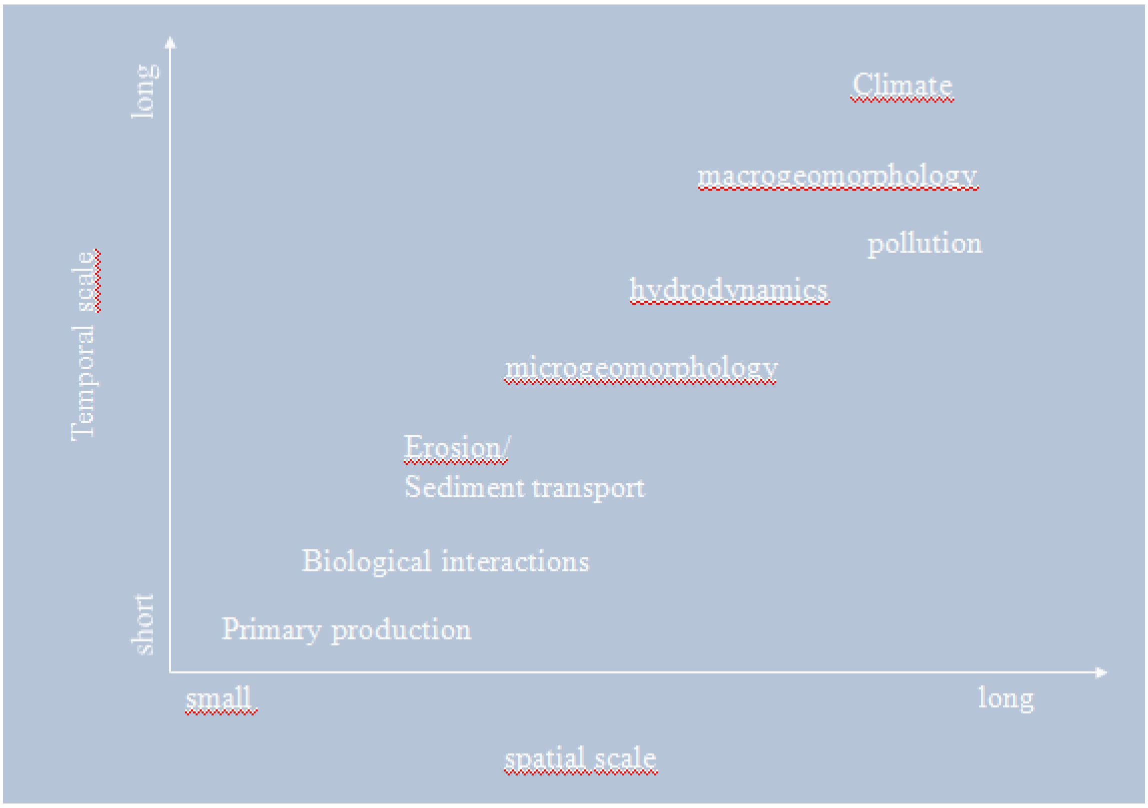


*Figure 2: Overview of how different processes are working on different time and spatial scales*

Processes at small and short scales are impacted by all processes at larger and longer scales, but on the other hand, the large scale processes are as well impacted by the short scale ones. Ultimately, climate change is impacted by the primary production as this is an important sink for carbon dioxide. This means that the system is subject to a continuous change and that the impact of past measures is not necessarily measurable yet or finished. In other words, an estuary is continuously changing and these changes are now not only from natural disturbances or changes, but also from anthropogenic disturbances. Disentangling the impacts of both type of disturbances is then of course an extremely difficult, if not an impossible task! Nevertheless, we must come to an evaluation of the present state of the system. For this evaluation I think two aspects are very important: 1) are some aspects of the system seen as unfavorable with regard to one or another issue and 2) is there a risk that the development of the system can lead to an undesired state. This last point is extremely important in the light of the complex interactions of the many processes at the different time and spatial scales. The reaction on stressors can take different forms (Fig. 3a). The relation between the ecosystem state and the stressors can be rather linear. However, systems having a large resilience can absorb disturbances to a certain degree without a clear reaction. At a given moment a threshold might be reached after which the system collapses or switches to a different state (fig. 3a panel c and d).

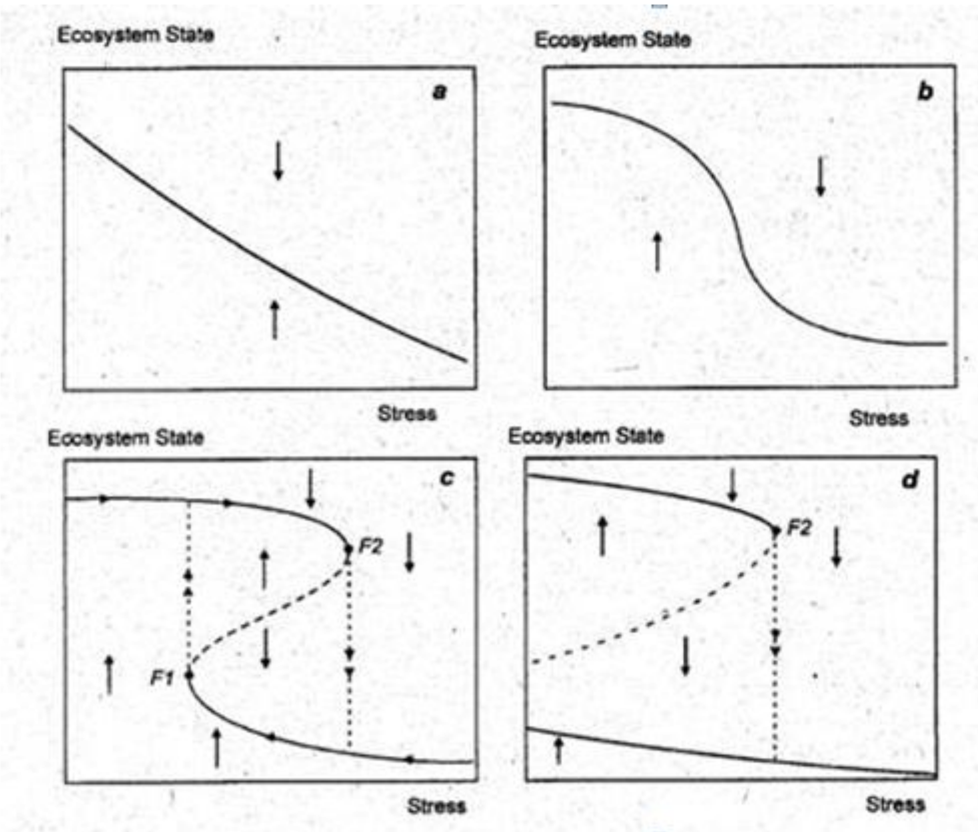

*Figure 3a. Schematic representation of possible responses of ecosystems to stress imposed by human use. The lines represent equilibrium states. The arrows indicate the direction of change when the system is out of equilibrium.*

These figures, although theoretical at this stage are extremely important. First of all, the existence of thresholds or tipping points and multiple stable states in estuarine systems is more and more documented. Secondly, this has tremendous consequences for restoration. If the system has collapsed after reaching a threshold, this means that the stressor must be reduced quite substantially before any real effect is measurable. In the situation of multiple stable states, this even means that the stressor must be reduced to a level much lower than the level where the system switched from state 1 to state 2. Finally, a system can reach a completely new state in which no recovery is possible (panel d in Fig. 3a. These concepts hold for both ecological as well as for geomorphological and hydrodynamic characteristics. The change from an exporting to an importing system, from a heterotrophic to an autotrophic system, from an eroding to an accreting (or vice versa) marsh are just some examples. A regime shift was clearly documented in the Schelde estuary by Cox et al. (2009). Here it was shown that the primary production in the fresh water parts of the estuary increased as nutrients went down, completely opposite to the expectations that primary production is related positively with nutrient concentrations. The ratio between production and consumption changed dramatically and it can be seen that the system is now occurring in a different state. This is explained by the fact that at very low oxygen conditions, phytoplankton production might be hampered. At somewhat higher oxygen concentrations, this inhibition is taken away and plankton can produce at full capacity and supply enough oxygen to the river to compensate for mineralization and nitrification. This regime shift could be applicable to the Elbe to explain the oxygen sack (see further). Another example of a regime shift is the transition from a multichannel system to a one channel system. Infilling of anabranches/side channels by dumping or natural processes can move the system towards a one channel system with fundamentally different morphological features.

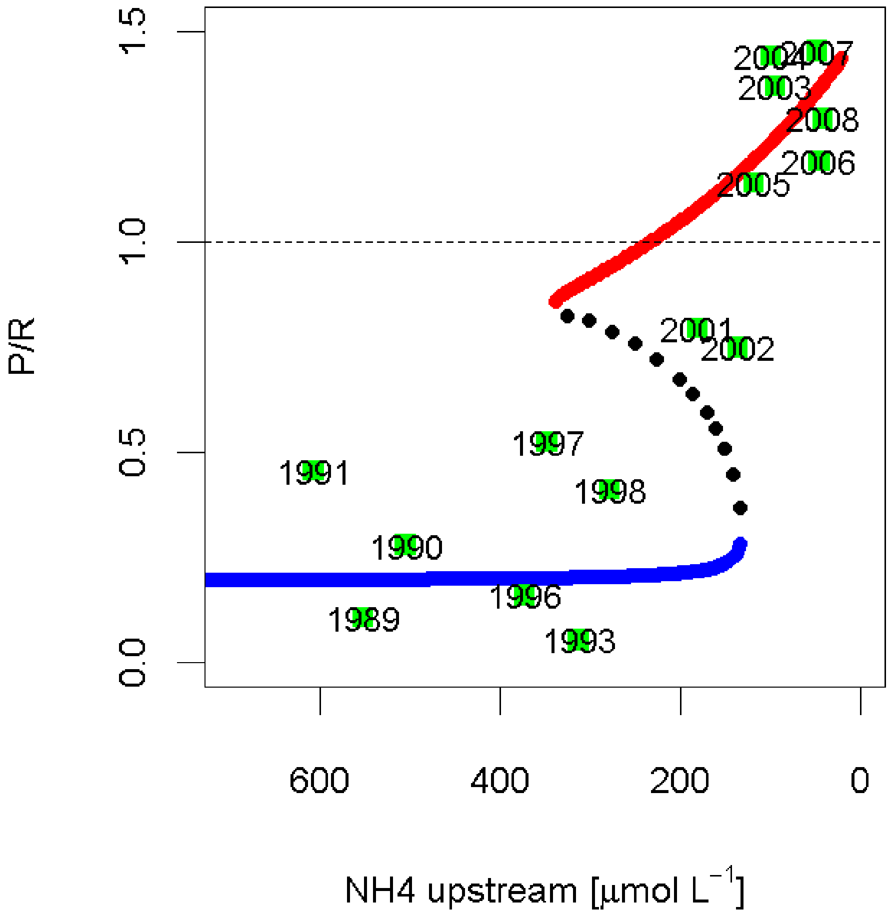


*Figure 3b. The ratio of oxygen production (algae) and consumption (respiration and nitrification) at steady state (full lines) and at the unstable equilibria of the system (dotted line). Data of different years are indicated by the year (adapted from Cox et al. 2009).*

This concepts indicate we cannot look at the individual measures taken, but must assess the overall development of the system and it is impossible to assess the influence exerted by past expansion, river engineering and dredging strategy as such, certainly not within the framework of this assessment. Therefore we assess the development of the system that is the results of the complex interaction between human and natural impacts.

### 1.1.2 What is estuarine ecology?

The next question we have to answer is, what is estuarine ecology? The loss of biodiversity has been a major concern since many decades and this has lead to a large number of international and national legislations in the hope to halt the loss of biodiversity. All the different “nature” legislations have in common that they focus on the structural biodiversity. They are oriented towards species or habitats and do not take into account the ecological functioning of the system. This is the sum of all processes and interactions in the system and the dynamics related to this. Estuaries are by definition very dynamic areas in which there is a complex interaction between the morphology, the hydrodynamics and the organisms living in it (Fig. 1).

The ecological functioning can be subdivided into 3 main series of processes:

1. Maintenance of geomorphological processes
2. Maintenance of biogeochemical processes
3. Maintenance of ecological processes

I will focus the evaluation on these 3 series of processes. With the maintenance of these processes we mean that the system is performing in such a way, is functioning in such a way that the natural processes are going on in the estuary. By embankment crucial processes will not occur any more at the same rate as before, for example the embanked marshes will no longer play a role in the sedimentation processes, exchange processes etc. The management should be done in such a way that these natural processes are least disturbed and/or enhanced to deliver the required structures. Indeed, the maintenance of geomorphological processes (such as erosion and sedimentation) within "normal" limits will result in the presence of different habitats, tidal flats, marshes,…, which form the structure of the estuary.
However, an assessment inherently means that you compare a given situation to another one. We make a judgment about a state of the system. For the structural biodiversity this is rather easy, we can rely on existing legislation, presence of protected species etc. For most aspects of ecological functioning this is less obvious. Some aspects are included in legislation (eg Chlorophyll a as a measure of primary production is a parameter in the water framework directive (WFD), as several other water quality parameters) but they are included as static independent variables. For Nitrogen and Phosphorous a norm is set below which the concentrations much be. However, for plankton development, the ratio N/P is more important that the concentration of N and P as such. This ratio is not included in the requirements of the WFD. The functioning of the food web is neither included in a directive, only the presence of some species.

In restoration ecology frequently either historical or geographical references are used. A historical reference is the situation of, in this case the Elbe, some time ago (often 100 years ago). This is useless as going back to that period is impossible given the developments that toke place. On top of that also the natural conditions changed and similar conditions (tides, climate,…) as before cannot be restored. Therefore more often a geographical reference is used. Here one looks for a similar system in the neighborhood. This could be the Weser, or the Ems, the Schelde. However it is also clear that each other estuary has also specific characteristics, differences in shape, size, fresh water discharge etc. that this can work neither.

Therefore I use a kind of hypothetical reference based on basic ecological knowledge: what are essential processes and what is a state of the system we don't want to reach. This largely relies on the concept of ecosystem services. This is simply mentioned, the benefits humans derive from nature. This means that an ecosystem is seen from an anthropogenic perspective. Where most nature legislation aims at the protection of species and habitats based on their intrinsic value, the concept of ecosystem services is based on the benefits we derive from the system.

This is however based on the knowledge that many of these benefits are dependent on species and habitats and their complex interactions. This is very clearly summarized in the figure produced by TEEB (The economics of ecosystems and biodiversity, a large EU project, see www.teebweb.org ) (Fig. 4). The ecosystems and associated biodiversity result in the generation of biophysical structure and processes, this is the different habitats including their typical species (the subject of nature legislation) but also the important processes like primary production what results in different functions like biomass production generating a service, e.g. a viable population of an edible fish. This service can then be turned into a benefit, if you can catch the fish and consume it. The benefit is both a contribution to your health as an economic benefit, being the commercial value of the fish. An estuary has several very important services.

