

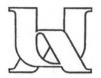


## ECSA LOCAL MEETING

## ABSTRACT BOOK

Ecological structures and functions in the Scheldt estuary: from past to future

Antwerp, Belgium October 7-10, 2002



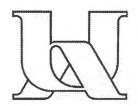


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## **ECSA Local Meeting**

# **Ecological structures and functions in the Scheldt Estuary: from past to future**

Antwerp, Belgium October 7-10, 2002

Conveners: Patrick Meire (University of Antwerp (UIA) Belgium); Stefan Van Damme (University of Antwerp (UIA) Belgium); Carlo Heip (NIOO-CEMO, The Netherlands), in cooperation with Waterways and Marine Affairs Administration (AWZ); Environment, Nature, Land and Water Management Administration (AMINAL), Institute of Nature Conservation (IN); Flemish Environmental Agency(VMM) and financial support of the Fund for Scientific research (FWO).

#### Scope and objectives

This ECSA local meeting will focus on the Scheldt estuary, situated in the Netherlands and Belgium. It is a highly dynamic estuary, the tidal range reaching up to 6 m. This, together with its full salinity gradient, including a 60 km long fresh water tidal zone, makes it a peculiar system. Subject to a strong anthropogenic influence, degradation of water quality and changes in hydrodynamics and morphology are prominent plights. The Scheldt estuary has been studied in numerous research projects, funded by national as well as European resources. It has become one of the most documented estuaries in the world.

In the past, most of the research focused on the saline and brackish part of the estuary. Knowledge of the fresh water part was urgently needed. This demand was met through the OMES integrated research program, which gave rise to the present meeting. This program (Investigation of Environmental Effects of the Sigma plan) was set up in order to underpin alternative ways of dike construction, including the layout of controlled inundation areas. As such, it covers key topics in estuarine functioning such as hydrodynamics, geomorphology, biogeochemistry, vegetation, trophic levels, and ecological modelling.

The scope of this meeting is to present an integrated description of the complete estuarine reach, from freshwater to saline parts, a multidisciplinary approach to the functioning of an estuarine ecosystem, a scientific background for management issues, and views on future research needs. This meeting also fits in the activity program of an international 'Scientific Research Community' around the Scheldt estuary, funded by the Fund for Scientific Research – Flanders (Belgium) and founded to enhance integration of estuarine research efforts, and to propagate the scientific importance of the Scheldt abroad. The Scheldt will be situated in the context of international research of estuarine ecology.

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Estuarine research: the crossing of frontiers

35115

#### C. Heip

Netherlands Institute of Ecology, Yerseke

Estuaries are the transit zones where the river basins drain into the sea. These rivers are convenient borders between countries and historically they have been separating rather than bringing together people. In the present day situation, the handicap of river basins often covering several countries is still all too visible, despite the important efforts to coordinate and tune management and research. The Scheldt is a typical example where historically the interests of different users have often led to conflicts, and this continues till today.

It is well known that human use of the Scheldt has brought the system to the limits of its resilience and beyond. The biogeochemical state of the system has changed in a qualitative way and despite increasing and costly efforts to clean up, it will take many years before it returns to its original state, if at all. In the saline part of the estuary most of the human impact over the centuries has been through constructing dykes and dredging the channels, and restoration of (part of) the original ecosystem will be difficult as well as costly.

All the past impacts and the present international context have greatly stimulated scientific research in the basin. The Scheldt estuary is one of the best studied in the world but still a lot of uncertainties exist. This may be due to intrinsic characteristics of the basin (a difficult river system to understand) or because the research itself has been fragmented, within the agencies and the academic institutes and between them, or because the research has been ill-guided (or poor).

In the last few years there have been several efforts to overcome these difficulties and to go for rational management of the entire basin. This will require good cooperation between countries, agencies, academic research and the end-user. The new initiatives (Flemish-Dutch Cooperation in Estuarine Research and the LTV) will certainly help to achieve this long-term objective.

## The Scheldt estuary from past to future: setting the scene

#### P. Meire, S. Van Damme and E. Struyf

Ecosystem Management research group, University of Antwerp

The Scheldt estuary, the tidal part of the river Scheldt, is 160 km long, which is little less than half the total length of the river! This situation came about since the Middle Ages due to a complex interaction between sea level rise and large scale embankments resulting in a gradual upstream movement of the tidal limit. The presence of tidal marshes and flats along the whole salinity gradient is a rather unique feature and their inherent biological value resulted in many conservation measures. However, the estuary is nowadays subjected to many anthropogenic pressures resulting in habitat loss and degradation, bad water quality and increased risks of inundation. Some major trends will be presented. Water quality is improving, oxygen levels increased, heavy metal concentrations decreased but nutrient loads still increase and signs of eutrophication can be seen. Major morphological changes occurred and very high sedimentation rates on both tidal marshes and flats result in a change of inundation period, on marshes leading to major changes in vegetation.

Towards the future we will have to deal with major new challenges: what will be the impact of global change (sea level rise, changes in discharges), the impact of changes in land use and management in the Scheldt basin, morphological changes in the estuary due to further dredging etc. The possible consequences of some of these expected changes will be explored.

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3.

An antagonist holding a mirror: the Seine estuary

A. Romaña IFREMER

Over the centuries nature has shaped the estuaries and conferred on them great biological potential. Because estuaries are located at interfaces between the river catchment's area and the sea, their physical, chemical and biological characteristics have been strongly modified by human activities through settlements, contaminants inputs and waterways constructions to satisfy navigation. The same processes which give them their biological richness (salinity gradient and mud retention) are also those which contribute with the action of pollutants to their degradation. Like the Scheldt, the Seine estuary illustrates these problems.

After outlining the actual estuary characteristics, we will examine: (1) the shape history and progressive lost of volume and surface, (2) the economic activities related to the Seine estuary and their consequences, (3) the classical progressive increase of problems of water quality and measures adopted to improve it, (4) the restoration prospects, and finally (5) the initiative to build a multidisciplinary and applied scientific program (Seine-Aval) to support political decision in solving these kinds of problems.

On the other hand, the recent awareness of the state of extreme degradation of this particular environment and a new important harbour project have conducted to the idea of a "global management of the Seine estuary". We are going to explain how today this general idea has begun to be applied.

4. Morphological changes in the scheldt estuary and its consequences on hydrodynamics

J.C. Winterwerp, Z.B. Wang, J.A. van Pagee, F. Mostaert, Y. Meersschaut, T. De Mulder and J. Claessens

This paper starts with a brief physical description of the estuary and a summary of its historical developments, with emphasis on human interference, such as the loss of storage area in the basin, sediment circulation by dredging and dumping, etc.

Next, the various relevant hydrodynamic processes are described, responsible for the morphodynamic development of the estuary:

- · tidal asymmetry, length of ebb and flood period, length of HWS and LWS-period, and
- effect of the hypsometry (cross sectional shape of the estuary) on the tidal propagation.

The impact of morphological changes on the overall tidal movement and on the overtides is treated in the last two sections of the paper. Where possible, the interaction between morphological changes and water movement is discussed.

#### Freshwater management in the Scheldt basin and consequences for discharges in the Zeeschelde

#### K. Van Eerdenbrugh, F. Mostaert, J. Baetens and J. Balduck

The rivers Scheldt and Meuse are the main water bodies of the major river catchment area in Flanders. Both have international dimensions having their origin in France and flowing into the North-Sea in the Netherlands. Therefore, an important part of the water supply in Flanders depends on upstream water management. The catchment areas are linked by a network of channels, supplying the Scheldt Estuary with a considerable amount of Meuse water. Links also exists between several subcatchment areas of the river Scheldt.

Balanced internal water management implies, among other things, an efficient set of measures (permanent and operational) necessary for intervention during low flows. In order to substantiate the choice of strategy, knowledge of the quantitative aspects of supply (water balance), demand (users and consumers) and potential measures is necessary.

The final step is to translate those aspects into a concrete, practical and acceptable low flow scenario.

The lecturer will handle briefly several aspects of water supply and distribution in the catchment area of the river Scheldt. An overview will be given of the way in which the Flemish Administration deals with the existing bottle-necks, currently and in the future.

6. Sediment discharge in the Scheldt estuary

35124

### F. Mostaert, K. Maeghe, J. Engels and E. Taverniers

The environmental effects of erosion, movement and deposition of sediment can be serious. The variation in drainage basin and precipitation characteristics results in significant differences in the quantity of fluvial sediment. This difference requires the manager of the navigable waterways in Flanders (Administration of Waterways and Marine Affairs, AWZ) to monitor the suspended sediment transport at the upstream boundaries of its territory. This monitoring network provides sediment data that can be used to (1) evaluate the effects of landmanagement practices that will reduce erosion rates, (2) determine the morphological effects of riverbed enlargment measures, (3) estimate the quantities to be dredged (4) fulfill the monitoring aspects of the EU Water Framework Directive, (5) enlarge the knowledge of the watersystem and (6) provide basic information for treatment of dredging material.

The approach consists of a continuous hourly monitoring method completed with topographical cross section measurements, measurements of turbidity samples, calibration of the turbidity monitor and correlation between local turbidity and cross section turbidity. Finally sediment transport is calculated from turbidity and validated discharge measurements.

Sediment data were collected at eight stations from 1999. Data for 1999 and 2000 were published in the annual report.

Data collection at different locations and processing of sediment samples will continue. All data will be published in annual data-reports and in the future on the internet.

7. Sediment transport in the seine estuary

35126

## P. Le Hir<sup>1</sup>, P. Lesueur<sup>2</sup>, J.P. Dupont<sup>3</sup> and R. Silva Jacinto<sup>1</sup>

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First the physical forcings (tide, waves and river flow) of the macrotidal Seine estuary are reminded, as well as the main geometrical features. Then, the morphological evolution of the estuary since the XIX<sup>th</sup> century is presented: a strong reduction of intertidal areas is pointed out, and a general progradation of sediment deposits at the mouth is described: progressively the estuary tends to behave like a delta.

In a second section, the distribution of the surficial sediment is commented: in the upper estuary the bottom is mainly gravelled, but narrow muddy intertidal flats are observed on the sides and between small islands. Downstream in the channel, the sediment cover is sandy and rippled, and is proved to move upstream in some circumstances. At the mouth, fine sand is dominant, but cohesive sediment patches are more and more numerous, and muddy areas are in extension. An important feature is the seasonal variability of the fine sediment deposits, which depend on the wave and river flow regime.

The third part concerns the sediment transport. The upper and lower estuaries are considered separately. The former experiences periods of fine sediment accumulation followed by a mean flux in the downstream direction, but after the high river flow, inducing a phase-lag between the river input and the flux into the lower estuary. In addition, a significant part of the river input is trapped in the Rouen harbour. Interestingly, marine particles have been proved to move far upstream in the estuary, thanks to radioactive tracers.

Downstream, the movement of sand is commented, in relation with the tidal currents asymmetry, modified by submersible dykes built in the seventies. The potential role of dredging and sediment outfall is discussed. A deeper insight is given on the cohesive sediment movements and the turbidity maximum, by means of a validated numerical modelling. The respective roles of the fortnightly tidal cycle and the river regime are pointed out, but also the impact of waves: for instance, local measurements on intertidal flats showed that a single storm is likely to resuspend a sediment mass of the same order of magnitude as the one constituting the turbidity maximum. Fluid mud patterns have been observed mainly in two locations of the channel, and can be related either to the tide and river regime concerning the upper one, or to the wave regime for the other one. Lastly, attention is paid on the (cor)relation between waves and wind, with possible consequences on suspended sediment tracks following wave-induced resuspension.

Also, a regular monitoring of the estuarine water showed that the turbidity maximum and the associated fine sediment deposits moved downstream during the last 30 years, due to the engineering works in the lower estuary.

Last, computations of sediment budgets and fluxes are given in different locations of the estuary, and the relation with physical forcings is discussed.

## Life in an extreme environment: phytoplankton blooms in the upper Scheldt estuary

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Being extremely turbid environments characterised by short residence times and rapid changes in salinity, the upper reaches of estuaries comprise an extreme environment for phytoplankton to live and grow in. Nevertheless, in many estuaries including the Schelde estuary, these reaches often support dense phytoplankton populations. In the past, these phytoplankton blooms in the upper reaches of estuaries have often been found difficult to explain. In this presentation, we will describe the extent and composition of phytoplankton blooms in the upper Schelde estuary and aim to evaluate the environmental conditions that allow these blooms to occur. In addition, the importance of these blooms in the functioning of the Schelde ecosystem will be discussed.

Suspended solids, light penetration and primary production in the Scheldt estuary

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In strong tidal estuaries such as the Scheldt, the hydrodynamic conditions display large variations, with current velocities ranging from zero during slacks up to 2 m.s<sup>-1</sup> during ebbs and floods. This highly fluctuating water velocity induces a periodically varying shear stress at the sediment-water interface, resulting in a cyclic pattern of sedimentation and resuspension. As a result, the suspended solid concentration in the water column follows a marked tidal fluctuation which causes significant variations of the light-attenuation coefficient. Since the underwater light field depends on both the incident light and the light-attenuation coefficient, the instantaneous light availability (PAR) in the water column has to be computed from these two periodic signals.

In this paper, we present some characteristics of the underwater light field in the Scheldt estuary. We show that the estimation of gross primary production (GPP) by phytoplankton is strongly affected by the time-variation of the light-attenuation coefficient  $(k_d)$ . In particular, the common practice of considering a constant (time-averaged)  $k_d$  value leads to an erroneous assessment of the time- and depth-integrated GPP. Finally, we show some estimates of the phytoplankton net primary production (NPP) in the Scheldt, computed from a coupled model that takes into account the hydrodynamic conditions, the light penetration and the phytoplankton dynamics.

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Spring zooplankton communities in the Scheldt estuary: from the 60 ties till present

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Abundance and taxonomical composition of the spring zooplankton community in the Scheldt is compared for the brackish water zone and the fresh water zone using data collected in the 60'ties, the 80'ties, the 90'ties and in spring 2002. Zooplankton spatial distribution is related to oxygen concentrations and particulate matter concentration and composition and hydrological conditions. Special attention is given to the Calanoid copepod *Eurytemora affinis* 

## The predation impact of herring and sprat on estuarine zooplankton in the Scheldt estuary

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Every winter, young-of-the-year herring and sprat migrate to North Sea estuaries and become the dominant member of the estuarine fish assemblage, both by numbers and by biomass. These winter migrations have been related to abiotic factors (temperature and salinity), estuarine productivity and the reduced predation pressure in turbid brackish water areas. During estuarine residency, herring and sprat mainly feed on calanoid copepods. We have estimated the food consumption of zooplankton (g C m<sup>-3</sup> day<sup>-1</sup>) by herring and sprat which overwinter in the Scheldt estuary using two models of feeding in fish: a bioenergetic model based on physiological parameters and a model based on the change in stomach contents over time. To assess the impact of fish on the copepod biomass of the brackish part of the estuary, we have developed a simple copepod biomass model and included food consumption by fish as a biomass sink. In general, the consumption of zooplankton by fish is too low to represent a major source of copepod mortality. The low impact of fish predation may be a function of the low fish biomass in spring at a time when copepod production increases.

### Evolution of mud in the Scheldt estuary

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For a sustained management of a man-made estuary like the Scheldt estuary knowledge of the behaviour of fine sediments and the mud balance—is necessary because fine sediments determine habitats, provide food for organisms, transport contaminants, determine the pollution status of the bottom sediments and influence the access from the shipping channel to the harbour (docks). The determination and the monitoring of the mud balance of an estuary is however difficult to accomplish especially when anthropogenic influences are profound like in the Scheldt estuary. For some elements of the mud balance of the Scheldt estuary quite a lot knowledge has been obtained the last decade. The following elements of the mud balance will be discussed.

- 1. The occurrence of mud in the estuary. Mud occurs on the tidal flats near the salt marsh (mud flats), in harbours with a free opening to the river, and also, in the high turbidity zone of the Beneden ZeeScheldt (middle estuary) in the river channel. The sediments in this area are sandy muds and differ from the mud in the access channels mainly by the amount of sand.
- 2. The supply of fluvial mud to the estuary. This supply has been estimated with some degree of precision for the last 10 years. It decreased from 1992 till 1996 from 250 ktons to 95 ktons and from then on increased again to 350 ktons.
- 3. the evolution of the quantities (stock) of mud in the bottom sediments in the Beneden ZeeScheldt. With bottom maps, compiled by several authors between 1963 and 1999, the change in mud volume in the bottom sediments in the Beneden ZeeScheldt can be evaluated. Between 1964 and 1986 the mud volume increased with 2% per year. Between 1986-1999 a further increase of 0.7% per year, is observed. Most of this "new and polluted" mud has sedimented in the access channels to the sluices of Zandvliet, Berendrecht and Kallo and is removed from 1993 onwards, especially from the access to the Kallo sluice by a large scale operation. The 2.8 million tons of sediments removed are dumpted in a harbour dock on the left bank. From the data it can be concluded that during the post-1986 period the mud supply to the river bed has been reduced by approximately 50% compared to the previous period.

- 13. Biotic effect on sedimentary processes in intertidal areas
- J. De Brouwer, E. Dedeckere and P. Herman

Abstract not submitted

## Sediment dynamics and geomorphic changes in tidal marshes

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Tidal marshes act as net sinks of sediment, which leads, in the long-term, to geomorphic and ecological changes of marshes and estuaries. Tidal marsh sedimentation is studied in the Scheldt estuary on different spatial and temporal scales.

On the small-scale (10-100 m and 1 tide to 1 year), field measurements show that temporal variations are controlled by a positive linear relationship between incoming suspended sediment concentration (SSC), at the beginning of marsh flooding, and maximum inundation height, at high tide. The spatial sedimentation pattern is determined by three parameters: elevation of the marsh surface, distance to the nearest tidal creek, and distance, along this creek, to the marsh edge.

The long-term (10-100 years) implications of these sediment dynamics were investigated using a physically-based numerical model, which takes the observed increase of incoming SSC with maximum inundation height into account. The modelling results, which are in good agreement with observed long-term accumulation rates, show how young low marshes accumulate much faster than old high marshes and how both tend to the same equilibrium elevation. This explains the generally flat topography of tidal marshes. The model also simulates the fast formation of natural levees along tidal creeks, and also here a geomorphic equilibrium exists: once levees grow 20 to 30 cm higher than inner marsh basins, which are located farther away from tidal creeks, the influence of distance to the tidal creek is compensated by the influence of surface elevation, so that levees and lower marsh basins accumulate at the same rate.

## Variations of water quality in the Scheldt estuary

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Since December 1995 the monitoring of the Scheldt estuary is integrated in a coordinated border-crossing campaign from river mouth to the upper tidal reach. Concentration profiles showed an improvement of the water quality. Is monthly monitoring of surface water sufficient? The monitoring results are situated in a frame of estuarine variations. Nitrogen concentrations changed within a vertical salinity gradient in the brackish zone. Tidal cycles can show peculiar patterns. The water quality picture changes when discharge is taken into account. A five-year period of continuously increasing discharge was used to study possible impact of global change on estuarine nutrient fluxes. In the upper freshwater parts of the estuary, higher discharges resulted in lower N and P concentrations due to dilution. Silica concentrations strongly increased at higher discharges due to flushing of diatoms. Lower residence times in the freshwater zone resulted in a negative effect on water quality further downstream. Nitrate and silica concentrations in the coastal waters, two major actors in coastal eutrophication, were significantly correlated to total yearly discharges observed upstream.

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16.

## Suspended Matter in the Scheldt Estuary

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The Scheldt estuary is characterised by a specific energy pattern resulting from the interaction of tidal energy, river energy and wave energy. Suspended matter (SM) transport and distribution along the estuary is powered by and follows this energy distribution pattern. Observation of SM transport shows the existence of three estuarine turbidity maxima (ETM), an important one between Lillo and the Rupel mouth, a second one at the estuarine mouth in front of the Belgian-Dutch coast, and a third one near Ghent. Fluvial-marine equilibrium of SM exhibits 90% of marine origin at the estuarine mouth, 30% at the Belgian-Dutch border and decreases gradually to Ghent. SM is a key parameter in an estuary, because it determines habitats, is involved in food web, and transports contaminants. The characteristic of SM is induced by and is a function of e.g. tidal phase, spring-neap tide, longitudinal and vertical distribution mechanisms, seasons, short and long terms of anthropogenic influence and/or estuarine maintenance. SM consists of a variable amount of an inorganic fraction (average of 89%) and an organic fraction. The grain-size of the inorganic fraction shows distinctively different types in the upper, middle and lower estuary as well as along the water column. SM occurs largely as flocs, which size is remarkably larger in the upper part of the estuary. These flocs not only harbour suspended sediments, nutrients, contaminants as well as organisms, but also provide a microenvironment with its ecological function, which is subject to anthropogenic influences. Finally the effect of anthropogenic impact on the SM characteristics is illustrated with the example of maintenance dredging of the shipping channel and harbours.

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#### 17.

#### Methane and nitrous oxide in tidal estuaries

### J. J. Middelburg, M. de Bie, J. Nieuwenhuize and BIOGEST partners Netherlands Institute of Ecology, Yerseke

Estuaries contribute significantly (5-10 %) to the marine emission budget of methane and nitrous oxide. During the BIOGEST project we have measured the distribution of these two gases in the water column of nine tidal estuaries.

In well-mixed estuaries, methane concentrations were high in the river end-member and initially decreased with increasing salinity, then increased at intermediate or high salinities before decreasing again going offshore. Tidal flats and creeks were identified as a methane sources to estuarine waters. Methane concentrations in river-dominated stratified estuaries were rather erratic.

Nitrous oxide concentrations were always above atmospheric saturation levels and showed consistent and systematic relationships with distribution patterns of oxygen, ammonium, nitrite and nitrification activities. Nitrous oxide concentrations were very high in ammonium-rich and oxygen-depleted systems such as the Scheldt and Thames estuaries. Nitrous oxide concentrations were also high in the suboxic zone of fluidised mud systems of the Gironde estuary. If time permits, we will show laboratory results for nitrous oxide production in Scheldt water and we will speculate on the role of sediment versus water-column processes.

Dissolved inorganic carbon dynamics and CO<sub>2</sub> atmospheric exchanges in the inner and outer Scheldt estuary

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Université de Liège

Since 1992, the Chemical Oceanography Unit of the University of Liège has carried out on a regular basis field cruises in the Scheldt inner estuary and the river plume (outer estuary), during which were measured: pH, total alkalinity, dissolved inorganic carbon, partial pressure of CO<sub>2</sub> (pCO<sub>2</sub>), dissolved oxygen and atmospheric flux of CO<sub>2</sub>. In the inner Scheldt estuary, pCO<sub>2</sub> values in the upper estuary can be as high as 9000 ppm that is about 25 times the value of atmospheric equilibrium (presently around 370 ppm). These high pCO2 values induce a high CO<sub>2</sub> efflux and the entire Scheldt can emit up to 790 tons of carbon per day (tC day<sup>-1</sup>) to the atmosphere. The annually integrated CO<sub>2</sub> emission is estimated to 456 tC day (Frankignoulle et al 1998 Science 282: 434-436). Along the salinity gradient, dissolved inorganic carbon dynamics are dominated on one hand by nitrification at salinities around 5 and on the other hand by dilution. Total alkalinity is not conservative in the upper estuary (salinity 0 to 5) due to intense nitrification which produces H<sub>3</sub>O<sup>+</sup> and leads to a decrease of total alkalinity and a minimum of both pH and oxygen saturation level. For salinities higher than 5, total alkalinity has a conservative behaviour (Frankignoulle et al 1996 Limnol. Oceanogr. 41: 365-369). A simple carbon budget shows that aerobic heterotrophic activity and nitrification produce similar amounts of CO2 and can explain most of the CO<sub>2</sub> emission from the inner estuary to the atmosphere. The input of CO<sub>2</sub> from fresh water inputs represents only 10% of aerobic heterotrophic activity and nitrification and 10% of the estuarine emission to the atmosphere. The advective flux of CO<sub>2</sub>, from the river to the estuary and from the estuarine mouth to the North Sea are one order of magnitude lower than atmospheric exchange in the estuarine zone (Abril et al 2000 Comptes Rendus de l'Académie des Sciences Paris 330: 761-768). In the outer Scheldt estuary, pCO2 shows a distinct seasonal evolution related to the cycle of biological activity. Throughout the year, the river plume is over-saturated (average pCO<sub>2</sub> value of about 450 ppm) except during the *Phaeocystis* bloom when values of pCO<sub>2</sub> as low as 50 ppm are observed (Borges and Frankignoulle 1999 J. Mar. Syst. 19: 251-266). The outer Scheldt estuary emits CO<sub>2</sub> on an annual basis at a rate of about 110 tC day<sup>-1</sup> that corresponds to about 25% of the emission of CO2 by the inner estuary. A simple carbon budget shows the input of CO2 from the inner estuary contributes to about 30% of the emission of CO<sub>2</sub> from the outer estuary. The remaining emission of CO2 is from the net heterotrophic activity fuelled by organic carbon inputs from the inner Scheldt estuary and the Belgian coast (Borges and Frankignoulle 2002 Biogeochemistry 59: 41-67).