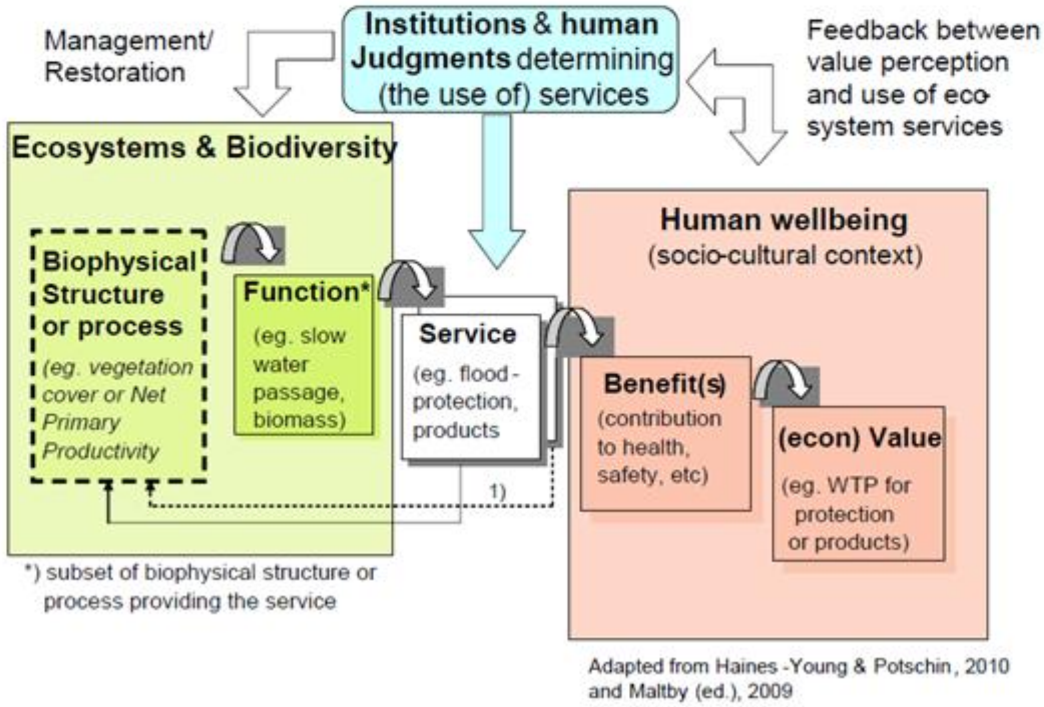


*Figure 4: The pathway from ecosystem structure and processes to human well-being. (from TEEB).*

Table 1 gives a broad overview of the different ecosystem services. The overall categories are based on the TEEB study. Of course not all are important in the Elbe estuary. For the provisioning services, the production of food is of major importance for the fisheries (eel, shrimp, smelt,…) in the estuary, mainly in the downstream part. Water is used for different sources but is estimated less important at this stage.

*Table 1a: Overview of the provisioning services.*

| **PROVISIONING SERVICES** | | **Individual services** | **Benefits** |
|---|---|---|---|
| 1 | **Food** (e.g. fish, game, fruit) | Viable populations of edible species | The benefits are nutrition |

| | | | |
|---|---|---|---|
| 2 | **Water** (e.g. for drinking, irrigation, cooling) | Potable water for household use<br><br>Cooling water for industry<br><br>Irrigation water for agriculture:<br><br>Water for transportation | improved production (both agricultural and industrial)<br><br>human health<br><br>shiping |
| 3 | **Raw Materials** (e.g. fiber, timber, fuel wood, fodder, fertilizer) | Sand<br><br>Clay<br><br>Wood<br><br>Plant materials (reed, bulrush, …)<br><br>peat | building material, |
| 4 | **Genetic resources** (e.g. for crop-improvement and medicinal purposes) | Providing important genes | Improved products (breeding new strands, genetic manipulation,…) |
| 5 | **Medicinal resources** (e.g. biochemical products, models & test-organisms) | Biochemical products | Improved health |
| 6 | **Ornamental resources** (e.g. artisan work, décorative plants, pet animals, fashion) | All kind of species and material | Improved well being |

The regulating services of the estuary are however of utmost importance (Table 1b). The impact on air quality is still largely unknown, but the estuary is important for climate regulation, both on a global scale (by its impact on de Carbon cycle) and on a local scale (impact on temperature, precipitation). The importance of the different habitats within the estuary for moderation of extreme events and water flow regulation is crucial. Tidal energy is dissipated, flood water can be stored, waves are attenuated by the vegetation etc. The ecosystem is also responsible for water and sediment purification and the regulation of erosion and sedimentation processes.

*Table 1b: Overview of the regulating services.*

| **REGULATING SERVICES** | | | |
|---|---|---|---|
| 7 | **Air quality regulation** (e.g. capturing (fine)dust, chemicals, etc) | Removing fine dust<br><br>Providing aerosols rich in Iodine | human health |

| | | | |
|---|---|---|---|
| | | Removing pollutants from atmosphere by<br><br>Air-water exchange<br><br>Biogeochemical reactions due to activity of organisms | |
| 8 | **Climate regulation** (incl. C-sequestration, influence of vegetation on rainfall, etc.) | **Impact on climate regulation through an impact on the carbon cycle**<br><br>Primary production<br><br>Carbon sequestration by burying in the sediments<br><br>**Impact on climate regulation by an impact on temperature**<br><br>Cooling due to evaporation (summer)<br><br>Warming due to heat exchange (winter)<br><br>**Impact on climate regulation by impact on precipitation patterns**<br><br>Production of DMS impacts cloud formation<br><br>Evaporation | Human health<br><br>Improved crop production<br><br>Mitigation of climate change<br><br>Overall productivity of environment<br><br>Overall viability of the area |
| 9 | **Moderation of extreme events** (eg. storm protection and flood prevention) | Tidal energy dissipation, discharge buffering<br><br>Flood water storage<br><br>Wave reduction | mainly reduced risks of flooding or natural disasters<br>Property protection<br><br>Less dike maintenance/repair costs |

| | | | |
|---|---|---|---|
| | | | |
| 10 | **Regulation of water flows** (e.g. natural drainage, irrigation and drought prevention) | Drainage of river water (transport of water)<br><br>Prevention of saline intrusion<br><br>Dissipation of tidal and river energy<br><br>Water for landscape maintenance | Maintenance of suitable living conditions for humans<br><br>Shipping (commercial and recreational)<br><br>Less shipping accidents<br><br>Fresh groundwater bodies<br><br>Energy production (tidal)<br><br>Landscape and ecosystem maintenance |
| 11 | **Waste treatment** (especially water purification)<br><br>Sediment | Transport for wastes and other byproducts of human activities<br><br>Reducing the pollution load coming from the catchment associated both with water and sediments:<br><br>Organic carbon<br><br>Nutrients<br><br>pollutants | good water quality which has an impact on many other aspects of the system (food production) protection of the coastal zone from pollution, indirectly also human health, recreation,…. |
| 12 | **Regulation of erosion and sedimentation** | Sediment transport<br><br>Habitat formation (balance of sedimentation and erosion)<br><br>Sink for sediments<br><br>Shoreline stabilization | Channels for shipping<br><br>Reduction of sediment relocation /dredging costs<br><br>Reduction of maintenance costs<br><br>Platform for building |
| 13 | **Maintenance of soil fertility** (incl. soil formation) | Deposition of fertile soils (in the river valley) | Agricultural production |
| 14 | **Pollination** | Viable population of pollinators | Agricultural production<br><br>Maintenance of natural vegetation |

| | | | |
|---|---|---|---|
| 15 | **Biological control** (e.g. seed dispersal, pest and disease control) | Trophic interactions that:<br><br>Prevent spreading of invasive species<br><br>Reduce spread of diseases<br><br>Processes that contribute to the dispersal of propagules of species<br><br>Seeds (hydrochory, zoochory,….<br><br>Eggs,<br><br>Larvae,<br><br>…. | Reduced damage of diseases on commercial species<br><br>Maintenance of biodiversity |

Apart from regulating services also habitat and cultural and amenity services are defined. Although the last category is very important they are not considered here. The habitat services on the other hand are also extremely important. It consists of the maintenance of biodiversity and eg the nursery function for commercially important species.

*Table 1c: Overview of habitat and cultural services.*

| | | | |
|---|---|---|---|
| **HABITAT SERVICES** | | | |
| 16 | **Maintenance of life cycles of migratory species** (incl. nursery service) | | Biodiversity maintenance |
| 17 | **Maintenance of genetic diversity** (especially in gene pool protection) | | |
| **CULTURAL & AMENITY SERVICES** | | | |
| 18 | **Aesthetic information** | | |
| 19 | **Opportunities for recreation & tourism** | | Recreational swimming, boating, fishing, walking,…. |
| 20 | **Inspiration for culture, art and design** | | art |
| 21 | **Spiritual experience** | | Human well being |
| 22 | **Information for cognitive development** | | Educatin of the population |

Although there is no quantitative reference against which we can assess the present situation, the delivery of services and the human benefits related to this are used as the reference. So measures or impacts that have negative influence on the production of fish populations, on the dissipation of tidal energy, on the possible volume of flood water that can be stored etc. will be assessed as negative.

The concept of ecosystem services is rather new, it received a lot of attention in the last decade. As such it is not yet integrated in any legislative document, however it is very rapidly being integrated into EU policy. The TEEB project is extremely influential and the different publications translate the concept to different types of stakeholders and it is very likely it will be a major leading principle in environmental management in the next years. The major importance of the concept is that it provides a framework for a more integrated management of a system and it also provides a clear link between the biophysical reality and our socio economic system. Therefore I strongly recommend to use this concept also in the RESMC. Indeed, several of the proposed measures have an impact on different ecosystem services and making this more explicit might broaden the support for some proposed measures. The concept also allows to make some goals more quantitative. Indeed, flood protection can be translated in a certain level of protection, eg a risk of flooding of less than once in 1000 years, or for energy dissipation a goal could be that the increase in high water levels near Hamburg may not be higher than x cm in 100 years, even given sea level rise. The application of this concept may clearly allow to put the proposed measures into a much broader perspective and be an important step towards a more integrated management plan.

This review is fundamentally different from the evaluation of Roger Morris, as his task was to evaluate the system with reference to the present legislation. Here I do not take into account this present legislation but base my evaluation solely on scientific criteria. As indicated above, I will consider 3 main groups of processes.

### 1.1.3 Maintenance of geomorphological processes

Each estuary is characterized by a series of different habitats, from deep channels up to high marshes. The presence of these habitats is an equilibrium between hydrodynamics forces, sediments and biota. The presence and location of habitats is not stable due to the dynamics in the system, however under natural conditions the sedimentation and erosion patterns are in equilibrium and a mosaic of habitats is occurring and maintained in the system, although the location of the different habitats might shift over time.

During the last century, riparian forests, large marsh and semi-terrestrial areas bordering the rivers have been embanked for coastal protection and for agricultural purposes. Very significant losses occurred of both shallow water and tidal areas in the fresh and brackish part of the Elbe. In the marine part, very significant parts of the so called forelands disappeared (see Table 2) (http://ebookbrowse.com/000120-eurosion-elbe-estuary-pdf-d65325594).

*Table 2: loss of habitats in the Elbe over the last 100 years (from website Eurosion).*

| | Elbe 1896/1905 vs. 1981/82 |
|---|---|
| tidal flats | brackish 21%<br>freshwater 51 % |
| shallow water | brackish 63%<br>freshwater 85 % |

| Elbe 1896/1905 vs.1981/82 |
|---|
| Northern Bank 52%<br>Southern Bank 75% |

Clearly, like in all other estuaries, the Elbe suffered a very significant loss of habitat over the last century. However, the major question is whether the remaining habitats can be maintained by the present hydrodynamic and geomorphological processes. The development of tidal marshes is described by Schroder 2004 and Stiller 2009a,b. No clear conclusions can be drawn based on their data but seemingly there is no clear indication for an expansion of marshes. There might be some changes in the different vegetation types as reedbeds have increased (Schröder, sd). However, the stability of the marshes is reduced and to prevent further erosion of march cliffs, several measures were taken. This can clearly be seen in fig 5 and 6 showing large scale protection measures.

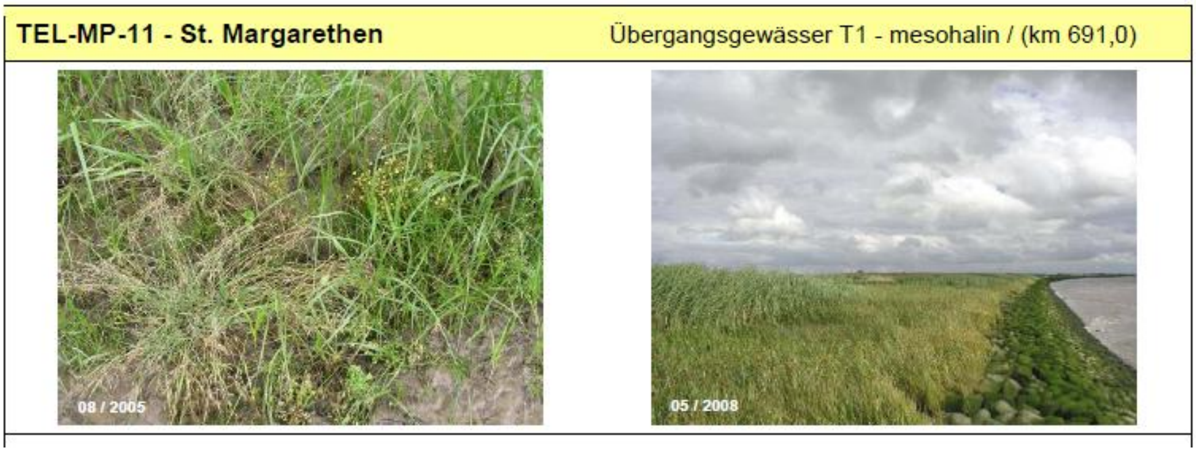


*Figure 5. Example of marshes protected from erosion by wrip wrap. (from Stiller, 2009).*


*Figure 6: Aerial photograph of Schwarztonnensand (left) and Pagensand (right) showing different concepts of groins and revetments (yellow) protecting tidal marshes from erosion (from Witte & Eichweber (s.d.).*

The development of tidal flats and shallow and deep areas in the estuary is described in detail by the other experts but it is clear that also here major changes occur.

It is also clear that the changing hydrodynamics (increasing tidal amplitude, increasing tidal asymmetry) in combination with the historical loss of habitat (due to different reasons) and possibly changes in sediment loads had a very important impact on the geomorphological development of the estuary and it is unlikely that tidal habitats, especially tidal marshes and flats, can be sustained without human interventions (like revetments), at least in a significant part of the estuary. This indicates that the maintenance of geomorphological processes is seriously hampered and human intervention is needed to maintain the structure of the habitats.

This changes in hydrodynamics and geomorphological processes can also have an impact on the ecological quality of the marshes. An evaluation of the different vegetation communities by Stiller (2009) reveals that many of the sites show an impoverished community.