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19.

## The nitrogen cycle in the Seine en Scheldt estuaries.

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The Seine and Scheldt estuaries are both located in the same geographical area and they represent important tributaries of the North Sea. Due to their high population density and large agricultural areas, the Seine and Scheldt estuaries receive extremely high nitrogen loads, mainly originating from wastewater and land fertilisers. The way this nitrogen is transformed in the system and exported to the North Sea depends on the characteristics of each system. The Seine and Scheldt estuaries are the outlet of river systems with respectively 78600 km² and 21500 km² watershed area, 420 and 108 m³/s average discharge, 46 and 40 % of agriculture area, and 195 and 425 inh./km² population density. Major difference between the estuaries lays in their hydrological characteristics. While the Seine estuary is typically channelled over most of its length with very reduced intertidal areas and short residence times (in the order of 1 week on the average), the Scheldt estuary has a typical funnel shape with large intertidal areas and long residence times (in the order of 1 month). The influence of these characteristics on major N-transformation processes (inorganic N assimilation by plankton, organic N mineralisation, nitrification, and denitrification) is presented and discussed, and the importance of both estuaries as sources of N for the North Sea is be evaluated.

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Whole ecosystem <sup>15</sup>N labeling to identify nitrogen cycling in marshes.

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It is generally thought that fringing marshes act as a filter for the estuarine water by removing inorganic and organic forms of nitrogen from the floodwaters. We studied this process in an integrated *in situ* study on the processing and retention of nitrogen in a tidal freshwater marsh. The study is a combination of a whole ecosystem <sup>15</sup>N pulse labeling study with a classical exchange study.

<sup>15</sup>N-ammonium was added to the incoming tidal water in a small creek feeding an isolated freshwater marsh area (app. 3500 m<sup>2</sup>). The processing of the <sup>15</sup>N label by the marsh was subsequently followed in the flood and ebb water of several consecutive tides as well as in important sinks within the marsh (sediment and plants). Furthermore, the incorporation and transfer of <sup>15</sup>N into the benthic marsh food web was studied. Discharge characteristics of the creek such as tidal height, water movement and concentrations of the different N pools were assessed over the entire study period.

The first results reveal that label was successfully distributed within the entire marsh. In the water phase the <sup>15</sup>N label was recovered in all the pools analyzed (NH<sub>4</sub>, NO<sub>3</sub>, N<sub>2</sub>O, N<sub>2</sub> and PN) suggesting nitrification to be an important process. The long term objective of the project is to construct an integrated view of the role of tidal marshes in the nitrogen retention and processing of ammonium and nitrate in a typical marsh system.

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Upstream from the estuary: Modelling processes in the drainage network of the Seine and Scheldt basin

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The biogeochemical behaviour of any estuary is deeply influenced by the riverine input of material originating from the upstream watershed area. Land use and urban activity in the catchment, as well as processes leading to transformation, retention or elimination of chemical species during their downwards transfer through the river system, are therefore quite important to understand and model for understanding the functioning of an estuary.

The Riverstrahler model has been developed for establishing the link between the biogeochemical functioning of large river systems and the constraints set by the meteorology, the morphology of the drainage network and the human activity in the watershed. This approach has been applied to the Seine River System (Billen et al, 2001) and allowed to explain the observed long-term trends in water quality changes over the last 50 years, as the combined effects of climate variations and urban, industrial and agricultural development.

Here we apply the same retrospective approach to the Scheldt River System, using water quality data at the entrance of the estuarine zone available since the 1960'ies. Based on this analysis, we compare the long term trends of human development, as well as the resulting riverine processes, in these two contrasting basins.

Trace contaminants in water-column and food-web of the Scheldt estuary

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Action plans for a better protection of the North Sea were presented at the successive North Sea Conferences. These plans included far-reaching undertakings to reduce aqueous discharges and atmospheric emissions of substances such as trace metals that are toxic, persistent and liable to bioaccumulate. For cadmium, lead and mercury the reduction targets were achieved, but an additional effort is necessary for copper and zinc. It is interesting to compare, for the various trace metals, the above mentioned emission reduction percentages with the immission reduction levels observed in the Scheldt estuary over the same period.

The Scheldt estuary is not only a receiving water body: evacuation of pollutants to the sea, storage in the bottom sediments and depuration via efflux to the atmosphere all contribute to a reduction of the metal burden in the water column. All in- and outgoing flows have been put together in a box-model, and a mass balance for each box has been calculated. Only in 5 boxes on 30, the imbalance was larger than 20% with a highest value of 29%.

For mercury, also the food-chain transfer in the Scheldt, including bioconcentration and bioaccumulation factors, has been studied. Despite the fact that Hg levels in the Scheldt estuary are much higher than in the North Sea, it appears that Hg concentrations in fish are even slightly lower in the Scheldt. A more striking observation is the very low MMHg fraction in Scheldt fish (average 57%), compared to that in North Sea fish (average 95%).

## Geochemical properties of sediments in the Scheldt estuary with emphasis on trace metals

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Surficial sediment of the Scheldt estuary were collected with a Van Veen grab at 57 stations between Temse and Vlissingen. They were analyzed for major elements (Si, Al, Fe, Ca, Mg, Na, K, Corg, Cinorg, Norg and P) and trace metals (Mn, Cr, Ni, Co, Zn, Cu, Cd, Pb, Li). Factor analysis indicates that 44% of the variance can be explained by one factor which exhibits a high saturation for trace metals, organic matter, Al and Fe, all variables typical of fine muds. The high scores of this first factor are almost exclusively present in the upper estuary except for one area in front of Terneuzen. The second factor which explains 23% of the variance is typical of the carbonates and the third one (19% of the variance) is representative of the clay minerals. These two factors are more evenly distributed over the estuary.

As usual, there is a strong influence of granulometry on the distribution of elements in the sediments. Intercomparaison of their composition within the Scheldt or with other aquatic systems require thus a normalization procedure. This problem has been studied in detail by analysing various size fractions (63-16:; 16-8:; 8-4:;<4:) separated by elutriation or by using a typical parameter of the fine fraction such as the specific surface area of the samples or the concentration of a selected element (Al, Fe, Li, Corg). The normalization of trace metals allowed us to evaluate an enrichment factor of the trace elements in the estuarine deposits due to man's activities. In addition, it allows also to demonstrate the marked decrease of the anthropogenic impact by comparing the composition of sediments collected in 1976 and in 1994.

Finally, we have developed a new method based on the titration of the suspended sediment with HCl, which allows to gain information on the speciation and potential reactivity of trace metals. This method indicates the Zn and Cd are associated with sulfides and are rather reactive. Copper is released together with Al indicating a possible link of this element with clay mineral whereas Pb and Cr are redissolved together with Fe. The dissolution curve also indicates that Mn is present as rhodochrosite in the easily dissolving carbonate phase and as oxy-hydroxide in the more refractory phase. Mn is strongly correlated to Co.

From fluxes to bioavailability and effects of micropollutants in the Scheldt estuary

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The Scheldt estuary receives large amounts of pollutants from mainly freshwater sources. This results in rather strong decreasing pollutant gradients from the freshwater to the seawater end of the estuary. Although the situation has improved considerably over the last decade the gradients are still clearly present. Metal and organic pollution loads are usually expressed in terms of the total concentrations of the pollutants present in the exposure phases (i.e. dissolved, suspended, sediment). However, in many cases there is no clear relationship between the concentrations of the contaminants in the environment and the accumulation and effects in biological systems. This is related to the fact that both uptake and effects strongly depend on the biological availability of the pollutants and on the physiological organisation and condition of the organisms being exposed. The situation is especially complex in estuarine systems such as the Scheldt, which are characterised by relatively strong salinity and pollution gradients. The development of functional models for the effects of pollution on estuarine organisms requires the coupling of exposure, to accumulation and effects data taking into account changes in abiotic and biotic conditions. Using both field and laboratory approaches the effect of exposure conditions on the accumulation and toxicity of heavy metals and some classes of organic microcontaminants are studied using sentinel organisms such as the blue mussel, Mytilus edulis. The results are used to evaluate the pollution status of the Scheldt estuary, determine the relative importance of different exposure routes and set exposure treshold values based on exposure-effects relationships.

Environmental risk assessment of contaminants in the Scheldt estuary: integrating exposure and effects

C. Janssen

Abstract not submitted

## Process Ecology: Another Perspective on Causality in Nature

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In the normal scheme of science, all causes are assumed to be efficient (mechanical) and to propagate from smaller-scale phenomena to larger. Ecosystems science does not readily conform to such a scenario: It is primarily relational in nature, and much emphasis to given to the role of context in ordering affairs. It can be argued that agencies other than those mechanical are operative in ecosystems. Specifically, configurations of processes are often more enduring than their constituent populations and mechanisms. They are non-mechanical insofar as they impart a direction for the selection of constituents (downward causality), and they serve to define the system as an independent entity by generating their own focus of centripetal activity.

Quantifying the agency of coupled processes is initiated by identifying individual processes, estimating their magnitudes, and signifying how they are linked together in nature. In the ecological theatre, this usually consists of estimating and analyzing networks of trophic interactions. The agency of (autocatalytic) configurations of processes is usually manifested in the form of progressive (sometimes hidden) constraints that channel flows along those pathways that (cyclically) augment their own action. The overall magnitude of constraints in ecosystem networks can be quantified using information theory. The magnitude of the constraints, when scaled by the magnitude of the total action channeled by the constraints is called the system ascendency. The complement of the ascendency, the degrees of freedom or adaptability, can be assessed using the same calculus and is called the system overhead. Finally, the sensitivities of the ascendency with respect to the trophic processes can be used to pinpoint the controlling processes and elements in the ecosystem.

27. The use of graph theory in system analysis

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It is common to analyse complex problems using a systems approach. In such approaches a problem is divided into carefully selected sub-problems that are easier described and investigated. The behaviour of the system as a whole is then explained from the state of the system elements and the interactions between them. System descriptions explaining the values of the system elements and changes therein may be regarded as (conceptual) models of reality. Conceptual models often provide the argumentation regarding what should and should not be researched. An obvious problem applying a systems approach is getting agreement, among users of the same (conceptual) model, on the constituent elements and how they should hang together. Increasing the grip on the conceptual modeling process could greatly improve communication between researchers and users and thus enhance the effectiveness of knowledge development projects.

Knowledge graph theory is a promising method to increase this grip. Interconnected vertices and edges together constitute a graph. Labeling of the vertices and edges yields a so-called knowledge graph. Contrary to most other qualitative reasoning or knowledge representation techniques, knowledge graph theory works with an ontology of relations as its main toolbox. This, combined with common algorithms that may be applied to normal graphs, e.g. path analysis, make knowledge graph theory a powerful tool in conceptual modeling processes. Procedures have been developed to objectify the transformation of (scientific) texts into conceptual diagrams. Algorithms have been implemented in software to display, analyse and aid interpretation of the resulting knowledge graphs. In the presentation an introductory overview is presented.

## The Water Framework Directive and Estuarine Monitoring

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According to the European Commission, water is not a common commercial product but a 'heritage'. Based on this starting point it was decided to arrive at sustainable management and protection of freshwater resources by creating legislation to avoid the long-term deterioration of freshwater quality and quantity. A transparent, effective and coherent legislative framework was found in the Water Framework Directive (WFD) which was adopted in December 2000.

To properly evaluate qualitatively and quantitatively the developments, monitoring has been proposed. Of particular importance is to reverse any significant trend in concentrations of any pollutant. The EU required appropriate, evident and transparent as well as justifiable criteria in the river management plans to meet the goals. The ultimate goal is to establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater. Protection of the waters may also result in the protection of the 'ecological status' of these bodies of water. The problem, however, is how to monitor these systems so, that both the water quantity and quality as well as the ecological quality are guaranteed. In the present contribution some suggestions will be done to meet the ecological requirements with those of the water quality requirements. Apart from chemical standards, also important functional links by specific biological species have to play a crucial role in the monitoring program. The intrinsic biological values of the marine areas under consideration has to be described quantified and judged, habitats defined and mapped, its use regulated and its integral (socio-economic and ecological) management defined. As long as we do not know the local ecological role of already adopted 'indicator species', the monitoring has to be based on all the species available and their activities within the different communities. Ecological network Analysis may be a challenging approach to meet the above EU requirements.

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Giving scientific advice on cost effective measures for a cleaner Baltic Sea using linked models in a decision support system

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The Baltic Sea is one of the areas of the world that is most severely affected by human activities.

Although there is an international agreement that nutrient input should be reduced, the measures taken so far have not resulted in major reductions in nutrient inputs nor in environmental improvements. The reasons are partly due to lack of knowledge on large-scale relationships and couplings between physics, biogeochemistry and ecological properties. But there is also a lack of overall drainage basin wide analyzes on cost effective measures. There is a danger in making wrong decisions, e.g. implement reduction schemes that are at worst ineffective or at best, far from cost effective.

Now researchers from many disciplines are faced with a common challenge: To develop a decision-support system, which can be used as the scientific base for cost-effective measures for the entire Baltic Sea. Such an effort is now made within the research program MARE (<a href="http://www.mare.su.se">http://www.mare.su.se</a>). A first prototype of this system, called NEST, is now ready for testing, evaluation and further development, in dialogues with scientist and environmental managers.

NEST link models of physical transports and biogeochemical transformations of nutrient in seven sub-basins of the Baltic, nutrient retentions in 23 different coastal regions adjacent to 23 sub-drainage basins for which retentions as well as cost estimates for 17 different abatement measures are calculated. Network analysis of nutrient is a key component of the system, linking biogeochemistry with economy. The user of the NEST can select a desired environmental improvement, currently Secchi depth improvement, for any or several of the sub-basins and the system calculates the minimum cost solution to reach this, distributing cost between measures and countries.

The foodweb in the Scheldt estuary

P. Herman

Abstract not submitted

## The food web in the lower part of the Seine estuary

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The Seine estuary illustrates the alterations in estuaries due to man: strong inputs of pollutants of various origins and large changes of its morphology since the middle of the XIX century. The intertidal mudflats have been greatly reduced (< 30km<sup>2</sup>) after management of the channels of the Seine River. It plays an important role in the dynamics of the eastern English Channel ecosystem; nevertheless, its biological compartment remains poorly known until the beginning of the '90. The objectives of the Seine Aval program were to identify the life resources of the Seine estuary: macrobenthos, zooplankton, suprabenthos, and fish populations and to define the main trophic links in the lower part of the estuary (i.e. from the polyhaline to the oligonaline zones). There is an impoverishment of the biological diversity from the polyhaline zone to the oligonaline zone. The benthic and pelagic fauna of the Seine estuary is similar to other north-eastern Atlantic estuaries, but there are great differences between the biological compartments with areas of very high abundance of organisms (benthos on the muddy intertidal zone and, zooplankton in the lower part of the estuary) and areas with very low abundance of organisms (macrobenthos in the channel). There is also a contrast between the high abundance of the first levels of the trophic chain in a contaminated environment and the low abundance of fish. The pelagic fauna, especially the copepod Eurytemora affinis and the shrimp Palaemon longirostris seemed to be more abundant in the Seine estuary than in other estuaries. Two macrobenthic communities occurred in the estuary: a diversified and abundant Abra alba-Pectinaria koreni community in the outer part of the estuary and a Macoma balthica community in the inner part. This latter was especially poor in specific richness, density and biomass, in all areas, except on tidal mud flats. Two trophic chains were identified. In the oligonaline zone corresponding to the maximum turbidity zone (high turbidity, low concentration of oxygen), the trophic chain was exclusively planktonic due to the dredging of the estuary which prevented permanent benthic fauna formation. In this zone, the number of fishes was relatively low in spite of high biomass of mesozooplankton and suprabenthos. In the outer part of the estuary, low turbidity and high concentration of oxygen are more favourable to fish populations which feed especially on benthic fauna. So, in spite of a high contamination and human modifications, the Seine estuary remains an European estuary with high abundances for young fish and birds especially the limicoles. Nevertheless, in the future, a global management of the Estuary would be necessary to ensure the actual functioning of the biological compartments and to propose measures to ensure the rehabilitation of migrating fish.

# Assessment of the pelagic food web structure of the Scheldt estuary from C and N stable isotope ratios

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It is well known that the  $\delta^{13}$ C and  $\delta^{15}$ N signatures of the inorganic/organic substrates at the basis of the food web set the isotopic signatures of the higher trophic levels.

For the Scheldt system, seasonality of the (high) input of nutrients and organic matter and intensive reprocessing of this material in the river and estuary induce temporally and spatially variable isotopic compositions at the food web base, complicating the understanding of interdependencies at the higher trophic levels. Reprocessing of nutrients includes carbon fixation, heterotrophic respiration, uptake, excretion, ammonification, nitrification, denitrification. For C the most likely processes influencing  $\delta^{13}C$  of dissolved inorganic carbon are heterotrophic respiration and carbon fixation. For N, the processes influencing  $\delta^{15}N$  of dissolved inorganic nitrogen are organic matter mineralisation, nitrification, denitrification and autotrophic and heterotrophic uptake. The spatial and temporal variations in stable C and N isotopic composition of the suspended microbial biomass, including primary producers, reflect the seasonality of nutrient reprocessing and differential functioning between river and estuary. The impact of this seasonality and spatial variability is transferred up the food chain.

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## The nursery function of the Scheldt estuary: a review for fish and macrocrustaceans

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<sup>2</sup> Flanders Marine Institute

Several habitats (subtidal and intertidal soft substrates, saltmarsh creeks, etc.) are present within the Scheldt estuary. This complex system can function as spawning ground, nursery area, feeding ground and/or pathway in diadromous migrations for several fish and crustacean species.

During the 1990s several studies were performed on (post)larval, juvenile and adult fish and macrocrustaceans, both in the WesterScheldt and in the ZeeScheldt. The different life history stages and subhabitats required specific sampling strategies and they were sampled during different periods. This makes it difficult to compare studies. This presentation is a compilation on the significance and role of selected habitats in the life cycle of the dominant fish and macrocrustacean species in the Scheldt estuary. Both habitat availability and habitat use are quantified. The importance of estuarine biotopes as habitats for fish is evaluated through a Habitat Utilisation Index. Data on species diversity and seasonal and spatial differences in growth and abundance are presented. Both short and midterm patterns can be related to changes in the environment. Next to the ecological guilds, also feeding guilds are used to assess the relationship with the lower consumers. A generalised food web structure within the Scheldt estuary is proposed, which illustrates the importance of mysids and other small crustaceans in the food of juvenile fish and shrimps. An impression is given on the gaps in our knowledge about the nursery function of the Scheldt ecosystem.

<sup>&</sup>lt;sup>3</sup> Aquatic Ecology, Catholic University Leuven

# Soft-sediment macrobenthic species distributions in estuaries: from pattern to prediction

### T. Ysebaert and P. M.J. Herman

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There is growing awareness of the need to address the issue of scale more explicitly in (benthic) ecology. If spatial heterogeneity is important for the functioning of ecosystems, ecosystem models should include the spatial organization of populations, species assemblages and their environment.

Macrobenthos plays an important role in the system dynamics of estuaries and is a good bioindicator. However, few attempts have been made to model and predict responses of macrobenthic species to environmental variables at different spatial scales. For the Scheldt estuary (NW-Europe) a large macrobenthic database is available, covering different spatial (from a single tidal flat to the complete estuary) and temporal (from month to decade) scales. Apart from the biotic information, this database contains several environmental variables such as salinity, current velocities and sediment characteristics.

Besides more classical approaches such as classification and ordination (e.g. direct gradient analysis), we applied geostatistics and regression models (e.g. generalized linear models such as logistic regression) to the data in order to elucidate the role of environmental conditions in explaining the occurrence (presence/absence, abundance, biomass) of the benthic macrofauna at different spatial and/or temporal scales. Our results showed that at meso-scales (>100m-10 km) a considerable fraction of the variation in occurrence, density and biomass of macrobenthic species correlated very well with physical factors (depth, tidal current velocity, sediment composition). At larger scales within the estuary salinity changed these relations significantly. However, a large and statistically significant amount of unexplained variation still occurred at the smaller scales (< 100 m). Possible mechanisms evoking these small-scale patterns are discussed.

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35.

## Patterns and processes in intertidal vegetation

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The salt marshes along the Western Scheldt Estuary have very distinct spatial vegetation patterns, depending on salinity (between marshes), elevational gradients (within marshes) and hydrodynamics (within marshes).

We will start with a brief description of the plant species distribution both within and between marshes, briefly explain some of the most important underlying physiological plant characteristics, and briefly elucidate some of the consequences for biochemical processes (research focus of former NIOO-department of Littoral Vegetations).

We will then introduce our current research on plant-benthos interactions and on hydrodynamic processes in salt marshes (research focus of the in January 2002 founded NIOO-department Spatial Ecology). This summer, we did an extensive sampling campaign to identify the macro-benthos within vegetations at different elevational heights (i.e., macro algae vs. *Zostera noltii* meadows vs. *Spartina* marsh). We also manipulated the environment for the benthos in parts of the *Spartina* marsh. With respect to hydrodynamics, we measured wave energy, current velocities and sediment load in the water column, during the plant growth season 2002. In addition, we performed detailed experiments in a laminar-flow flume and in a wave-generating flume, using both natural and artificial vegetations. Preliminary results will be discussed.

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36.

## The Western Scheldt: an analysis of the water level

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The Western Scheldt is one of the few natural estuaries left in Western Europe. Besides the ecological value, the estuary also has an important economical function, in particular as a shipping route for container ships to the harbors of Antwerp and Flushing.

The Western Scheldt is monitored extensively, with emphasis on parameters of morphological and fysical changes that may have consequences for the ecological functions of the water body. For this reason it is important to carefully analyse and evaluate these parameters.

In 2002 a pilot study was started to detect possible changes in the physical and morphological behaviour of the Western Scheldt estuary over the past 30 years. The parameter 'water level' has been the subject of the first analyses since this parameter is expected to have a high potential to detect changes and is frequently monitored on many locations.

The analysis was based on hourly values of the water level in the period between 1971-2001. Analysis of the yearly averaged amplitude of the most important frequency components resulted in some remarkable results. For example, in the period 1986-1988 a disturbance in the normal repeating pattern of the  $M_2$  component seems to occur. Furthermore, during the last five years the trend of the  $M_2$  component in the eastern part of the estuary differs from the trend in the western part of the estuary and from expectation. These effects are possibly due to anthropogenic impact on the Western Scheldt system. More research has to be carried out to identify the causes of these observations.