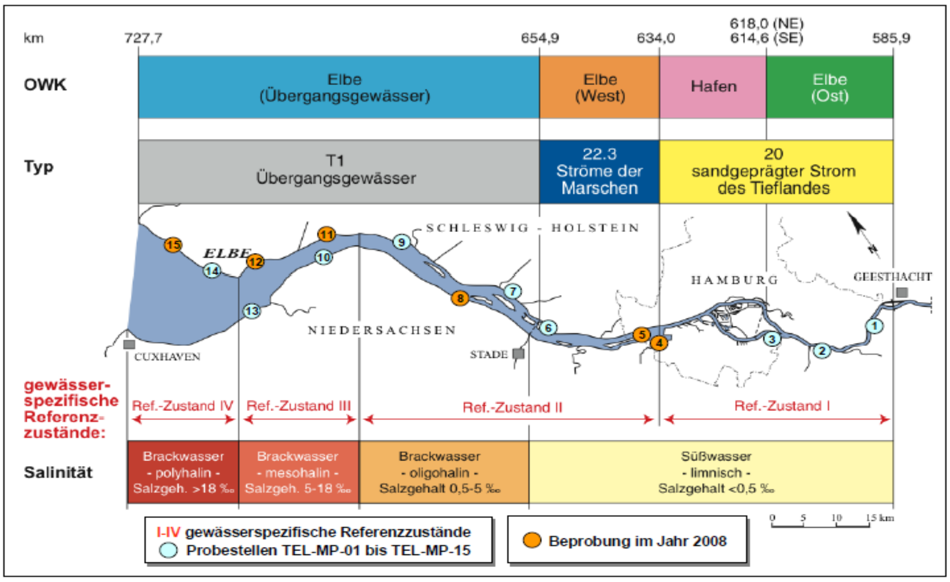


Abb. 1: Lage der 15 WRRL-Monitoringstellen (TEL-MP-01 bis TEL-MP-15) und der sechs für die Untersuchungen im Jahr 2008 ausgewählten Probestellen im Bearbeitungsgebiet Tideelbe (ARGE ELBE 2007, verändert)

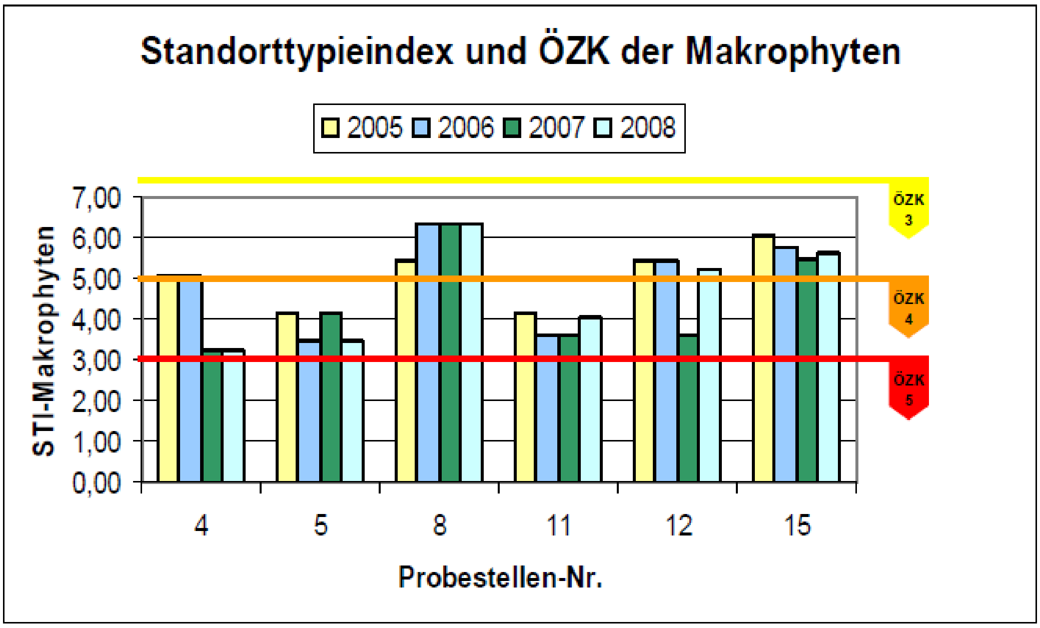


Abb. 2: Standorttypieindex sowie **ökologische Zustandsklassen** (ÖZK) der ausgewählten Probestellen im Untersuchungszeitraum 2005-2008 für die Qualitätskomponenten Makrophyten und Angiospermen im Bearbeitungsgebiet Tideelbe

*Figure 7: Overview of the ecological quality of several marshes (from Stiller, 2009).*

The reasons for the poor status is partly due to natural causes, but to a large extend also linked to anthropogenic impacts, either increased sedimentation or erosion, see table 3.

Clearly information is lacking (or not at my disposal) concerning the vegetation development on the marshes. Indeed, the vegetation is the result of both abiotic factors (inundation time, nutrients,…) and biotic factors like grazing. As many marshes were/are grazed, this can have a significant impact on the vegetation composition. Also factors like ship waves can strongly impact vegetation, but although it is assumed it will be important in some places, as yet no evaluation can be made. This all points to the importance of evaluating trends. Indeed, the development of vegetation is a long term process and assessing the state of the system based on a point measurement can lead to wrong conclusions. It can be that the system is degenerating, but the impact on vegetation is not yet measurable, but it can be the other way round as well!

*Table 3: Natural and athropogenic causes of a reduction in ecological status of marsh vegetations (from Stiller, 2009).*

*'Ursachen für die Variabilität der Qualitätskomponenten Makrophyten und Angiospermen an den ausgewählten Probestellen im Monitoringzeitraum von 2005-2008.'*

| | natürliche Ursachen | | anthropogen bedingte Ursachen | |
|---|---|---|---|---|
| TEL-MP-04 | | keine | x | starke Aufschlickung mit Fließ-schlick und in der Folge Überschlickung der Vegetation |
| TEL-MP-05 | x | klimatische oder populationsdynamische , d. h. bestandsinterne Faktoren | x | starke Erosionserscheinungen mit Uferabbrüchen einschl. der dort sie-delnden Vegetation am Nordufer |
| TEL-MP-08 | x | klimatische oder populationsdynamische , d. h. bestandsinterne Faktoren | | keine |
| TEL-MP-11 | x | klimatische oder populationsdynamische , d. h. bestandsinterne Faktoren | | keine |
| TEL-MP-12 | | keine | x | periodische Störungen der Ufermor-phologie und Vegetation durch Baggerei mit Baggergutablagerung zur Vorlandentwässerung |
| TEL-MP-15 | x | populationsdynamische, d. h. bestandsinterne Faktoren; Standortaufhöhung infolge Sedimentation | x | Aufschlickung, Auflandung des Standortes; Überwachsen der natürlichen Vegetationsbestände (Queller) mit Schlickgras (Neophyt) |

However, overall we can conclude that the maintenance of different habitat types in the estuary is under pressure and that measures should add to improve the maintenance of geomorphological processes necessary for providing the different habitats in the estuary.

### 1.1.4 Maintenance of biogeochemical processes

Estuaries are very important bioreactors. Sediments, nutrients and pollutants originating in the whole catchment are transported towards the estuary. Due to complex biogeochemical processes, many of these substances are either transformed or removed. Also sedimentation attributes to the removal of mainly pollutants. Transformation and/or removal of substances within the estuary is of utmost importance as the estuaries act as a filter between the catchment and the coastal sea. Especially removal of nutrients is crucial to prevent further eutrophication of the coastal sea. Furthermore the biogeochemical processes are determining essential water quality parameters such as the oxygen concentration. Primary production on the other hand is the driver of the estuarine food chain.

Fig. 8 gives a summary of the major processes. In general, nutrients are imported in the system either as inorganic salts ($NH_4$, $NO_3$, $PO_4$) or in organic molecules. Organic matter is mineralized consuming $O_2$ and producing $CO_2$. Ammonia is nitrified and this process of nitrification is also consuming $O_2$. Under anoxic conditions, $NO_3$ is denitrified to $N_2$. Nutrients and $CO_2$ are taken up by algae during the process of photosynthesis producing $O_2$. Algae are grazed by zooplankton that is a crucial food source for higher trophic levels like fish. They can also be filtered by benthic filter feeders that are on their turn food for fish and birds. This food web, from primary production to higher trophic levels is crucial as this support both bird and fish populations. However, also a microbial food chain exists in which either allochtonous or autochtonous organic matter is mineralized by bacteria that are then grazed by microzooplankton which does not flow through to higher trophic levels. These processes, described above very briefly and incomplete, determine water quality in the estuary. These processes are in their turn also impacted by external factors. Primary production is next to nutrients, dependent on light. Light conditions are mainly determined by suspended solids: the higher the suspended load, the less light is penetration to deeper layers, limiting primary production. But also the salinity is very important. Indeed in the fresh water tidal zone a community, adapted to these low salinities develops, but as it is transported to the brackish zone these species die as they are not adapted to increasing salinities. Therefore the brackish zone is often described as a graveyard. Indeed marine species moving upstream also die in this zone because for them salinities are too low. Therefore the brackish zone is mainly a heterotrophic zone in which organic matter is decomposed, while there is very little primary production. This is also the reason that residence time of the water is so important. With low residence times, the phytoplankton populations are transported very fast downwards to the brackish zone where they die and in the short time they are not able to build up large populations.

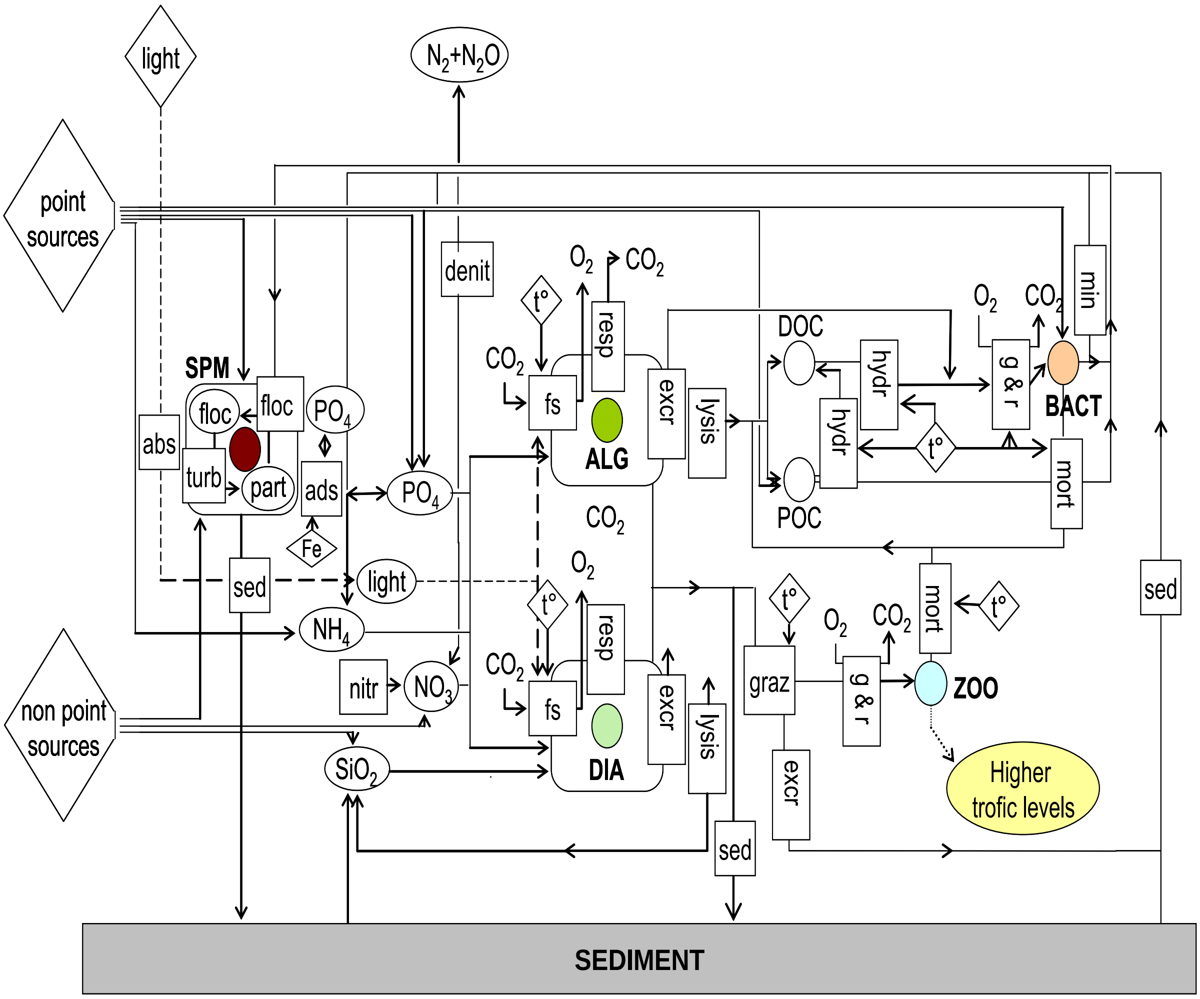


*Figure 8: Schematic view of the funtioning of the ecosystem. (abs: absorption; floc: flocculation; turb: turbidity; sed: sedimentation; Fe: iron; Alg: algae; excr: excretion; fs: fotosynthesis; resp: respiration; mort: mortality; graz: grazing; (adapated from Billen et al.)*

The system is even more complex as we do not only have the processes, briefly and incompletely described above, in the pelagic, there are also major fluxes between the pelagic and the benthic phase (sediments of the subtitdal and tidal flats) and between the pelagic and the tidal marshes. These exchanges are the consequence of sedimentation/erosion, diffusion, infiltration and exfiltration. Essential is the fact that the water quality parameters are to a large degree determined by the interaction between pelagic and benthic phase, indicating that the morphology of the system is crucial for the ecological functioning. Hence the RESMC can have profound effects on the ecological functioning via the impact on suspended solids and changes in habitat structure:

- The amount of suspended solids determines the light penetration in the water column and hence the possibility of primary production. Any change in suspended matter concentrations, especially in spring and summer will have immediate consequences on the production
- The average depth of the estuary has an impact on the time plankton can be in the photic zone.

- During high water, the amount of water exchanged between the main channel and the tidal areas (both tidal flats and marshes) will determine to a large degree the exchange processes. It is well known that marshes act as a sink for sediments, nutrients, organic matter and pollutants associated with the sediments. Also the marshes are a sink for nitrogen and a source for silica. Any changes in the amount of water exchanged between tidal area's and the channel will impact the ecological functioning, hence the link between morphology and water quality.

The complexity of this system makes it again difficult to make a simple assessment. However, we can focus on a few parameters representative for many different processes. Oxygen concentration is such a parameter.

Primary production and oxygen

Oxygen is one of the most important water quality parameters as the concentration determines the presence of higher organisms. The concentration of oxygen in the system is the result of different processes and determines the conditions for higher trophic levels. Therefore a more detailed analysis is made of the oxygen condition as a proxy for the ecological functioning.

Over the years a substantial improvement in oxygen conditions occurred, although recently, an oxygen sack is seen in summer months in the Hamburg region. The data from Seemannshöft show the clear increase in the nineties and the following drop (Fig. 9).

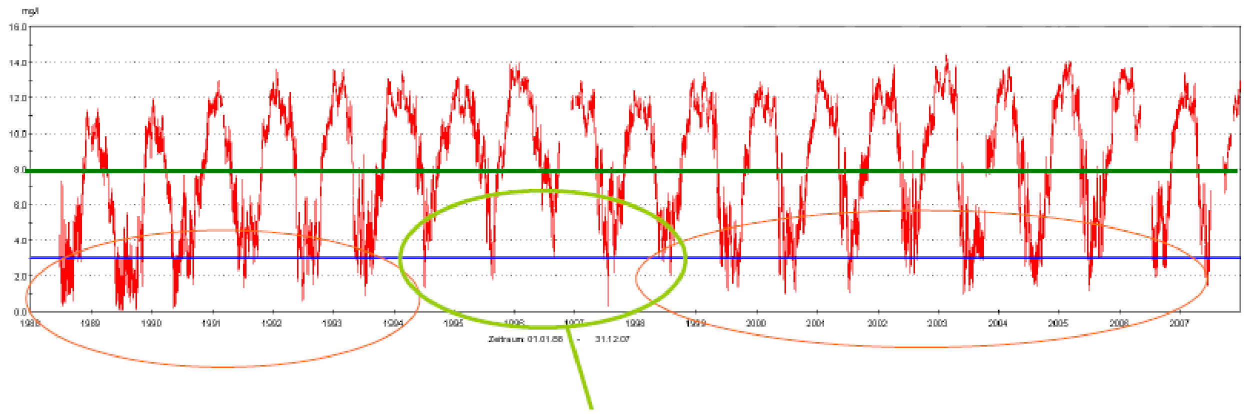


*Figure 9: Long term trend of oxygen at Seemannshöft. (From: Blomh, workshop ARGE Elbe).*

Detailed profiles of oxygen during summer clearly show these oxygen sacks (Fig. 10). It is obvious that there is a great year to year variability both in the depth of the sack as well as in the place where it occurs. In 2002 it occurred much more downstream, in 2007 much more upstream than the other years. A detailed analysis taking into account meterological conditions and river discharge is needed to try to understand these year to year differences.

The crucial question to answer is whether this drop of oxygen, especially in summer periods is due to local conditions within the estuary or entirely dependent on upstream conditions. In the first case this has strong consequences for the management of the estuary, in the second case it urges more to take extra measures in the river Elbe.

Kerner (2007) shows there is a clear increase in BOD after 1999 in the stations Zollenspieker, Seemannshöft but not any more in Grauerot. He concludes the organic carbon (OC) is mineralised in the upstream part from Grauerort and no upwards transport of degradable OC occurs. Therefore I looked at the data avaible form upstream Geesthacht to see what changes can be detected there.

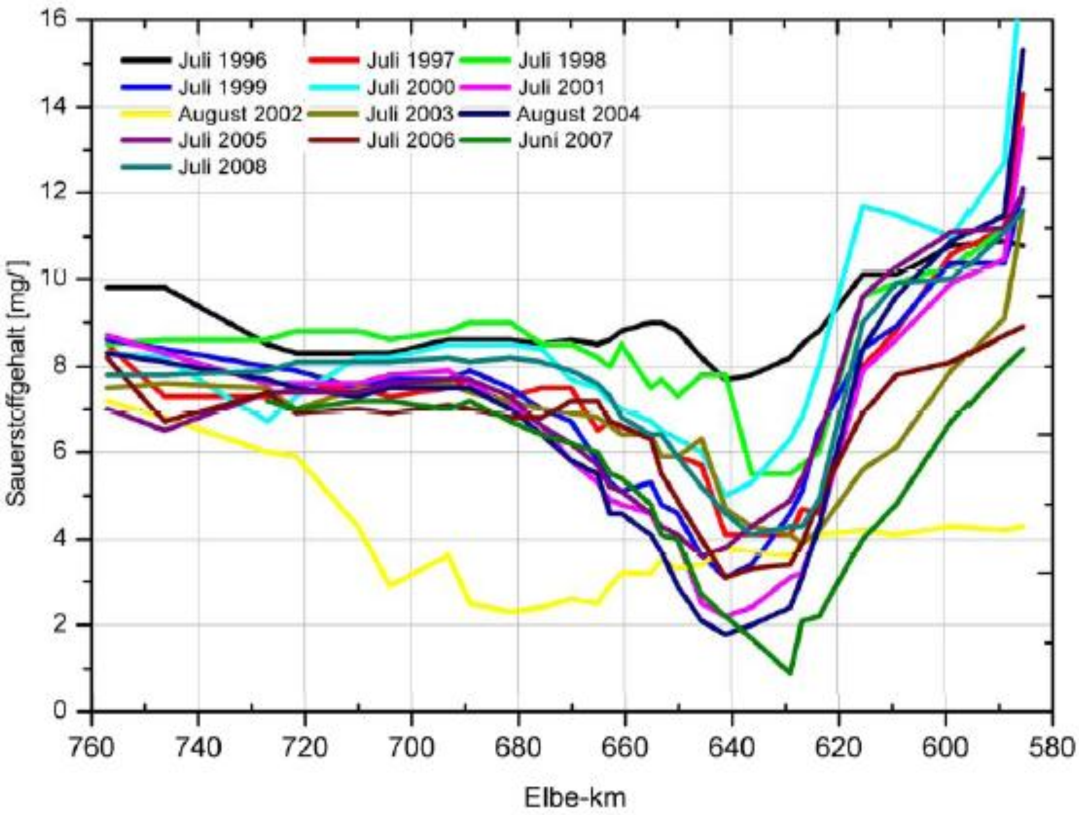


**Abbildung 3-24: Längsprofile des Sauerstoffgehaltes in der Tideelbe im Juli bzw. August der Jahre 1996-2008 (auf Basis der monatlichen Hubschrauberbefliegungen durch die ARGE-Elbe)**

*Figure 10: Longitudinal profiles of oxygen along the Elbe during different campaigns in summer.*

The data from the last years from Snackenburg (see appendix 1) show rather a decrease in BOD and Chla towards 2005, 2006, 2007 and 2008, periods that have also a clear oxygen sack. BOD and Chla are clearly lower at Seemanshöft (appendix 2) and Grauerot (appendix 3). This can be partly due to mixing and dillution, but it is certainly also due to the mineralisation of organic matter in the upper part of the estuary.

To get a better insight in what is going on, longitudinal profiles of some parameters are summarize in appendix 4. These figures show some extremely interesting patterns. First of all, it is clear that major changes occur in the transition form river to tidal river. Chla concentrations remain more or less constant, BOD and oxygen concentrations drop after the weir. However, the concentrations of nutrients increase after the weir. This is extremely strange and can in fact only be explained by a local supply. This can be either a release from the sediments (maybe due to release of nutrients stored in sediments deposited a long time ago) or from mineralisation of organic material. The drop in BOD could indicate that in the estuary organic matter is very quickly degraded, or the nutrients can come from an additional source (effluent of waste water treament plan, small tributaries,….). This should be studied in more detail. A detailed  inventory of all discharges in the harbour area should be a first approach. As it can be anticipated that the discharges would be very small compared to the river discharge, these additional sources should have very high concentrations. Release from sediments or from resuspension is more difficult to study. Experiments measuring the release of nutrients from sediment cores could bring some more insight.

When looking at the concentrations of $NH_4$, they are decreasing strongly from Seemanshöft towards Grauerort (fig. 11) which probably points to a very intensive nirtification, a process that is know to use much oxygen.

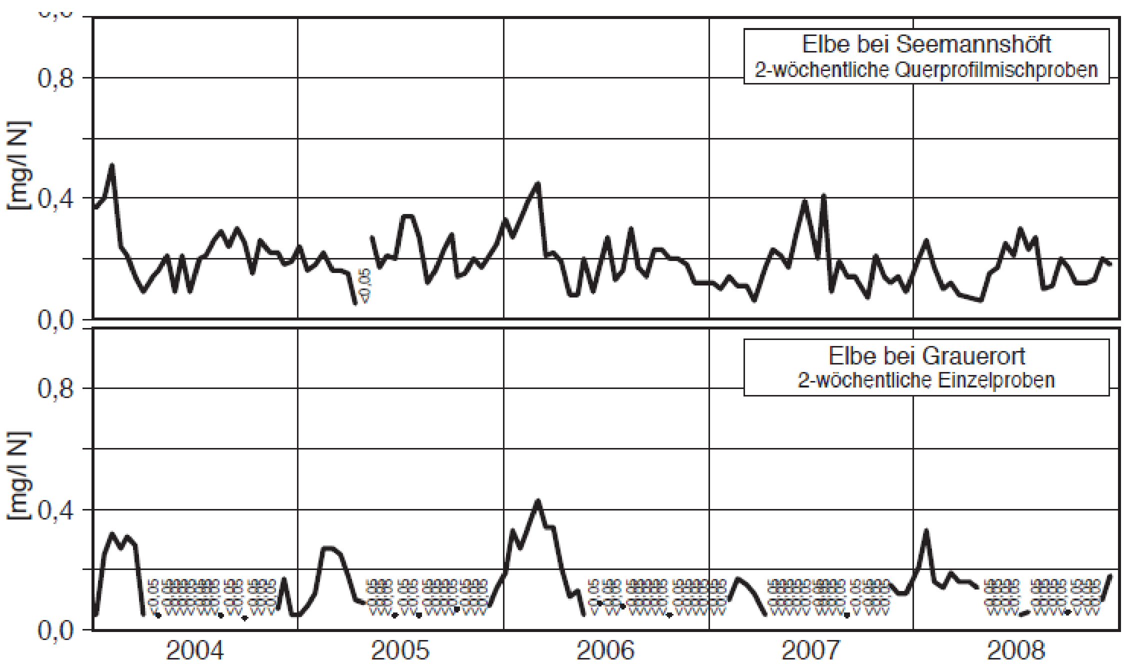

Abb. 16 Ammoniumgehalte der Elbe - 2004 - 2008

*Figure 11: Ammonium concentrations at two stations along the Elbe.*

The behaviour of nutrients was also studied in detail by Dhanke et al. (2008). Based on detailed measurements of stable isotopes they concluded that no NO3 was removed in the estuary but that there is a source in the lower salinity region due to nitrification! But as NH4+ levels are to low to account for the drop in delta 18 O, this must be nitrification of amonia derived from the degradation of organic matter (fig. 12).

All this evidence point to the fact the oxygen sack is not the result of upstream input but rather from local processes. It is guessing what this might be, but a plausible hypothesis is that local resuspension of sediments might result in the input of OC to the pelagic that is then quickly mineralized, producing ammonium that is then nitrified. Both the mineralisation and the nitrification are using a lot of oxygen and this could be the reason for the sack. Question remains where the resuspension occurs. The presence of "fluid" mud in some areas (eg Muhlenberger Loch) could be a source. Organic matter is imported absorbed to small sediment particles and is settling together with the mud. As a large amount of the transport occurs in winter, this OC is not mineralized at that time. When during summer, fine sediments are resuspended, this OC is mineralized starting the cascade described above.

This point is of great relevance for the RESMC. If resuspension in this part of the estuary is important, then probably dredging and dumping activity in its own will not have a major impact on water quality, as the amounts of sediments brought in suspension will be negligable compared to the amounts resuspended. Stabilisation of the sediments would then become the major issue. In the Muhlenberger Loch, there has been an important sedimentation. The development of a creek system is however rather limited and the sediment is very soft and probably the drainage during low water is very limited (very large area and few creeks). The consolidation of the mud, and the development of vegetation on the higher part of these tidal flast will be very difficult under these conditions.

To better understand these problems it is recommanded to study in detail the sediment delivery from the catchment. Detailed measurements of the sediments over the cross section near the weir should be made and the amount of organic matter associated with these sediments should be estimated. Maybe these data exist, but were not at my disposal. There might be a big discrepancy between the BOD measured on surface samples as a measure of the input of organic matter compared to the amount of OC transported along with the sediments near the bottom. This would clarify the amount of OC transported into the estuary. Next much more attention should be given to measure the resuspension over tidal flats and the transport of sediments in the different parts of the river, not only in or near the fairway (see further).

As far as could be analysed, there is clear evidence that the ecologcial functioning in this part of the estuary is heavily hampered.

The study of Dhanke et al. (2008) also prove that there is no sink of N in the estuary. They state: "Loss of sink function of estuary for N is due to a decreased surface due to filling up shallow water marshes and building flood gates. All these measures effectively decreases the sediment area that is in contact with the overlying water column”. The nitrogen retention capacity of rivers decreases with increasing water depth!

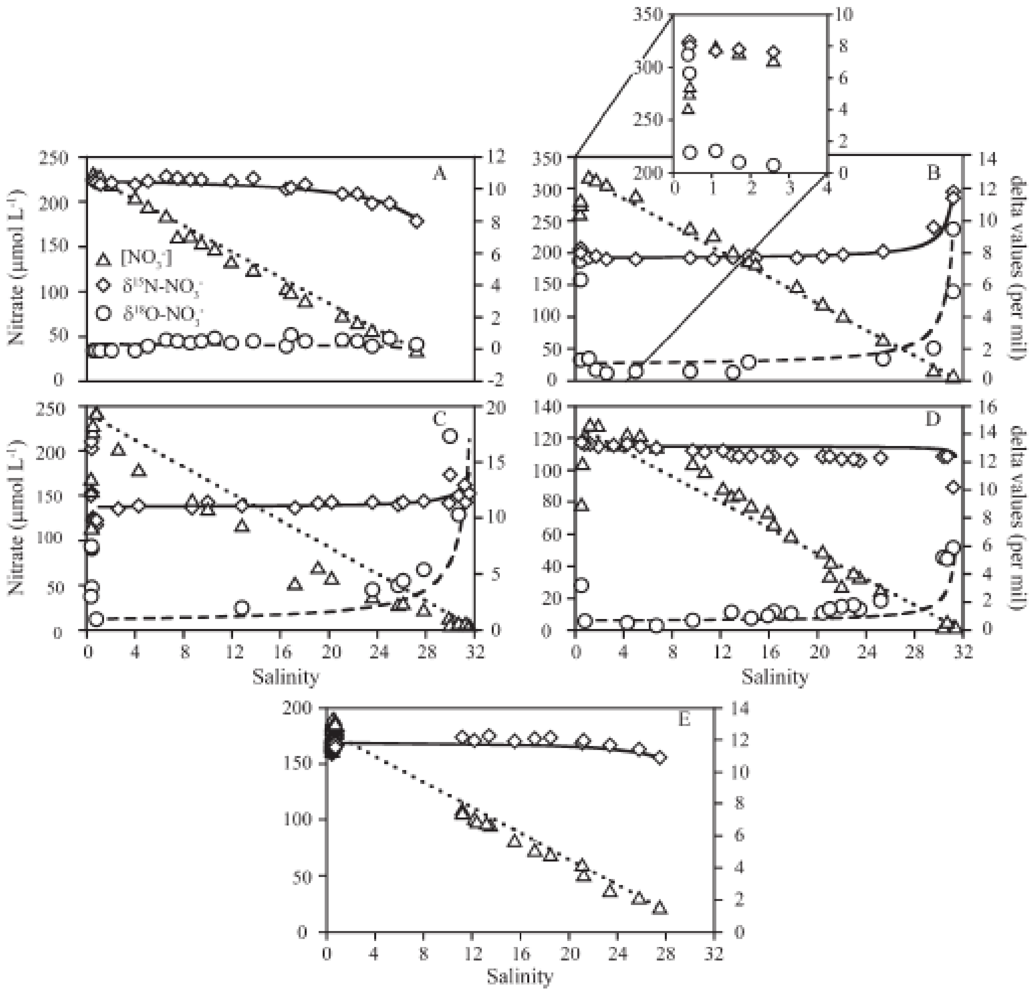


Fig. 2. Nitrate concentrations and isotopic values of nitrate along the salinity gradient in the Elbe estuary. (A) December, (B) May (insert shows the increase in nitrate concentrations in the upper estuary), (C) June, (D) August, (E) October.