## Ecological assessment of physical changes in the Scheldt estuary

#### J. Graveland

National Institute for Coastal and Marine Management (RIKZ)

The relationship between morphodynamics and ecology is a major research topic in the Scheldt estuary. The discussion about access to Antwerp harbour and the implementation of strict EU-legislation for nature conservation are responsible for this. Another development is the quest for indicators that summarize the physical and ecological state of water systems in a way that managers and policy makers can understand.

The paper presents two studies by RIKZ tackling these two issues.

One study explores physical parameters at the scale of a complete water system (such as the Western Scheldt) that characterize the potential of the system for the maintenance or development of habitats such as tidal flats and salt marshes. A graphical presentation of these parameters should allow immediate assessment of the physical state of the system in for ecology relevant terms. A promising combination of parameters is the total cross section of tidal channels and the amount of water that moves in an out at each tide.

Another study focuses on the potential importance of the curvature (vertical profile) and sediment composition of tidal flats, apart from the density of benthos (the birds' food supply), for the food intake of waders such as Oystercatchers. Present impact assessments (e.g. MOVE) only consider changes in available foraging area at low tide, while other studies show that sediment characteristics and emergence period determine foraging opportunities of waders as well.

The studies are placed in the context of the present discussion on increased dredging of the shipping channel to Antwerp.

Assessment of fish communities in the Scheldt estuary in Flanders (Belgium) by means of an Index of **Biotic Integrity** 

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<sup>5</sup> Flemish Environmental Agency (VMM)

Since December 2000, the European Water Framework Directive was adopted and all member states have to develop assessment systems for all water bodies within their administrative borders. A preliminary fish community assessment system was in this context elaborated for the Scheldt estuary in Flanders (Belgium).

The description of the reference conditions of this estuary was based on a combination of historical data, data from similar European Estuaries (e.g. Eems-Dollard), expert knowledge and recent data collections executed by the KULeuven. This latter data collection was executed with double fikes (type 120/80). The fikes were emptied every three days. The applied data were based on averaging data collections during one month and recalculated as average catch per day per fike for a particular month.

The score variables of the IBI (each score consist of a number between 1 (very bad) to 5 (excellent, reference conditions)) are: total amount of species; typical species; omnivores, invertivores, piscivores; tolerance scores (pollution, habitat quality); estuarine resident species, diadromic species, marine juvenile migrating species. The overall score classes of the estuarine fish index were obtained by taking the average of the 7 variables.

According to the developed estuarine fish index, the fish communities were bad to moderate during the period 1995-1999. Further research on the sensitivity and robustness of this fish index is however necessary to allow a reliable assessment needed for the implementation of the European Water Framework Directive.

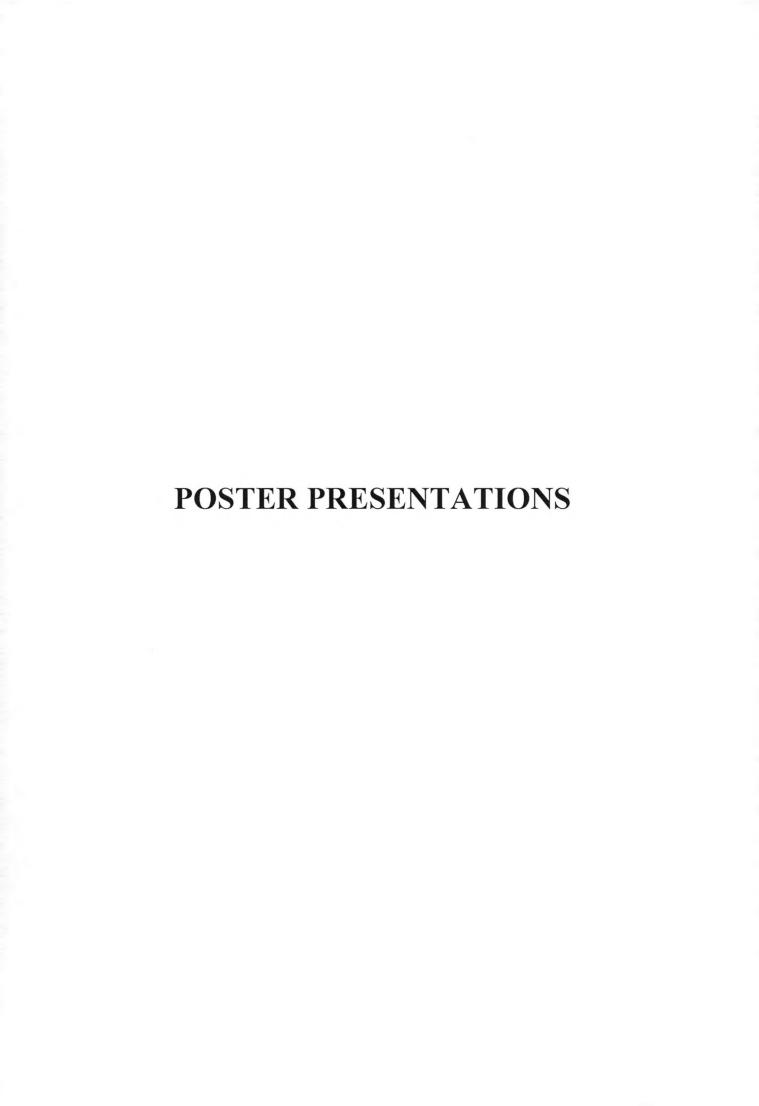
# A Nature development plan for the schelde estuary

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The Schelde estuary is one of the last European estuaries with a gradient from salt over brackish to fresh water tidal areas. Especially these last are a very rare habitat. However the ecological value of the area is strongly reduced due to water pollution, habitat loss and degradation. Simple protection measures like designation of these sites under national and international nature conservation laws are no guarantee to safeguard these sites as the external pressures are so important and major new infrastructure works for safety and shipping are planned. A more integrated approach is needed. In this paper we present an approach, based on the concept of ecosystem health, to derive ecological quality objectives, mainly based on the different ecological functions of the estuary. These objectives were then translated into different restoration strategies. The first one is mainly based on small improvements in the present management. The second one explores the possibility of extending the wetlands adjacent to the estuary in order to reduce the input of water and nutrients. The third scenario maximises the estuarine surface by managed retreat and the development of controlled inundation areas with a tidal regime. The possibilities but also the problems associated with each of these scenario's will be discussed.



P1.

MULti sectoral, INtegrated and Operational Decision Support System for Sustainable Use of Water Resources at the Catchment Scale (MULINO): a Belgian case study

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The Mulino [1] project is a 3 year European Commission funded project. The main objective is the creation of a Decision Support System (DSS) supporting the implementation of the Water Framework Directive (WFD) at the scale of a hydrological catchment. The DSS will incorporate a set of socio-economic and environmental modelling techniques built around a geographical information system (GIS) to describe a series of hydrological and socio-economic properties in terms of external drivers and pressures. The decisional context is defined by a set of end-users directly involved in the implementation of the WFD. The DSS prototype will be implemented in a series of test catchments, including the Walloon part of the Dyle.

A hydrological model, the physically-based SWAT model (Soil and Water Assessment Tool) [2], is integrated in the DSS system. The AvSwat2001 version was used, which is fully integrated within an ARCVIEW TM environment. The model, however, needs to be validated for a specific catchment before application. In the example presented here, the hydrological modelling component was first evaluated on the Thyle subcatchment (59 km²), but later applied to the Dyle upstream of Archennes. Primary results show that the predicted hydrographs with the SWAT model are sensitive to the input parametrisation schemes (e.g. soil parametrisation). Model sensitivity needs therefore to be addressed before the model can be used within the DSS.

#### Acknowledgements

This research was carried out within the framework of the EU Mulino project (contract no. EVK1-2000-22089). The authors would also like to acknowledge the developers of the AvSwat interface.

#### Reference

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[2] Arnold, J.G., Engel, B.A., Srinivasan, R., 1993, Continuous-time, grid cell watershed model. Proc. of the 18-19 June 1993 Conf. Spokane, Washington, 267-278

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P2.

# Flocculation in the Scheldt Estuary: a case study of intertidal mudflats

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The flocculation mechanism dominates the fate of suspended matter in the estuarine environment. As it modifies the texture of suspended matter, flocculation thus affects suspended matter's transport and deposition. In order to understand the complexity of the flocculation mechanism, a case study was performed on two intertidal mudflats in the Scheldt estuary, a freshwater and a brackish water one. A one-year biweekly survey investigated the seasonal variation of flocculation, physical properties of suspended matter, organic matter content and suspended matter deposition in the intertidal area. The flocculation study includes floc's shape, sphericity and microfabric, which properties are believed to be significant in the suspended matter transport processes in the estuary. This study shows that floc size as well as floc sphericity positively correlates with the change of organic matter. Moreover, it reveals that with increasing organic matter floc expands in a threedimensional way. It is observed that relatively dense, small and elongated flocs appear in winter and spring periods, while loose, large and spherical flocs occur in summer time. The study also reveals that suspended matter transported as dense and fine-to-medium sand-sized flocs have a greater effect on its short-term deposition than loose and medium-to-coarse sand-sized flocs. As the measured suspended matter deposition is much higher in winter-spring than in summer time, it is deducted here that highly concentrated and relatively dense flocs contribute to fast deposition during winter and spring periods resulting in a compact layer, while loosely formed flocs likely lead to an easier erodible layer in summer time. This study concludes that floc density is a more determining parameter in suspended matter's transport processes than floc size.

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P3.

## An inventory for lateral input into the Sea Scheldt

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By order of the Waterways and Maritime Affairs Administration, division Sea Scheldt, the Flanders Marine Institute developes a database containing information regarding the lateral input into the Sea Scheldt.

Water quality and quantity data of tributaries, industrial discharges and input trough locks are gathered and compiled into a cohesive database. The parameters included are flow, biochemical oxygen demand, total suspended matter, Kjehldahl N, nitrate and nitrite, ammonium and oxygen concentration. By determination of the XY-coordinates for the different discharge locations, the data is linked to Arcview and can be visualized by making selections on a GIS-map. Easy access to the contained information is assured by the possibility of making selections on different levels: for every company, nature of discharge, time and place a query for water quality and water quantity data can be made.

The aim is to provide a well-structured inventory of discharge data that is needed for ecological modelling purposes. The database is made structurally compatible with the OMES-database in which it will be incorporated.

P4

Sediment characteristics affecting bioavailability of heavy metals in flooding areas and intertidal zones along the river Scheldt

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Mobility and bio-availability of heavy metals in intertidal zones and floodplains is currently studied at the Laboratory of Analytical Chemistry and Applied Ecochemistry (Ghent University). The relation between sediment properties and metal uptake by reed plants (*Phragmites australis* (Cav.) Steudel) was investigated based on field observations at selected locations along the estuary of the river Scheldt (Flanders, Belgium). The sites represented a varying degree of metal contamination and salinity. At each site, reed plants were sampled and analysed for heavy metals. Sediments were also sampled and characterised for metal contents and various physico-chemical properties. Cd contents of *Phragmites australis* (Cav.) Steudel were higher on sites with lower total Cd contents in the upper 20 cm of the sediments. Contents of leaves, stems and rhizomes were also higher on sites with lower total Zn contents in the sediments, but, in contrast to Cd, were negatively correlated with chloride contents. When the sites with the lowest salinity were considered separately, the Zn content of leaves and stems on the one hand and the ratio of exchangeable Zn to the total cation exchange capacity on the other hand were significantly and positively correlated. This can suggest that reed plants do not take up Zn selectively, and that the uptake and/or transfer mechanism is adapted at the highest salinity.

Cu contents of the plants were negatively correlated with chloride contents in the sediments. However, Cu contents in leaves and stems were significantly and positively correlated with Cu contents in the reducible fraction of the sediments, according to the BCR sequential extraction procedure. At the sites with the largest reducible Cu fractions, the mean water level was also higher and the upper sediment layer was reduced at sampling time.

P5

# Feeding and growth of the mysid Neomysis integer on aggregates in the MTZ of the Scheldt estuary

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In the brackish part of western European estuaries the mysid *Neomysis integer* is dominating the hyperbenthic fauna and plays an important role in the local food-web. Estuarine aggregates showed to be abundantly present in the stomachs of *N. integer* living in the estuarine turbidity maximum (Fockedey *et al.*, 1999). However, it was not clear if the mysids actively fed on the flocs, nor if they could survive or grow on this dietary item.