*Figure 12: Nitrate concentrations in the Elbe estuary (Dhanke et al. 2008).*

Next to nutrient cycling, primary production is a crucial indicator of the ecological functioning. Some information is summarized in fig. 13. The overall concentrations of Chl a are not extremely high and show a clear decreasing trend. Very interesting as well is the difference between Elbe and the Nebenelbe. There is a clear pattern that the Chl a concentrations in the Nebenelbe are nearly always higher than in the Elbe. This can only be due to the different conditions in both areas, but it also shows there might not be so much mixing of these water bodies. This should be studied in more detail, also related to the transport of sediments!

Si concentrations (not shown) are consistently low in summer indicating a very strong Si limitation for phytoplankton. No information is available on the composition of the phytoplankton communities.

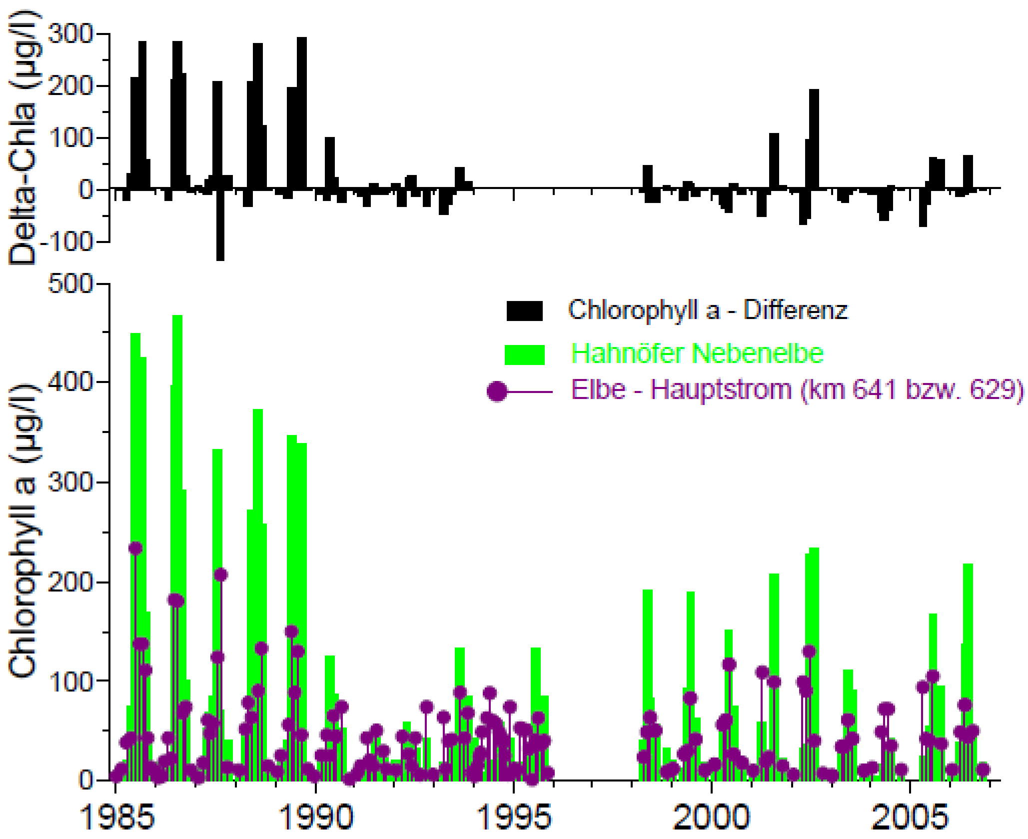


**Abb. 3: Langjähriger Trend (1985 -2006) der Algengehalte im Hauptstrom der Elbe bei km 641(ab 1992 bei km 628,8) und in der Hahnöfer Nebenelbe (TN 14)**

*Figure 13: Trends in primary production (indicated as Chla) in the Elbe and Hanofer nebenelbe.*

These differences are also clear from detail measurements as shown in Fig. 14. From measurements in the Schelde we expect at one site an increase of oxygen at high water as the more oxygenated water is pushed upstream by the tide. The data from fig. 14 show a completely opposite picture. Oxygen is highest at low water and lowest at high water, and this independent on the diurnal cycle. This would point to the fact that primary production is less important than mineralization and other processes that are independent of the light. Very strange as well is that during some days, the oxygen at both stations is similar, whereas in the last tidal cycles measured, oxygen drops much more in the main river compared to the Nebenelbe.

In general we can conclude:

- Oxygen patterns are a problem, but still not really understood. It is however more than likely that the problems are due to local phenomena within the estuary, rather than to the import from upstream.
- There are indications that local resuspension might be very important.
- Primary production is rather low, or at least not high, but why is there such a severe Si depletion?
- How can the local differences be explained?

- What limits PP is unclear, but a plausible hypothesis could be the Zm/Zp ratio. The Zm is the average mixing depth, that is the average depth of the estuary. Indeed during high and low tide, plankton cells will go down in the water column as there is no turbulence to keep them in the upper water layers. The deeper the estuary, the deeper plankton can sink. The Zp is the photic depth, the depth in the water column where there is sufficient light for the plankton to grow. If this is very small (due to high concentrations of suspended sediments) and the mixing depth is large, then this means that individual plankton cells can stay a long time in the dark, not able to produce. As the Elbe is deep and the amount of intertidal areas is limited this ratio is probably unfavorable for primary production.

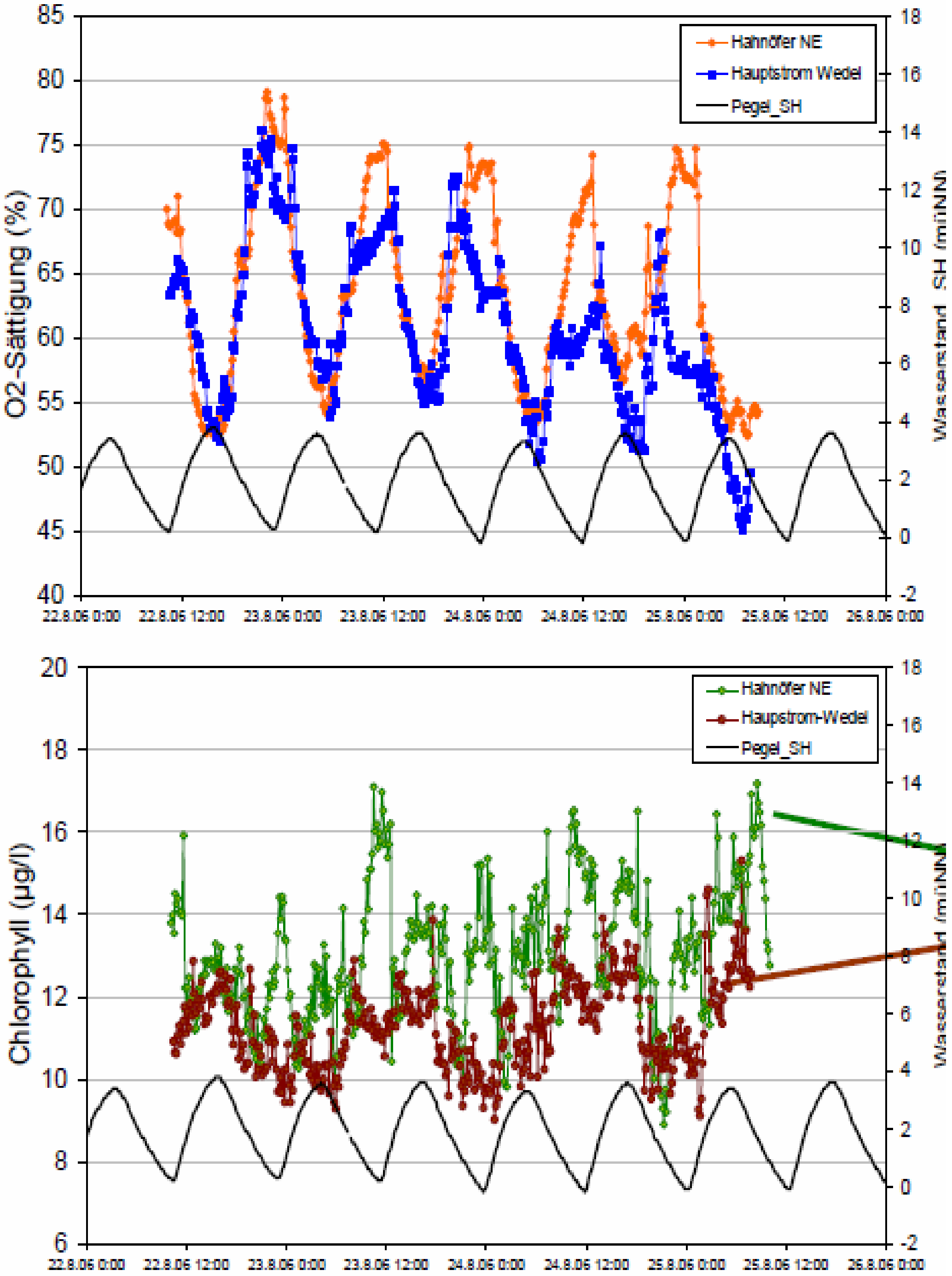


*Figure 14: Detailed measurements of tidal height, oxygen an Chla in the Elbe and the Hahnofer Nebenelbe.*

In overall conclusion, we can say that the ecological functioning of the system is certainly hampered and it is more than likely this is to a large extend due to the different measures taken in the past. As average depth, resuspension, current patterns and concentrations of suspended solids are all influenced by measures in the RESMC, the impact of the measures on ecological functioning should be studied and evaluated in detail.

#### 1.1.5 Maintenance of ecological processes.

Although in the previous section several ecological processes as primary production are discussed, the maintenance of the food web, transfer of matter to higher trophic levels, maintenance of biodiversity are other important ecological processes. The information for benthos, birds and fish in the estuary are too scattered, absent or not available at this stage that an analysis of these ecologically very important groups is not possible.

#### 1.1.6 Overal conclusion:

It is clear the past measures have had a strong impact on ecological functioning. The geomorphology and hydrodynamics are not in equilibrium and further developments of the tidal amplitude towards even more tidal asymmetry and/or increase of tidal amplitude would be very negative for the system. The ecological functioning is also impacted but overall it is clear that still a lot of open questions exists. Especially understanding of how the system will further develop and whether or not some thresholds are reached leading the system to another state.

# 2 Assessment of the situation as of 2005 and with further implementation of the RESMC:

The main aim of the river engineering measures is the minimum possible intrusion in, of alternatively, even making use of the natural dynamics of the estuary, while taking into account the necessary demands made by traffic and flood protection (HPA ² WSV, 2008). This starting point as well as the objective to counteract the unfavourable natural and anthropogenic morphological and hydrological developments is assessed very positive.

## 2.1 What is the assessment of the objective “reducing tidal pumping” as a sediment management strategy from an estuary ecology perspective?

Tidal pumping is a natural phenomena that occurs in many estuaries, but very often it is amplified as a result of changes in hydrodynamic and sedimentary conditions as a consequence of large scale changes such as climate change or mostly by human activities. Tidal pumping leads to the import of sediment but also to the upward movement of planktonic organisms. Upstream sediment transport leads to sedimentation and hence habitat creation, upstream transport of organism can allow populations to move upward and increase their residence time in a zone of can allow colonization; so in its own, tidal pumping is not a negative ecological issue.

The consequences of tidal pumping for the insilting of the fairway, docks and other infrastructure is clearly a problem for the management of the economic functions of the river, rather than for the ecological functions. It is unclear yet to what extend tidal pumping might have an impact on the natural habitats in the Elbe (tidal flats and marshes) both in terms of sedimentation rates and type of sediment that is deposited. However, as the overall aim must be to sustain both the economic and ecological functions, tidal pumping is a problem. For the ecological functioning, it is the increased dredging to counteract tidal pumping that has potential consequences and as such, if the objective of reducing tidal pumping requires less maintenance dredging this is positive, given that the remaining maintenance is done in an environmentally sensible way (both the dredging and the disposal).

## 2.2 What is the assessment of the river engineering measures envisaged for "reducing tidal pumping" from an estuary ecology perspective?

The engineering measures can be divided in different groups (see HPA & WSV, 2008):

- river engineering measures in the mouth of the Elbe to restrict tidal energy as it builds up.
- river engineering measures to dissipate the tidal energy on its way up to Hamburg
- the creation of additional water surfaces or alternatively tide potential for the absorption and dissipation of tidal energy
- additional measures which influence the transport processes within the tidal Elbe.

A detailed assessment is not possible as this must be based on the detailed engineering of each project as the individual design is crucial to the success. One measure can turn out to be extremely good or bad depending on the design AND the local conditions. Therefore only a general evaluation can be given.

### 2.2.1 Some general remarks

Reducing, or dissipating tidal energy is of utmost importance and it is clear that this cannot be achieved by one measure but that it will require a series of measures at very well selected sites along the estuary. All these measures will lead to a change in morphology. Successful measures should fulfill several criteria like, require as less as possible maintenance, trigger further "wanted" morphological developments, such as sedimentation or build up of intertidal areas. "Soft" measures are preferable over hard engineering and measures should be reversible. Indeed, the morphological development of estuaries is still not very well understood and even well designed measures may have unexpected negative consequences. Therefore it should be possible to adapt the measure according to the results and it is clear that adapting hard measures is more difficult. Reducing the cross section of the mouth is a potential measure that could reduce tidal energy. This seems to be a very sensible measure, but if this is realized by a hard structure it is likely to cause important unknown and possibly unwanted consequences. Therefore using a combination of dredged material and stones rather than a concrete dam might be preferable.

In recent years more and more experience is acquired with building with nature. In this concept dredged material is used in a beneficial way. The experiment "Walsoorden" in the Westerschelde is a very good example (Van der Wal et al 2010, 2011). Dredged material is deposited subtidal with a diffuser at the tip of a sandbank that was heavily eroding due to the currents. The deposited sands are now transported by the currents up the sandbank/tidal flat and in this way the morphological development is steered in the desired way. The experiment is seen as very successful and this method is now applied in several sites in the Westerschelde and an essential part of the dredging and disposal strategy.

Along the Dutch coast a huge experiment was recently started, the so called “sand motor”. In his project of coastal protection, the sand suppletion to the beached to counteract the intensive erosion of beaches and dunes is replaced by the creation of a large “island” of sand situated in such a position that the island will be eroded and the sand be transported by the currents to the coast. So instead of putting the sand immediately in the place where it is needed, the sand is supplied at a strategic location to the system from where natural processes will bring the sand in place. A large scale experiment is running now. The benefits of such an approach are many fold. First of all, the sand coming to the beach is well sorted resulting in nice beaches, the ecological impact is minimal as the sedimentation is at a natural speed. The loss of habitat at the disposal site is compensated by ecological gains of the sand island itself.

These type of measures, called morphological management, should be explored more thoroughly as I believe they have very large potential especially in the middle and the lower part of the Elbe. Of course these soft engineering alone will not solve all problems and probably a combination of soft and hard engineering will be necessary. However providing one hard structure could be a trigger for further soft engineering measures. A detailed analysis of the historical development the Elbe in combination with modeling studies must allow to make different scenarios for reducing the cross section of the Elbe mouth that could be reached by intelligent dumping strategies that can also provide a lot of ecological benefits.

### 2.2.2 River engineering measures in the Elbe mouth area to reduce the oncoming tidal energy

#### *2.2.2.1 Underwater storage sites in the Elbe mouth area*

Reducing the cross section at the Elbe mouth is likely to be a very efficient strategy to dissipate tidal energy and hence reduce high water levels, increase low water levels and reduce upward transport of sediments and this should be beneficial to ecological functioning.

The success of these measures will largely depend on the way it is realized. Different methods are available for reducing the cross section. As mentioned above, preference should be given to soft over hard measures. Dumping sediments at the mouth seems a good option. Very much care must be taken that by changing the cross section no new processes of unwanted morphological changes are initiated. Therefore measures which gradually decrease the cross section starting from the present intertidal areas (eg by disposal of sediments) and working towards the main channel should be preferred over hard constructions at the bottom of the fairway.

Additionally, the idea of constructing some islands (like Nigehorn and Sharhorn) has some potential. Of course this will be at the expense of tidal areas, but this could be balanced by increase of intertidal areas elsewhere in the mouth.

I would strongly advice to study as much alternatives as possible, as these measures might have far reaching consequences.

### 2.2.3 River engineering measures to reduce the oncoming tidal energy on the way to Hamburg

It is clear that habitat loss in the broad sense is one of the major causes of some negative developments in the Elbe. All measures that increase the surface of the estuary and create tidal volume are therefore positive. However, it must be clear that the impact of different measures can vary a lot. From the point of view of structural biodiversity, the increase in estuarine habitat is positive. However the value will depend on where the site is situated in relation to other sites and to the surface of the site. Indeed, we can say in general that there is a positive relation between biodiversity and the size of the area. So creating a small marsh far away from other marshes will be less beneficial than creating a large marsh or creating the same small marsh close to another large march. For the functional biodiversity the situation might be different. Adding a small marsh close to the mouth will be completely different than adding the same small marsh in the upper part of the estuary. Indeed, when considering the impact of the marsh on water quality, the volume of water flooding the marsh must be seen proportionally to the amount of water passing at that site.

#### *2.2.3.1 Reconnecting old Elbe side arms*

A multichannel system is very effective in dissipating energy. Also the presence of large side channels (side branches) of the estuary is very efficient for absorbing tidal energy. In the Westerschelde, some major areas like the Sloe and the Braakman have been embanked. These sites consisted of a big creek surrounded by large intertidal areas and a large amount of water entered these sites. The embankment lead to important changes in the tidal characteristics of the Schelde. The maintenance of the present multichannel system is a top priority for the management of the Schelde. Therefore reconnecting old Elbe side arms is a good measure with many potential benefits.

So in general it can be stated that reconnecting old Elbe side arms can be a very good measure. The degree to which it improves the ecological functioning and its overall impact on the system is not possible to assess but as mentioned, the impact might be very different depending for structural or functional biodiversity.

Based on the info, projects like the Borsteler inner Elbe, the Alte Süderelbe and Doveelbe are potential very good projects.

Restoration is one part of the coin, maintenance the other. Reconnecting side arms might enhance sedimentation and a very fast silting up. If seen from a sediment management perspective this can be positive, from an ecological point of view negative (but see further).

#### *2.2.3.2 Creation of flooding sites*

Flooding sites are considered here as areas where the tidal influence is increased, or introduced. It is stated that these areas contribute particularly effectively to a reduction of the tidal range, if at low tide the areas dry out as little as possible. These areas can be realized by

- Creation of flooding area in foreland
- Creation of flooding area in harbour basin
- Creation of flooding area by relocating dikes
- Creation of flooding area by reconnecting side arms, etc.

From the list on p.15 of HPA & WSV (2008) it is not always very clear in which way these flooding sites will be created. If it consists of managed retreat or removal of supralitoral habitats, this can be very positive. However if it consists of removing overgrown tidal flats, excavation of tidal flats as mentioned in the table this is most probably negative. A detailed assessment needs a comparison between the present state of the area and the future state. Removing tidal marshes will be regarded as negative as this is a serious loss of habitat that will not be countered by some changes in tidal characteristics as result of it. Excavation of present tidal flats (eg Bishorster sands) is seen as negative.

The concepts such as reconnecting the Dove Elbe and/or the Alte Suderelbe are certainly very interesting projects (see above) as well as the planned Spadenlander Bush/kreetsand area as these add new areas to the estuary. As already mentioned, the final assessment will depend on the detailed design, but these are the right type of measures, as well as removal of silt in harbor areas.

A major problem will be the stability of the area. As mentioned, the efficiency of the restoration site is the bigger, the lesser the area dries out at low tide. However these areas are likely to be important sedimentation areas, getting drier and drier at low tide. If this requires then frequent dredging the overall benefit will be small. In former harbor basins this is not such a problem, on the contrary, these sites could be used as preferential sedimentation areas, as these are what so ever artificial sites. For the other areas this is less likely.

These measures that really add new areas to the estuary (relocating dikes) should be preferred over measures that change existing areas impacted by the tides (with the exception of harbor docks, see above).

Reducing tidal energy by morphological measures is a very important and sensible management strategy, however, this does not protect the area from storm surges. Protection against flooding is a very important objective as it impacts a very large number of people and infrastructure. The approach followed in the Schelde could be used in the Elbe as well. The risk of inundations was calculated as the product of damage x chance of occurring. Based on these risk a system of higher dikes and flood control areas was designed. Flood control areas are low lying polders near the estuary. The dike near the estuary is lowered, a high dike is build more inland. During storm floods water is overtopping the lower dike and water is stored in the polder. During low water, the water stored in the polder is drained towards the estuary again so, the whole storage capacity is available for the next high water. These flood control areas are very important in protecting the land from floodings during storm tides. This system has many advantages. First of all it is a simple and cheap way to achieve safety. On the other hand it prevents any development of housing or construction of infrastructure in these areas close to the estuary. In this way these areas are safeguarded for the future when managed realignment might be necessary in the light of climate change. By combining flood control measures with ecological development higher benefits can be created. This consists of the system of controlled reduced tides within the flood control sites (a reduced tide allows the ecological functioning while keeping the storage volume for storm water). In the Schelde estuary, a small pilot project is realized in 2006 and the results are very promising. Monitoring studies showed clearly that the ecosystem functions are restored (see Jacobs et al. 2009). Now this system is being implemented in some larger projects covering many hundreds of hectares. Although sedimentation in these sites must be limited not to lose the storage capacity, sedimentation occurs and these sites can play a role in the sediment management. The development of flood control areas along the Elbe could be a very cost efficient way to reduce extreme high water levels and meanwhile play a role in the sediment management.

An alternative to these flood control areas with reduced tides is managed retreat. Managed retreat also can have impacts on tidal characteristics if well planned and organized. The success of these measures will entirely depend on the design and the location. If the area will be lowered up to the LW line, depending on the local hdyrodynamics it will develop into a sediment trap similar to some of the silted up old harbor docks with little added ecological value. Managed retreat should be designed in such a way that a mosaic of habitats can develop. It is clear that there might be a conflict between the objectives of creation of flooding areas for influencing tidal characteristics and the objectives of ecological restoration. However, it must be possible to design the projects in such a way that they fulfill both objectives. This might result in a larger area to be flooded, but this extra cost could be compensated by lower maintenance costs.

Recently, the concept of cyclic managed retreat was developed. This is a system in which a polder is flooded again. There will be an important sedimentation and when the level of the polder is high enough and marshes have developed, the polder is embanked again and another polder is flooded. In this concept, there is an increase in flooding areas (intertidal areas), but which areas are flooded differs from time to time. This concept is very interesting. First of all of course the increase in tidal areas can be part of the management strategy to change tidal characteristics, but they also act a sediment trap. Once embanked again, the difference in the level at both sides of the dike is much smaller which improves the stability of the dike. Major disadvantage is of course the large surface of grounds that is needed.

Several other measures are mentioned in the documents as well. The speed of propagation of the tidal wave is considerably influenced by the unevenness of the system. Increasing unevenness of the system by filling deep spots and the creation of underwater deposition areas are seen as positive as well, at least if the sediments will not be removed too fast from these sites.

One important possible drawback of different measures that might reduce the tidal amplitude is that the upper part of the marshes will get lost and become terrestrial habitats. The lower part of the intertidal will become subtidal. This is seen as not so important compared to the gains of reducing the tidal dynamics.

In conclusion we can state that most measures proposed are perceived as positive and are very likely to improve the ecological functioning. However a detailed assessment is not possible and will depend on the detailed design of the projects , the location and the combination of the different measures. The integration in an overall plan is of utmost importance.

## 2.3 What is the assessment of the current practice of using water injection in the Lower Elbe from an estuary ecology perspective? Are there comparative studies elsewhere?

There is very little literature to be found on the impact of water injection dredging (WID). Spencer et al. (2006) warn for adverse biological effects during WID due to the high concentrations of ammonia and toxicants in the pore water. Also Netzband et al. (sd) indicate that little information is available and present some measurements indicating lowering of oxygen saturation after WID.

In se, this might be a useful technique, but the further application might strongly depend on the type of sediment. In sand dunes the environmental consequences are probably minor as the pore water is mostly aerated and no strong biogeochemical effects are expected. In very muddy areas on the other hand, it might be more difficult to use. Indeed, typically only the top few millimeters of the sediment is aerated and in the anoxic porewater high concentrations of ammonia and other chemicals can be found. These sediments are also rich in organic matter and all of these might come in the water column and causing problems. However also by other dredging techniques resuspension occurs and pollutants and organic matter can be mobilized. I did not find any study comparing both techniques in a same environment. So I would strongly propose to set up such measurement before using WID in areas with fine sediments.

## 2.4 What is the assessment of breaking dredging cycles as a priority sediment management strategy from an estuary ecology perspective?

Breaking up sediment cycles consists mainly of the transfer of dredged material to avoid it coming back quickly to the dredge site so that it has to be dredge again. It is clear that reduction of the amount of dredging is beneficial but an overall assessment should weight possible consequences of the transfer of dredged material against the consequences of dredging more often the same sediment at the same place.

The use of the sand fraction for morphological management (see above) is certainly a very interesting option, the evaluation, of course, depends on the individual projects.

The measures presented for the fine material, removing sediment delivery to the flood tide dominated area of the tidal Elbe by relocation from this area, seems a very sensible measure. Also here the option of using the fine material for “building with nature” should be explored and might be more beneficial than just dumping of sediments.

The use of the ebb tides and high river flow in winter to carry fine sediments downstream seems a sensible strategy. As temperatures are low and biological activity is small, consequences for the ecological functioning are expected to be low or nihil. The consequences on sedimentation rates on intertidal areas are unclear. I did not find any suitable information on sedimentation rates on intertidal areas. However, as in these periods, currents and storms are more frequent, it is less likely that and increased sediment transport will also result in unacceptable sedimentation rates on tidal flats and marshes. Indeed, if sedimentation rates are too high, it is known to affect benthic populations if they cannot move as fast upwards as does the sedimentation. It can also affect plant germination and growth on tidal marshes.

The use of side branches as temporary sedimentation areas in the summer period is possibly a very interesting option. The success will however completely depend on the design. If a side branch is connected to the main channel, currents can still be high not promoting sedimentation. If on the other hand currents are low, very high sedimentation rates might occur and the risk exists that “fluid” mud layers (I mean very soft sediments) are created. Although not entirely clear yet, these “fluid” mud layers might be very negative for the water quality. At high tide there is a substantial resuspension and organic matter is coming in the water column. Depending on local conditions this could lead to lower oxygen conditions. So if these side arms should act as a sediment trap during summer and be dredged each winter, this might require very high sedimentation rates, causing ecological problems. Probably a strategy in which as much side arms as possible are used and in which conditions are created that the sedimentation rate is acceptable (few centimeters per year) and the side arms are dredged after a few years (so each winter a number of side arms could be dredged and after a few years the cycle starts again) could be a very interesting strategy.

The construction of sediment traps is another option, but see below.

In general we can conclude that breaking up the sediment cycle is a very positive strategy but care must be taken that it is not just moving the problem from one place to another.

## 2.5 According to what criteria should relocation sites / disposal sites be selected?

Relocation and disposal sites should be carefully selected. Following criteria should be taking into account:

- There might be no negative impact on biogeochemistry/ecological functioning. This means that resuspension of sediments should be minimal as well as the amounts of organic matter and nutrients that is brought into the water column.

- We should try to select all sites in such a way that the sites are not only suitable for getting rid of the sediments, but that sites are selected in such a way that we can make optimal use of the material to “build” habitat structures as explained above. In doing this of course we should think about habitat structures that have a maximal effect on tidal characteristics and on breaking the sediment cycle.

- Although probably very difficult, potential local negative effects should be weighed against larger scale benefits. This might be difficult in the light of present day legislation. So the main criterion should be the impact on the overall ecological and geomorphological functioning.

## 2.6 What is the assessment of the removal of sediments from the Elbe estuary (disposal on land and in the North Sea) in view of the long-term “solids balance” as well as consideration of the concerns of estuary protection, on the one hand, and those of marine protection, on the other hand?

Also here only a general assessment can be made. In principle, no sediments should be removed from the system, as sediments are an essential part of the system. However there are two main reasons why they should be removed, pollution and “too much” sediments.

The assessment of the pollution status of the sediments is not part of this review, but it is clear that major problems exists. Removing the contaminated sediments from the system is therefore a sensible management strategy. Although extremely expensive the processing of sediments in the Metha plant and the land disposal is evaluated as positive. The sea disposal might be a temporary solutions but given the large costs (also the $CO_2$ emission for sailing these distances) it is clearly unsustainable. Also, there is no added value at the dumping site with regard to morphological management. Therefore it would be much preferable to investigate other possibilities to make a beneficial use of the dredged material in the mouth of the estuary, certainly as soon as pollution levels allow.