The aim of this study was to identify the survival and possible growth of *Neomysis integer* feeding on estuarine aggregates. First, a technique to make laboratory-made aggregates out of natural water of the Scheldt estuary-by means of a roller table - had to be optimised. Subsequently, a 7 weeks lasting growth experiment was performed with laboratory-made aggregates as the main food item. The growth performance (measured by the mean growth rate, intermoult period and growth factor) on a diet of aggregates was compared with that on a diet of *Artemia* nauplii. The mysids survived well (70 %) and even grew significantly (0.059 mm day<sup>-1</sup>) on a diet of flocs, though less than the individuals on a diet of *Artemia* (0.094 mm day<sup>-1</sup>). Also, rough estimates of the feeding rate (38  $\pm$  18 aggregates h<sup>-1</sup>) and the gut passage time (30 minutes) of *N. integer* feeding on laboratory-made aggregates were determined.

Estuarine aggregates probably are an important additional food source for *Neomysis integer* living in the turbid zone of estuaries. The very high abundance and small effort needed to consume the flocs, might compensate their relative low energetic value.

Fockedey N. and Mees J. (1999). Feeding of the hyperbenthic mysid *Neomysis integer* in the maximum turbidity zone of the Elbe, Westerschelde and Gironde estuaries. Journal of marine Systems, 22: 207-228.

35200

P6.

## Habitat value of a developing estuarine brackish marsh

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Marsh creation receives worldwide attention in mitigating loss of coastal wetlands and in management retreat of estuaries. In the Westerschelde, the former Selena Polder, south of "Het Verdronken Land van Saeftinghe", evolved into the Sieperda marsh after several dyke breaches. Soon after the tides regained access to the polder, a tidal creek was formed. Ten years after, a developing marsh system is found close to a mature marsh system. This situation offered the rare and unique opportunity to compare under similar circumstances the utilisation by nekton species of a natural mature marsh with a recently created developing marsh.

Between April and October 1999 both the mature Saeftinghe marsh and the developing Sieperda marsh were sampled every six weeks on two consecutive days. Each sampling occasion covered the whole tidal cycle.

The most important environmental parameters (water height, temperature, salinity, turbidity and dissolved oxygen) were similar in both marsh creeks.

A distinct difference in nekton community structure between the two marshes was observed. Total biomass and densities of nekton species were remarkably higher in Saeftinghe.

In Saeftinghe, a density peak occurred in July and was mainly due to large numbers of the mysids *Neomysis integer*. In Sieperda, peak densities in September were caused by high abundances of the mysids *Mesopodopsis slabberi*. This difference in species dominance was observed during all sampling occasions.

Biomass peaked in July in the mature marsh and in October in the developing marsh. Mysid shrimp (*Neomysis integer*) and fish (mainly *Pomatoschistus microps*) were the main contributors to the biomass in the natural marsh. Herring, sprat (Clupeidae) and shore crab (*Carcinus maenas*) were more important in Sieperda. For *Pomatoschistus microps*, distinct differences in length-frequency distributions were noted between both marshes.

While creek morphology plays an important role, the development stage of a marsh is believed to be a prime factor in determining the habitat function of creek systems of developing and mature marshes.

P7.

# Functional guilds of fishes and macrocrustaceans in the Westerschelde and Oosterschelde estuary

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Several subhabitats (e.g. intertidal and subtidal soft substratum or saltmarsh creeks) have been defined within the estuarine reaches of the Westerschelde and the Oosterschelde. This complex system can serve as spawning ground, nursery area, feeding ground and as a pathway in diadromous migrations. This study concentrated on the significance and role of these selected habitats in the life cycle of fishes and macrocrustaceans. Therefore, both habitat availability and habitat use were quantified. The importance of estuarine biotopes as habitats for fish was evaluated through a Habitat Utilisation Index. Next to the ecological guilds, also feeding guilds were developed to assess the relationship with the lower consumers. A generalised food web structure within the Westerschelde was defined, which proved the importance of mysids and other crustaceans in the food of juvenile fish and shrimps. The results were compared with other systems to examine if the Westerschelde and the Oosterschelde comply with what is inspected in European estuaries.

P8.

Towards an integrated management of water resource issues in the Dyle catchment (Scheldt basin, Belgium) \_ The European MULINO project (MULti-sectoral, Integrated and Operational decision support system for sustainable use of water resources at the catchment scale)

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The pressure on water resources is continuously increasing in Europe. If a great deal of scientific knowledge is available in many fields, this knowledge is often treated in isolation. To support the scientific basis for integrated water management, the MULINO project, an acronym for MULti-sectoral, Integrated and Operational decision support system (DSS) for the sustainable use of water resources at the catchment scale, funded by the European Union, is currently executed. The purpose of the MULINO project is to provide a tool to improve the integrated management of water resources at the catchment scale, following the requirements of the EU Water Framework Directive (WFD, J.O.CE, 2000).

The DSS developed is a computer system based on hydrological modelling, multi-disciplinary indicators and multi-criteria evaluation procedures. The underlying design of the DSS is based on the Driving Forces-Pressures-State-Impact-Responses framework for reporting on environmental issues (EEA, 1999; OECD, 1993).

One case study is the 700 km² Dyle catchment situated in the centre of Belgium (50°38N 4°45E) and part of the Scheldt basin. A coupling of an integrated hydrological model (SWAT: Soil and Water Assessment Tool, Arnold *et al.*, 1993) with land use change modelling (SFARMMOD, Audsley et al., 1979) is developed in close collaboration with local end users and stakeholders. This work will provide a useful tool to analyse water resources management alternatives and to assist local managers in complex problems such as flooding, nitrate and pesticides contamination of waters, as to identify solutions for the implementation of the WFD at the catchment scale.

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P9.

Ecological-rainfall-changes and N, P, K, Mg influences on crop production under temperate climate conditions in Hungary

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Agroecological quality has a well estabished dependence on climate-rainfall changes because the water problems are pressing. There is, therefore, growing concern about the potentially wide ranging risks that climate change would have on these key industries as the nature and extent of anticipated changes have become more evident. It also includes changes in land use and in plant production and their management. These changes are unprecedented in terms of both their rate and their spatial extent. Changes in land use (agrotechnics, soil, cultivation, fertility, quality, protection etc.) and in plant production (plant, nutrition, rotation, protection etc.) are currently the main manifestations. As an interdisciplinary problem it is necessary to study such a complex matter in terms of agricultural production. Generally among natural catastrophes, droughts and floods cause the greatest problems in field crop production. The droughts and the floods that were experienced in Hungary in the early 1980's have drawn renewed attention to the analyses of these problems. New research on climate change-soil-plant systems are focused on yield and yield quality. This paper reports the climate change (rainfall) x soil (acidic sandy brown forest) x mineral N-, P-, K-, Mg fertilisation x plant interactions on rye (Secale cereale L.), on potato (Solanum tuberosum L.) and on winter wheat (Triticum aestivum L.) yields in a long term field experiment set up at Nyírlugos in north-eastern Hungary under temperate climate conditions in 1962. Results are summarised from 1962 to 1990. Main conclusions were as follows: 1. Rye: a., Experimental years were characterised by frequent extremes of precipitation variabilities and changes. b., By an average year, at a satisfactory fertilisation level (N: 90 kg ha-1 and NP, NK, NPK, NPKMg combinations) the maximum yield reached 3.8 t ha<sup>-1</sup>. But yield was decreased by 17% and by 52% due to drought and excess rainfall respectively. Negative effects (drought, excess rainfall) were diminished by 20-25% with Mg treatments. c., Correlation between rye yields and precipitation during vegetation seasons showed that optimum yield (4.0 t ha<sup>-1</sup>) will develop in the 430-470 mm range. 2. Potato: a., Trial years were estimated by recurrent extremes of climate. b., In vegetation seasons poor in rainfall yield safety in potato cannot be secured by fertilisation (N, NP, NK, NPK, NPKMg) alone. Under this weather condition yield was decreased by 35%, c., Optimum yields range between 17-21 t ha<sup>-1</sup> at 280-350 mm, 3. Winter wheat: a., Climate was manifested mainly by precipitation using average, drought, dry and rainy levels. b., Yields from drought year effects with N, NP and NK combinations were diminished to 48% and with NPK and NPKMg treatments fell to 51%. c., Optimum yields (3.5-4.0 t ha<sup>-1</sup>) were developed at 450-500 mm. This paper summarises quantified results of rye, potato and winter wheat research with regarding to interaction effects and relationships between climate (rainfall)-mineral nutrition-crop production changes in Hungary during a long term field experiment to agricultural sustainability.

P10.

# Influence of salinity and light climate on phytoplankton in the Schelde estuary

### M. Lionard, K. Muylaert, D. Van Gansbeke and W. Vyverman

In this study, we tested the effects of light intensity and salinity on estuarine phytoplankton communities of the Schelde river and estuary. We used HPLC in order to identify and quantify the different phytoplankton pigments. In two experiments (summer-spring), water was collected in the river and at two locations in the estuary (freshwater tidal and brackish). The water was mixed with an equal amount of filtered water (GF/C filters) from the same or a different site and was exposed to different light levels to test for the effects of the chemical composition of the water (including salinity) and the light climate on phytoplankton growth.

In spring as well as in summer, diatoms dominated the phytoplankton community, while green algae were relatively more important in summer. A reduction in light intensity strongly reduced growth (as evaluated by changes in chl a concentration) of phytoplankton from the freshwater tidal estuary as well as the river. In spring, at high light intensity, a relative increase of green algae was observed although diatoms remain dominant (as evaluated by fuc/chl a and lut/chl a ratio's). In summer on the contrary, green algae were negatively influenced by the high light intensity. Exposure of phytoplankton from the river to water from the freshwater tidal estuary had no effect on phytoplankton biomass and community composition. Phytoplankton from the river as well as from the freshwater tidal estuary was negatively influenced by an increase in salinity. Phytoplankton from the brackish part of the estuary, on the other hand, was not significantly influenced by a decrease in salinity.

P11.

Hydrology of saline grasslands in the polders of "De Schelde"

#### W. Beyen and P. Meire

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For economic reasons, the Flemish government and the Antwerp port authorities are enlarging the Harbour of Antwerp. Therefore, they create new docks and industrial sites in the polders of "Het Waasland", situated on the left bank of the Schelde – in front of Antwerp. Two decades earlier however, the Flemish government protected important parts of these polders by assigning them the status of Special Protection Area (SPA) under the EU Bird directive. In such cases, the Bird directive demands compensation measures for the loss of protected bird habitats.

Among these protected habitats are the very rare saline grasslands. Because these grasslands need very specific hydrological and ecological conditions to develop, it isn't possible to create them wherever we want to do. To find possible sites for the re-creation of these saline grasslands, we carried out a detailed study of the hydrology, geomorphology and ecology of the "Waaslandpolders".

The results indicate that the saline conditions originate from discharging groundwater passing through a saline peat layer. These conditions are related to the deposits of coarse grain soils, situated at the landside of dikes near former creeks. In the polders of "Het Waasland", three other parts have the same origin and lie outside the future extents of the harbour. Only in one of them, we found the same special hydrological conditions present in the existing grasslands. The presence of these conditions says nothing about the occurrence of saline vegetation in the future. Therefore, we now study the development of saline grasslands.

P12.

Hard substrate monitoring in the Scheldt estuary: Changes in species distribution from 1989 till 1998.

#### P. Schouten

In the scope of BIOMON (initiated by RIKZ) Bureau Waardenburg by executed hard substrate monitoring in the Scheldt estuary during the years 1989 till 1998. Sessile species can be indicator species for environmental changes and insight in their habitat can be of value during impact studies.

The monitoring took place at two locations: Ritthem and Kruiningen. The biodiversity of the Ritthem over the years has been relatively high. This is probably due to strong marine influences at this location. Several species of seaweed occur here. In 1998 seaweed's where responsible for more than 50 % of the total amount of species. Since 1991 an immigrant, the Japanese oyster (*Crassostrea gigas*), has become more and more abundant, causing changes in species distribution and abundance at this location.