Removing sediments in the estuary if there should be “too much” sediment is clearly not the right strategy. As sediments and pollutants are to some extend imported by the river, it is obvious that part of the solution must be found upstream. The investments in reducing pollution should be maintained and increased, but also the possibilities for removing sediments upstream should be investigated more in detail.

## 2.7 What is the assessment of the practice of sediment trapping for fine material management?

An efficient way to remove sediments is the construction of sediment traps. The present sediment trap near Wedel has seemingly no impact on environmental parameters and hence on ecological functioning (Winterscheid et al. sd). The efficiency as sediment trap is outside the scope of this review. As it allows to concentrate the dredging activities to certain periods (and of course in space) this can preferable to other dredging activities seen from an ecological point of view.

However, I would strongly advice to study the options of installing sediment traps more upstream, both in the river, upstream Geesthacht and in the port area. Several possibilities exist to increase sedimentation in shallow areas. Using old docks in the harbor might be very efficient to capture polluted sediments before they are mixed with the cleaner marine sediments. So I think sediment traps up and downstream of Hamburg might be beneficial.

Recently a small shallow area was reconnected with the Schelde through a culvert. The sedimentation rates have been in the order of magnitude of 1 meter per month! The area is much lower than the bottom of the culvert so each tide a significant amount of water remains in the area and as it is standing water at that time, sedimentation can take place. Each tide new sediments are brought in resulting in a very efficient sediment trap. This type of constructions could easily be made in the port of Hamburg area.

# 3 Overall assessment

## 3.1 Are the objectives of the RESMC formulated in the work order sensible in your opinion, also in view of the situation in other European estuaries?

- Yes, the objectives are very sensible and in agreement with the situation in other estuaries although they need to be formulated much more precise. Although no really new concepts are described, the overall approach is certainly ahead of many other estuaries/

## 3.2 Do the measures outlined in the RESMC represent overall the right way to achieve the objectives? Are the aspects of nature conservation, water protection and marine protection given appropriate and equally weighted consideration?

- Yes the measures represent the right way to achieve the objectives although it are by now mainly building blocks. However the objectives are defined very narrow in relation to the dredging/sediment problems. In this respect the aspects of nature conservation, water protection and marine protection are not at all equally weighted. The aspects of nature conservation are just mentioned, there is no link at all to the conservation objectives related to EU-HD and ecological functioning is not really mentioned

# 4 Recommendations for the further development of the RESMC

- Based on the above comment, a crucial step is to integrated these RESMC into a broader overall management plan for the estuary. Of course this is a long and painful process but in my opinion it is a crucial and necessary step. Indeed the measures proposed can have multiple benefits going far beyond the benefits for sediment management. Making these benefits clear might also be very helpful in creating a public acceptance for the plan. The concept of ecosystem services might be very helpful in this regard.
- A crucial step is also the formulation of clear and measurable objectives. Now, the objectives are formulated in very broad and general terms like “reduce tidal pumping”, but this is very vague. Integrated objectives, taking into account different objectives is crucial. Then it become also possible to evaluate the multiple benefits from the measures. A table like the one below (Table 4) would make very clear how a measure can add to different objectives

*Table 4: simple representation of how a measure (X or Y) can be beneficial (or not) to different objectives.*

| measure | Obj 1 | Obj 2 | Obj 3 |
|---|---|---|---|
| X | +++ | | ++ |
| Y | | -- | + |

- The success of the plan will also depend largely on the detailed planning of the projects as well as on the combination and the location of many different measures.
- A very detailed an integrated monitoring should be set up. Now already large amounts of data are collected but there seems to be lacking some coordination in the monitoring and there is certainly a need for more integrated reporting of data. The problem of collecting data on birds and benthos is a clear example of this. There is also a clear need for more ecological data from the estuary.
- What about climate change? It is likely there will be major changes in both sea level rise and river discharges. What will be the impact on the strategy should be evaluated and taken into account. Higher discharges, especially during winter, might bring in more sediments and lower discharges during summer might change residence time of the water and all of these will strongly impact the ecological functioning. Sea level rise on the other hand might counteract all measures taken to reduce tidal amplitude. Clearly this should be included in the further elaboration of the management plan.

- If there is a conflict between objectives with N2000 sites, this should be situated in an overall approach and not on a site by site basis

# 5 Overall conclusions

## 5.1 Identify goals

It is clear that the system is under heavy pressure and that management measures are necessary to maintain the different economic and ecological functions at a minimum of maintenance costs. The proposed measures of the RESMC can significantly help in reaching this goal. However reaching this goal requires a number of different issues.

The goals must be clearly formulated. The aims of the concept are obvious, but these aims need to be translated in concrete objectives. The measures proposed help in reducing high water levels, providing flood control, reducing tidal pumping etc. However, although extremely difficult, a start should be made in trying to quantify the objectives. This is important to underpin the size of measures to be taken. If you want to protect the area against storm floods from the North Sea, a measure of safety should be agreed upon and then it becomes possible to calculate the amount of flood control areas needed, in combination with dikes, to accommodate such a storm. This makes the area claims much stronger, as what so ever, there will always be strong competition for the land. If you want to reduce the tidal pumping, this should be translated in the shape of the tidal curve you need to reach to reduce that much of the tidal pumping and then an analysis of the different measures leading to this tidal curve can be evaluated.

Defining the goals should of course be consistent with the environmental legislation.

## 5.2 Environmental legislation

It is also clear that the some measures to be taken might conflict with the present requirements of the environmental legislation. It is likely that a measure in a protected area might result in a different habitat type. This would require a compensation of the lost habitat. If the implementation of the RESMC will be done in this way, this will inherently result in major costs, time loss and in the end no gain for the ecological values. Therefore I would strongly advise to make an overall plan and make a balance of the losses and gains at the level of the estuary and NOT at the level of individual sites. In the same way as I argued above that concrete objectives should be formulated for the goals to be achieved, integrated conservation objectives should be formulated for the estuary. Of course these can be subdivided, as the conservation objectives in the fresh water tidal area will be different from those in the marine part, but they should be formulated in a hierarchical way, what can be formulated for the whole estuary should be done at that level. These conservation objectives should also not be limited to the structural aspects of biodiversity (surface of habitats, population size of species,…) but include functional biodiversity (ecological processes, food web characteristics, nutrient retention, ….). The formulation of overall conservation objectives should be an important aim.

## 5.3 Integrated plan

Although the measures presented in this RESMC are a big step forwards compared to the past, this concept is still not an integrated plan. It can be seen as a crucial step towards a really integrated plan and this plan should be discussed with different stakeholders to add different other management perspectives.

## 5.4 Upstream management

The estuary is and will always been impacted by the discharge from upstream. A enormous amount of measures have been taken the last decades, clearly improving the situation. However still large amounts of sediments, nutrients, organic matter and pollutants are transported towards the estuary. As the estuary lost its function as a sink for nutrients, it remains crucially important to reduce nutrient levels in the catchment, in order to control primary production in the river itself, but also to prevent development of toxic algae in the estuary and to protect the coastal sea. Also the import of sediments from the catchment should be reduced by upstream measures.

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# 7 C.V.

## Curriculum Vitae Patrick MEIRE

**Patrick Meire** studied biology at the University of Ghent. He started his PhD work at the Laboratory of Animal Ecology, Nature Conservation and Biogeography of the University of Gent first with a research grant from the Belgium National Fund for Scientific Research, later as a research assistant. In 1990 he became senior researcher at the Institute of Nature Conservation, a research Institute of the Flemish Government. Since 1995 he holds the chair of Integrated Water Management at the Institute of Environmental Studies of the University of Antwerp (part time visiting professor) and since 1999 he is full time professor at the University of Antwerp, Department of Biology and head of the ecosystem research group. Since 2008 he is also chairman of the institute of environmental sciences and sustainable development of the University of Antwerp.

His research career is focused on the study of environmental impact on aquatic systems. It started with the study of the impact of the construction of a storm surge barrier in the Oosterschelde on waterbirds and macrozoobenthos. This work was extended to study the problems of safety against inundations and effects of dredging in and along the Schelde estuary. The research in the Schelde estuary got focused on the development of a management strategy in which the realization of a nature development plan became a central issue. To underpin this plan a large research project was set up aiming at the construction of an ecosystem model of the estuary. This model is needed to understand the effect of different management options (managed retreat, marsh restoration etc.) on the ecosystem functioning. What is their role in nutrient retention, water storage etc.

The main objective of the research group is to provide a sound scientific basis for nature and ecosystem management in general and integrated water management in particular. Therefore, the research focuses on the ecology of stagnant and running inland waters and estuaries and their associated wetlands. The processes in the land-water interaction along the whole river continuum from source to sea are studied at different scales: from individual organisms, over populations and communities, towards ecosystems and landscapes. These studies, which involve both descriptive and experimental field work, are integrated to make predictions on the impact of different management options on the functioning and biodiversity of the system.

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For more information see: www.ua.ac.be/ecobe

Appendix 1: Data on BOD, oxygen and Chlorophyll a in Snackenburg.

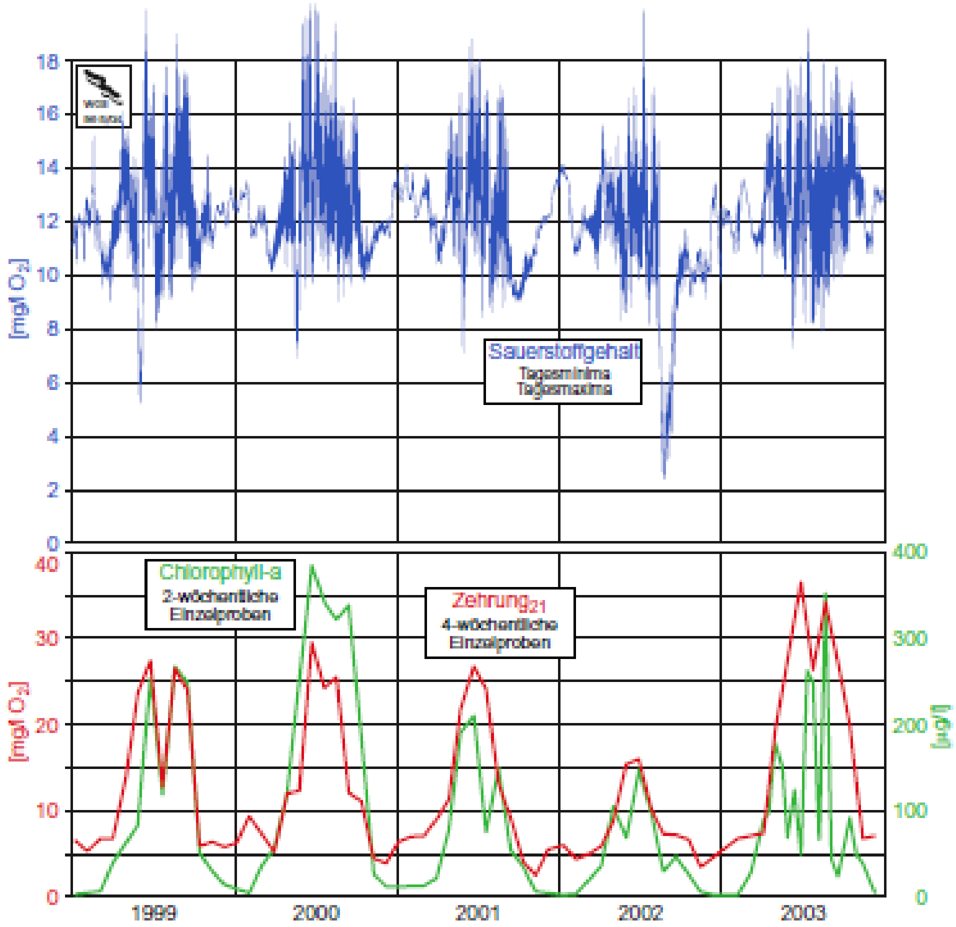


Abb. 6 Sauerstoff-, Zehrung$_{21}$- und Chlorophyll-a-Gehalte der Elbe 1999 - 2003 an der Messstation **Schnackenburg**

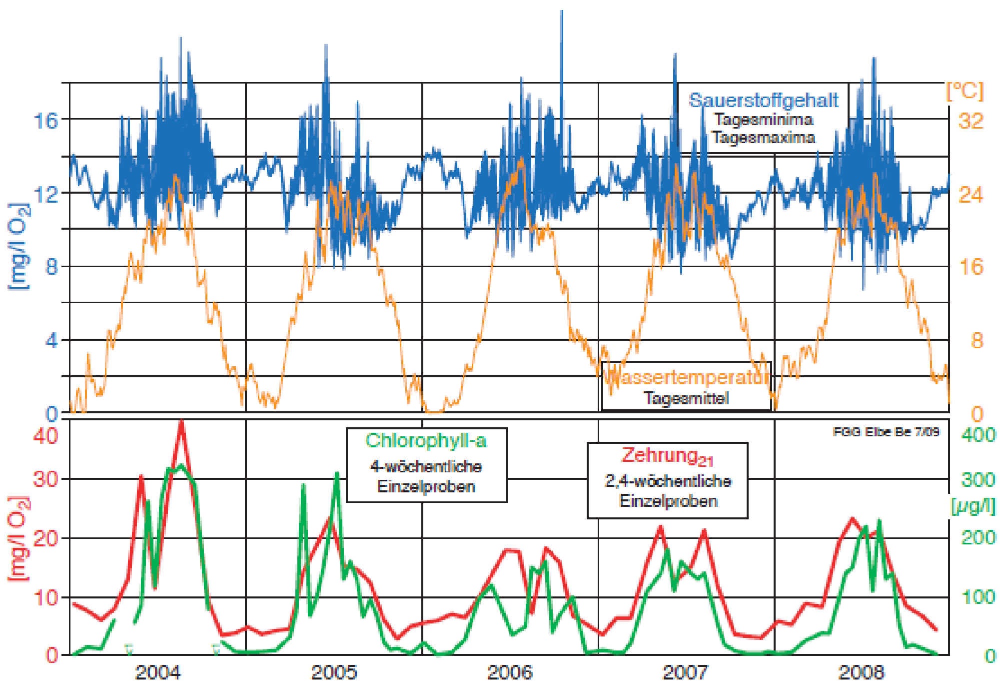


Abb.12 Wassertemperatur, Sauerstoffgehalte, Zehrung$_{21}$ und Chlorophyll-a-Gehalte der Elbe 2004 - 2008 an der Messstation **Schnackenburg**

Appendix 2: Data on BOD, oxygen and Chlorophyll a in Seemannshöft.