Kruiningen has a relative low biodiversity compared to Ritthem. This is probably due to strong fluctuations of the salinity at this location, also indicated by the appearance of brackish water species. Only one seaweed lives here (*Porphyra umbilicalis*). Several other species come and go over the years causing clear changes in species distribution and abundance at this location. In comparison to the results at Ritthem, the abundance of the Japanese oyster also made a big increase at this location.

The strong up come of the Japanese oyster can have a dramatic influence on the receiving ecosystem. With the rise of the oyster population original substrate disappears and there are indications the oysters compete with other filter feeders for food. What will come of this in the future remains to be seen.

P13.

Use of the GREAT-ER model to estimate mass fluxes of chemicals, carried into the Western Scheldt estuary from the Rupel basin

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The poster illustrates the application of the GREAT-ER model to estimate the mass flux of chemicals carried from a river basin into an estuary. GREAT-ER (Geo-referenced Regional Exposure Assessment Tool for European Rivers) is a newly developed model (1999) for management and risk assessment of chemicals in river basins (see www.great-er.org). Recently the Rupel basin has been made available for use within GREAT-ER. This now allows to make a reliable estimation of the contribution of pollutant point sources in the Rupel, to the pollutant load in the Western Scheldt Estuary.

A calculation of the mass flux in the last stretch of the river network was made for five household chemicals or pharmaceuticals (i.e. LAS, boron, HHCB, aspirin and ethinyl oestradiol) as an example. The 'Watershed Attenuation Factor' (WAF) concept allows to calculate the fraction of the total load of these chemicals eliminated on their way to the estuary through the combined action of sewers, municipal waste water treatment infrastructure and/or biological self-purification of the rivers. The calculated WAFs range between 0% (boron) to 85% (LAS) for this test set of chemicals.

If the GREAT-ER Rupel basin could in the future be combined with the other sub-basins in the Schelde watershed, this would open the perspective to make highly accurate estimations of the total estuary's pollutant input via its rivers.

P14.

The role of oxygen in the vertical distribution of nematodes: an experimental approach

M. Steyaert, S. Vandewiele, J. Vanaverbeke, L. Moodley and M. Vincx

The role of oxygen in the vertical distribution of nematodes was investigated by means of an experiment in which different oxygen conditions were imposed on sediment from an intertidal area of the Oosterschelde (The Netherlands). To test our hypothesis that the vertical distribution of the nematode assemblages was not influenced by changing oxygen conditions (e.g. nematodes do not migrate to favourable oxygen conditions), 5 cm sediment was inversed and incubated for 5 days at the lab. In a first treatment, food (diatoms) was added to the bottom; in a second treatment oxygen and food were added to the bottom. For each case and a control treatment, fresh, well-aerated Oosterschelde water was added on top of the sediment. The analysis of the field situation showed that nematodes were the most abundant taxon. Highest densities were observed in the subsurface sediment layer (1-2 cm). The lower abundance in the oxygen and algae-rich superficial layer (0-0.5 cm) could be due to the time of sampling relative to the tides or to biotic factors (e.g. macrofaunal activity). The vertical distribution of the nematode assemblages in the experimental and control treatments proved to be significantly different. An obvious segregation existed between the nematode species assemblage from the superficial (0-0.2cm) and the deeper layers (0.2-1 cm and 4-5 cm). Characterising genera for the superficial sediment layers were Daptonema, Ptycholaimellus, Prochromadorella and Microlaimus; for the deeper layers Terschellingia and Microlaimus. The occurrence of the first species assemblage is determined by the presence of free oxygen. The second species assemblage is adapted to the reduced sediment; nevertheless, artificial addition of limited amounts of oxygen to the deeper sediment layers favoured the assemblage as higher abundances were recorded. In general, oxygen seems to be important in determining the vertical distribution of nematodes in this experiment.

35213

P15.

## Potential effects of global change on estuarine nutrient fluxes

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One of the major worldwide problems in densely populated estuarine areas is the eutrophication of coastal waters. Studies, both observational and theoretical, addressing the issue of material fluxes to coastal zones under changing external forcing conditions, have a critical international importance. In contrast to N and P, the silica concentration in estuaries is hardly influenced by human pollution. Increased N-concentrations can lead to succession of diatom communities to phytoplankton communities with less favorable properties.

Global change models predict effects of climate change on hydrological regimes at the continental scale in Europe. Schelde freshwater discharges could increase up to 28 %. Strongly increasing freshwater discharges over the period 1996-2000 in the upper Schelde estuary could be an example for future changes in estuarine and coastal response to excessive nutrient loading due to human impact on the global climate.

Effects in the upper estuarine areas were totally different to effects at the mouth of the estuary. In winter, when discharge increase was highest, dilution resulted in lower concentrations of NH<sub>4</sub><sup>+</sup>, PO<sub>4</sub><sup>3-</sup> and total nitrogen in the upper and brackish parts of the estuary. Nitrate and oxygen concentrations increased. Significant regressions were observed between trends and discharge regime. In summer, when discharge increases were not as high as in winter, no dilution was observed. Moreover, lower residence times in the freshwater due to higher discharges, have a negative effect on water quality in the brackish estuary in summer, as more unprocessed NH<sub>4</sub><sup>+</sup> is transported downstream, which results in very low oxygen conditions. In summer, high discharges result in the complete flushing of entire diatom communities in the freshwater reach of the estuary, which resulted in much higher dissolved Si concentrations.

Total discharged loads of nitrogen, phosphorus and silica increased spectacularly over the study period. Nitrate and silica concentrations in the coastal waters, the two main actors in coastal eutrophication, were significantly correlated to total yearly discharges observed upstream. Effective measurements against non-point pollution and insight in the role of intertidal areas in regulating non-point nutrient fluxes become more important than ever in the light of increasing discharges.

P16.

Small-scale sediment transport and deposition patterns within a salt-marsh basin, Paulinaschor, Western Scheldt

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<sup>4</sup> Ecosystem Management Research Group, University of Antwerp

During inundation of tidal marshes, fine-grained suspended matter is transported to and partly deposited on the marsh surface. In this research the complex spatial patterns of sediment transport and deposition are studied at the temporal scale of individual inundations and spatial scale of a small tidal creek basin (ca. 6 ha) within the salt Paulina marsh, Western Scheldt. Field measurements are used for the implementation and validation of 2-dimensional numerical models for tidal marsh sedimentation.

Near the mouth of the creek system, the incoming and outgoing sediment mass is estimated, by way of water level, flow velocity and suspended sediment concentration (SSC) measurements. Spatial variations in SSC, at the moment of marsh inundation, are measured at about 35 locations within the creek system and above the marsh surface, using siphon samplers. Finally the sediment that is deposited on the marsh surface is sampled with sediment traps on 50 sites, both during 4 individual inundations (about 4-5 hours) and 2 spring-neap tidal cycles (15 days).

First, it is investigated how the 2-dimensional pattern of SSC and sedimentation can be described by statistical models, incorporating detailed topographic information on the creek network, surface elevation and vegetation pattern. Secondly, the application of physically-based hydrodynamic models, coupled with sediment transport models, is explored and evaluated against the field data. Once validated, these models may be useful to simulate flooding and sedimentation patterns in other tidal marshes and controlled inundation areas in the Scheldt estuary.

P17. Silica cycling in a freshwater tidal marsh

### E. Struyf and P. Meire

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Silica plays a major role in eutrophication of coastal waters around the world. Mechanisms controlling the production and fate of silica in estuarine systems are far from understood. Major indications have been reported that intertidal areas may be an important reservoir of silica in estuarine systems. This project intends to clarify the role of a freshwater marsh in the silica cycle within the Schelde estuary. Different silica pools in the marsh (vegetation, sediment, pore-water, groundwater and surface water) are quantified on a two-monthly basis in different vegetation types. Dissolved Si, taken up by plants, is stored as amorphous biogenic silica, and is unavailable to the estuarine ecosystem until these plants decompose. Although the monitoring has not yet been carried out over the intended full year period, Phragmites australis and Urtica dioica could already be identified as the major vegetation sinks for dissolved silica in the marsh. Biogenic silica in surface sediments in the marsh increased from winter to summer. In spring and summer, the marsh becomes a sink for BSi, as diatoms and decomposing material are imported into the marsh. Mass-balances carried out may-june 2002 confirmed this theory. BSi was netto imported into the marsh. In contrary, it was observed that dissolved Si was netto exported from the marsh. The marsh seems to act as a reactor, transforming imported BSi to DSi, and thus makes this silica again available to the estuarine ecosystem. In the future, mass-balances will be carried out in all four seasons, to further clarify this theory. Interactions between the different silica pools will be studied by decomposition and dissolution experiments, both in situ and ex situ. In the end, these major goals will allow to construct an integrated view of the role of freshwater tidal marshes in the silica cycle within an estuarine system, by focusing on retention and processing of silica within the marsh.

P18.

Evolution and spatial variability of heavy metals in mussels (Mytilus edulis L.) in the Scheldt estuary (1996-2002)

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This paper presents data on the heavy metal contamination of the soft tissues of marine mussels along the Scheldt Estuary. The study considered both arms of the Scheldt estuary, i.e. the relatively polluted Western Scheldt (WS) and the now marine tidal bay of the Eastern Scheldt (ES). The two systems present an ideal opportunity to investigate, in a field situation, the role of physico-chemical and pollution gradients on metal accumulation in mussels. In the WS, depending on the metal, tissues concentrations decreased by 2 – 6 times from Hansweert (the landward limit for mussels) to Westkapelle on the North Sea coast. Similar decreases were also observed in the ES. With a few exceptions (i.e. Cd, Cu), there were no clear differences in tissue metal concentrations between WS and ES. The study also showed strong positive correlations between tissue metal concentrations and distance from the sea in both systems for most metals. Similar trends were observed for both WS and ES indicating that salinity and metal gradients are not entirely responsible for increasing metal tissue levels towards the inland. Additionally, the influence of the constructed storm surge barrier was evident as heavy metal levels in mussels at sites around the barrier were considered elevated. Furthermore, there were only modest decreases in metal concentrations in mussel tissues between 1996 to 2002, further indication that even in the cleaner ES, efforts to reduce the impact of environmental metal pollution take time to give results.

P19.

The growth of Phragmites australis at different hydrological characteristics: a mesocosm experiment at the University of Antwerp

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<sup>2</sup> WLH

In 1995, the OMES-project (Onderzoek Milieu Effecten Sigmaplan) was started to study the impact of the SIGMA-plan on the ecosystem of the Scheldt-estuary. This project should result in an ecosystemmodel. It is known that reed (*Phragmites australis* (Cav.) Steud), which is a dominant species on the marshes of the Scheldt-estuary, influences the microbial processes in the soil and plays an important role in the nitrogen retention. It is able to withstand extreme environmental conditions such as extreme water regimes.

An increase in the reedarea could play an important role in the 'purification capacity' of the Scheldt-estuary and thus lead to a decrease in the nitrogenload of the Northsea. Therefore it is necessary to know how reed reacts at different tidal situations.

One of the objectives of the SIGMA-plan is the construction of 'controlled inundation areas' in which the hydrological characteristics will differ from those in the marshes. Yet, it is expected that in many of these 'controlled inundation areas', reed will be a dominant plant species.

At the University of Antwerp, a mesocosm experiment will be carried out, in which different tidal regimes are simulated. Reed is planted at different levels and will be subjected to different flooding regimes. The growth and biomass of reed during the growing season will be measured. The aim of the poster is to explain the construction and creation of the tidal regimes.