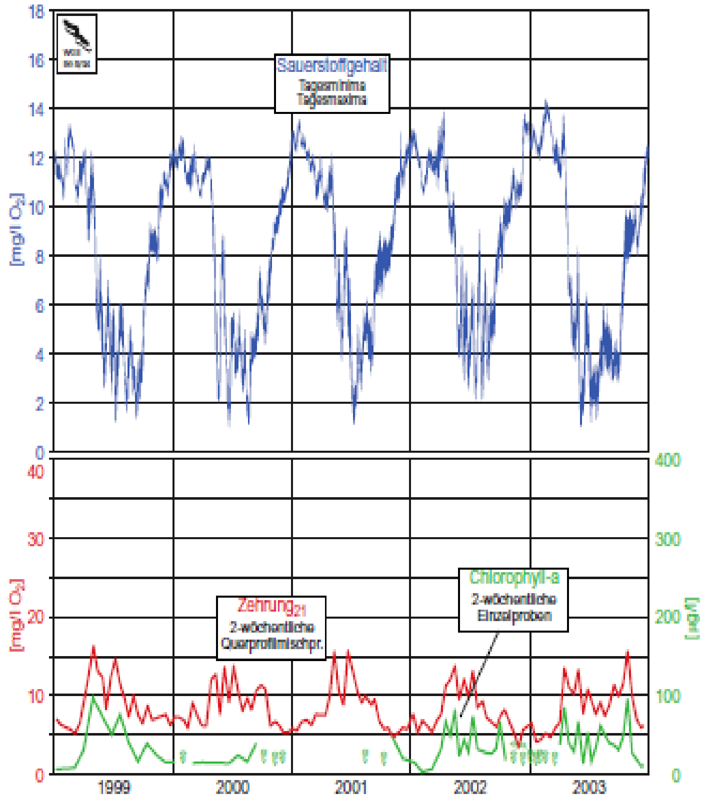


Abb. 7 Sauerstoff-, Zehrung$_{21}$- und Chlorophyll-a-Gehalte der Elbe 1999 - 2003 an der Messstation **Seemannshöft**

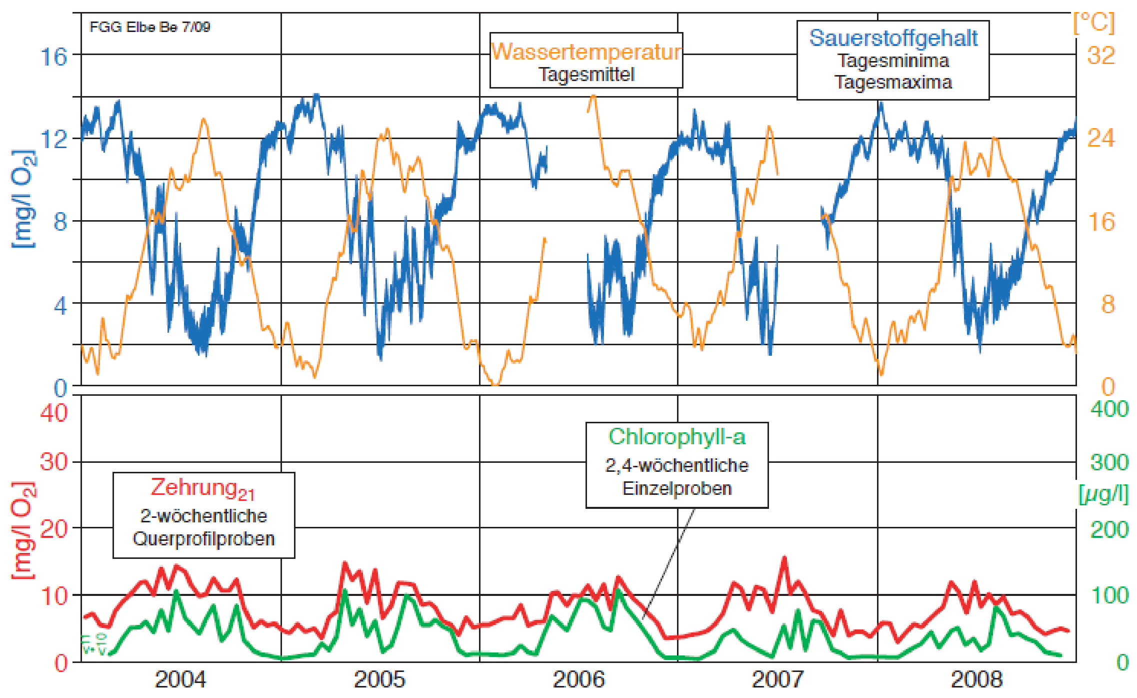


Abb. 13 Wassertemperatur, Sauerstoffgehalte, Zehrung$_{21}$ und Chlorophyll-a-Gehalte der Elbe 2004 - 2008 an der Messstation **Seemannshöft**

Appendix 3.

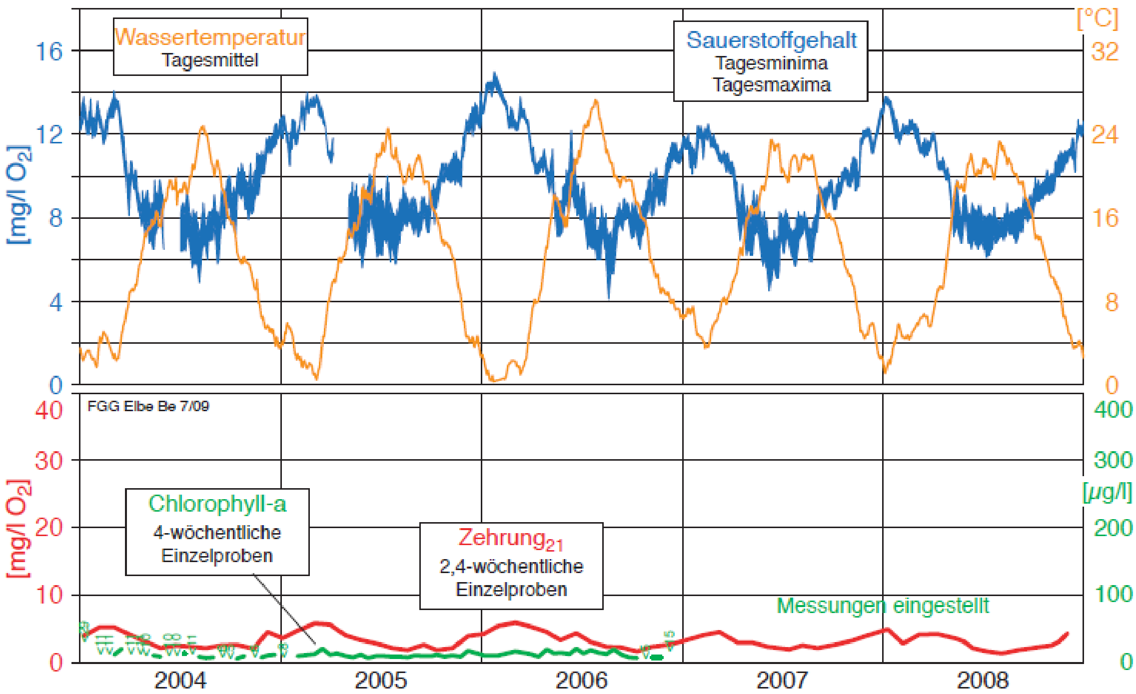


Abb.14 Wassertemperatur, Sauerstoffgehalte, Zehrung$_{21}$ und Chlorophyll-a-Gehalte der Elbe 2004 - 2008 an der Messstation **Grauerort**

Appendix 4:

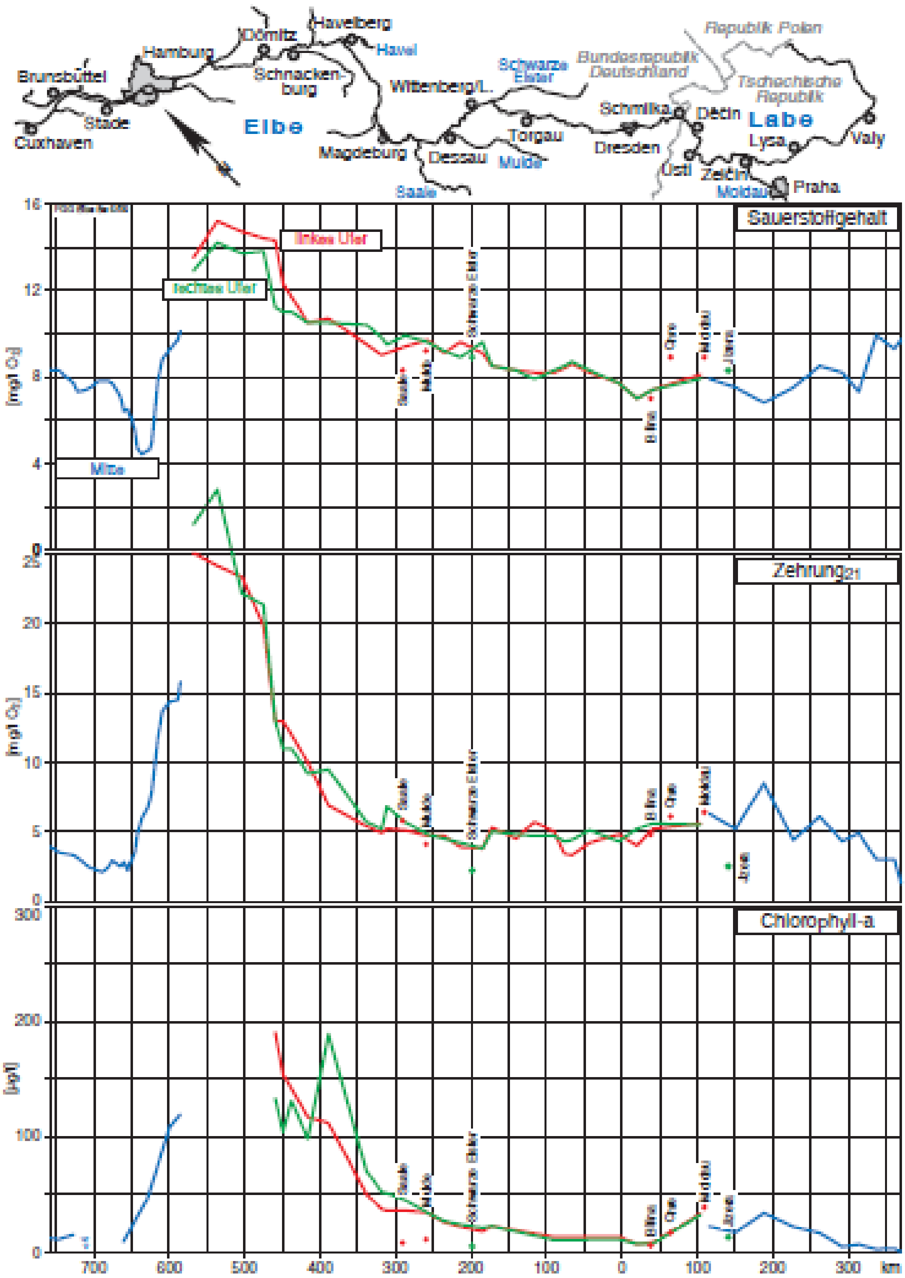


Abb. 15 Sauerstoff-, Zehrung$_{21}$- und Chlorophyll-a-Längsprofil der Elbe am 19.-21. August 2008

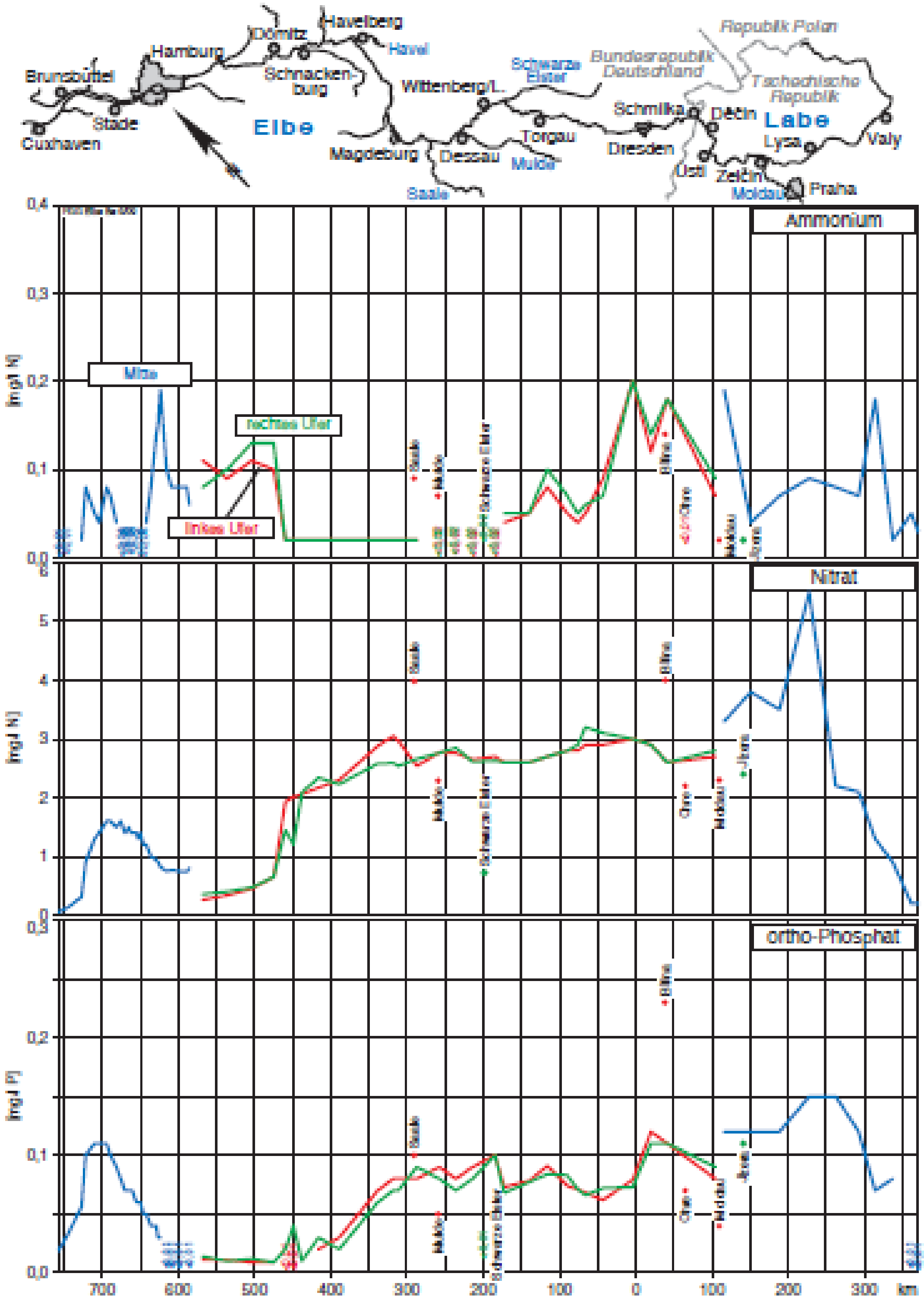


Abb. 21 Ammonium-, Nitrat- und o-Phosphat-Längsprofil der Elbe am am 19.-21. August 2008