P20

## Exposure patterns of perfluorooctane sulfonate in aquatic organisms from the Western Scheldt estuary

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Estuarine and coastline ecosystems are of major economic importance, but due to large industrial and domestic waste water discharges, the structure and functions of these habitats are often disturbed. Like other estuarine areas, the Western Scheldt estuary, situated in the southwest of the Netherlands and the north of Belgium, is a highly polluted ecosystem. Until now attention was primarly focused on organochlorines, pesticides and heavy metals because of their persistent character and ability to accumulate in aquatic organisms. Research investigating another group of important pollutants, the fluorinated organic compounds (FOCs), has received much less attention. As recent studies have indicated that FOCs occur worldwide in the environment, show high persistence and little or no biodegradation, it becomes more and more important to characterize the distribution patterns and effects of fluorinated organochemicals. An important representative of these fluorinated chemicals is perfluorooctane sulfonic acid (PFOS). In the present study, we determined, for the first time, the PFOSexposure levels in vertebrate and invertebrate biota from the Western Scheldt estuary. We sampled various organisms during several field campaigns. All tissue samples were extracted in methanol and concentrations of PFOS were determined using high performance liquid chromatography tandem mass spectrometry (HPLC/MS/MS). The concentration of PFOS in crab (Carcinus maenas), shrimp (Crangon crangon), bib (Trisopterus luscus) and plaice (Pleuronectes platessa) provide a basic set of data for estimating fluoro-organic chemical contamination levels in the estuarine environment and for further studies concerning the distribution patterns in estuarine ecosystems.

P21.

The decomposition of reed leaves in the Scheldt-estuary: spotlight on the Fungi

## G. Van Ryckegem and A. Verbeken

The poster presents preliminary results on a decomposition-study of reed leaves (*Phragmites australis*) in one site (PQ 206, near 'Schor van Doel'). In a brackish reed stand leaves make about 25 % of the above-ground reed biomass, being an important organic pool in the Scheldt-ecosystem and a potential substrate for phragmiticolous fungi. Fungal species composition and fungal biomass (and also some abiotic factors, not presented here) were followed during decomposition in litterbags on the sediment of a reed belt. Fungal biomass was measured using ergosterol quantification. During the survey 40 fungal taxa were found to colonize the leaves from standing green – to standing dead – to litterleaf-stage. Succession and vertical preference of fungal species is demonstrated during growth and decomposition. Leaves, although abscised from the culms, have an important standing dead decomposition with high fungal diversity and biomass (599  $\mu$ g ergosterol/ g leave, n = 10 corresponding with ! 0.12 g fungus/ g leave) just before abscission. Leaves were almost totally fragmented after a 10 month incubation on the sediment. With fungal crop ranging from 142  $\mu$ g ergo/ g leave to 346  $\mu$ g ergo/ g leave showing a steep decline in fungal crop after leaf abscission, a gradual recovery followed by a final decline towards the final stage. Despite the fact that a serious amount of fungal biomass is developed, less species seem to be adapted to colonize the litter leaves.

P22.

Spatio-temporal patterns in benthic macrofauna on a brackish mudflat (Schelde estuary, NW-Europe): results of ten years monitoring

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Estuarine ecosystems are characterized by largely varying physicochemical conditions, especially in the meso-/oligohaline zones. Knowledge of the environmental variability and related population effects on a range of spatio-temporal scales is fundamental to a better understanding of their functioning, stability, resilience and the way they are influenced by human impacts.

This study combines spatial and temporal variations in macrobenthic populations (and their environment) on a brackish mudflat in the Schelde estuary (NW-Europe). From 1990 to 1999, long –term year-to-year variations were monitored on 24 sites, short –term monthly variations on two sites.

The variation in macrobenthos and the physicochemical environment due to seasonal dynamics, spatial pattern, and annual as well as long-term trends, was quantified. The macrobenthic community on the mudflat was characterized by a few dominant species (*Corophium*, *Heteromastus*, *Nereis*, Oligochaeta), with spatial distributions related to sediment characteristics. Considerable year-to-year variation was observed and seasonality was evident for all species. It is argued that in the meso-/oligohaline zone, where salinity shows large seasonal fluctuations, benthic communities change frequently during the year, resulting in communities that seldom progress beyond early benthic-community succession. Annual variations are less pronounced. The impact of the construction of a containerterminal (1994), adjacent to the mudflat, on the macrobentic species distributions is discussed.

P23.

The Fish Assemblage of the Intertidal Salt Marsh Creeks in North Bull Island, Dublin Bay: Seasonal Changes.

## V. Koutsogiannopoulou

North Bull Island, an island of recent origin in Dublin Bay, has been designated as a Biosphere Reserve on the basis of its waterfowl, sand dunes, mudflats and salt marsh.

This project aims to describe the fish populations living within the salt marsh creeks and to determine the seasonal distribution of the species in this habitat. To do so, two salt marsh creeks were sampled from June 2000 till May 2002, to provide a 2-year cycle. A trawl net was used. The samples were collected almost every month for the first year and quarterly for the second year to assess the seasonal changes within the fish community. Sampling also included both ebb and flood phases, so as to reduce any sampling bias to a minimum. Water temperature and salinity were measured *in situ* with a ST probe. Water samples were also taken for SPM and Chlorophyll-a determination.

Ten fish species were found in the salt marsh creeks. The fish assemblage was dominated by the common goby *Pomatoschistus microps*, but juveniles of exploited and threatened species such as the bass, *Dicentrarchus labrax* and the catadromous *Anguilla anguilla* were also hosted. Four species (*Pomatoschistus microps*, *Gasterosteus aculeatus*, *Chelon labrosus* and *Platichthys flesus*) contributed almost 99% of all individuals sampled. A marked seasonal pattern was found, for the number of species, the number of individuals, the biomass, as well as for biodiversity [Shannon-Wiener species diversity index (H') & Shannon-Wiener Evenness Proportion (SEP)].

The presence of juveniles of all fish species in the creeks supports the premise that fish use this area as a nursery.

P24.

## Vegetation map of the polder of Kruibeke, Bazel and Rupelmonde

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The Sigmaplan is a protection plan against inundations from the Zeeschelde and its tributaries. Safety measures includes elevation of the dikes and the creation of controlled inundation areas. The polder of Kruibeke, Bazel and Rupelmonde (KBR) is the last and largest (600 ha) planned controlled inundation area. Construction works started in 2002. Unlike the other inundation areas its secondary function will be nature development rather than agriculture. In view of future developments and to establish starting conditions a vegetation map of the polder was made. A network of piezometers was installed in 1996 and expanded in 1998 to investigate the groundwater quality and regime.

In june-september 2000 a vegetation relevé was made in each vegetation unit (614 in total), according to he reductionistic method. TWINSPAN was used to establish a vegetation typology. Eighteen vegetation types were distinguished: 9 types of woodlands and 9 types of grasslands. Several hydrological variables were linked to the vegetation types. Groundwater level and development time are the principal determinants for the woodlands. The *Carici elongatae-Alnetum* and the *Alno-Padion*, respectively on stands with the highest and lowest groundwater level and with the shortest and longest development time, are the two (sub)climax vegetations towards which the other woodland types e.g. the several poplar stands and clearances will evolve. The *Lolio-Cynosuretum* and the *Lolio-Potentillion* can be considered as the (sub)climax grassland vegetations. Management and the inundation regime are the most important determinants. In most cases biological value of the grasslands deteriorates due to the applied management.

P25.

Zooplankton distribution across the brackish and freshwater zone of the Scheldt estuary.

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Zooplankton diversity and distribution in the brackish and freshwater zone of the Scheldt is studied, as a continuation of preceeding studies carried out in the periods 1967-1669 and 1995-1997. We report on species diversity and abundancy of the zooplankters, collected on a monthly basis, in 20 sampling sites along the salinity gradient. Calanoids occur mainly in the brackish part, with *Eurytemora affinis*, *Acartia tonsa* and *Eudiaptomus gracilis* as the dominant species. In the freshwater region, rotifers (*i.e. Brachionus calyciflorus*, *Keratella quadrata*, among others), cyclopids (*i.e. Acanthocyclops robustus*, *Cyclops vicinus*) and cladocerans (*Daphnia longispina*, *Bosmina longirostris*...) are the dominant zooplankters.

In addition, we report the presence of several species which were not detected in the former studies, such as the rotifers *Brachionus leydigi* var. *quadratus*, *Notholca labis*, *Platyias quadricornis*, *Euchlanis dilatata*, *Gastropus hyptopus*, *Testudinella patina*, *Polyarthra dolichoptera and Trichotria sp.*; the cladocerans *Acroperus harpae* and *Biapertura affinis*, and the harparticoid *Bryocamptus* (*Bryocamptus*) *minutus*.

P26

Vegetation development on a brackish sludge mound: a case study at the port of Antwerp

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The Antwerp Port Authority considers the application of dredged material from the maintenance of locks and docks for the construction of landscape dikes. These dikes could become an important part of the ecological infrastructure in the port area. In 2000, an experimental dike was constructed with consolidated dredged material near Magershoek, a small community north of the locks of Zandvliet and Berendrecht. Ecotoxicological and environmental risks as well as possibilities for nature development and forestry are investigated. The present poster only deals with spontaneous vegetation development and the effects of different management schemes. Four managements schemes are investigated: (1) spontaneous development, (2) spontaneous development with mowing, (3) sowing of grass with mowing, (4) sowing of a mixture of grass and herbs with mowing.

First year vegetation strongly reflects the brackish nature of the substrate. It is dominated by few salt-tolerant species such as *Matricaria maritima*, *Aster tripolium* and *Atriplex prostrata*. Other constant species include several Chenopodiaceae, *Sonchus oleraceus*, *S. asper*, and *Lactuca serriola*. *Matricaria maritima* remains strongly dominant in second year vegetation, whereas *Aster tripolium* and *Atriplex prostrata* decline. *Urtica dioica* and *Cirsium arvense* become better established.

The site was only mown twice until now, but changes are already obvious. Both in sown and spontaneous parts, mowing leads to rapid expansion of several grass species. But few of the sown herbs are established (e.g. Centaurea jacea, Daucus carota, Cichorium intybus).

In order to predict long term vegetation changes, the site at Magershoek is compared to older disposal sites with similar soil structure and contamination degree along the rivers Schelde and Leie.

P27.

Influence of diagenetic processes on the distribution and accumulation of major and trace elements in the sediments of the Scheldt estuary

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Sediment cores were carefully collected with a box corer in three areas of the Scheldt estuary (Antwerpen, Doel, Terneuzen) in August and repeated in December. The 20 upper cm were sliced under a nitrogen atmosphere in 0.5-1 cm thick layers. The slices were then centrifuged in order to separate the interstitial water from the solid phase. The following elements were determined in the solid phase Si, Al, Fe, Ca, Mg, Mn, Co, Zn, Cd, Cu, Pb, Corg and Norg. In addition, the following parameters were also measured in the pore waters: salinity, alkalinity, DIC, pH, DOC, NO<sub>3</sub>, NH<sub>4</sub>, PO<sub>4</sub>, Si, Fe, Ca, Mg, Mn, Co, Zn, Cd, Cu and Pb. The results for one core taken as an example will be shown on the poster.

The vertical distribution of most major and minor elements remains rather constant except that of organic carbon whose concentration profile is scattered, reflecting the presence of thin mud layers and lenses in sandy deposits.

The vertical profile of dissolved elements in pore waters exhibit generally marked gradients linked to the bacterial degradation of organic matter imposing strongly reducing conditions below the water-sediment interface. This is demonstrated by the rapid decrease of nitrate, the release of manganese and iron and finally the consumption of sulfate. The concentrations of trace elements fluctuate markedly in relation to dissolution and precipitation reactions.

In order to obtain additional information on the speciation of trace elements, titration experiments of the solid phase by HCl have been performed during which the release of major and minor elements are measured. The similarity in behaviour between elements allow to demonstrate their close association. This is for example the case of Mn and Co; Zn, Cd and  $S^{=}$ ; Cu and Al; Pb and Fe.

The use of a diagenetic model proposed by Yifenga and Van Cappellen (1996) is presently tested and tentatively improved to include the description of the behaviour of trace elements. Preliminary results will be shown.

W. Yifenga and Ph. Van Cappellen (1996) A multicomponent reactive transport model of early diagenesis: Application to redox cycling in coastal marine sediments. Geochimica et Cosmochimica Acta, 60, 2993\_3014.

P28.

The Lippensbroek polder as a case study for the innerdike restoration of ecosystem structures and functions.

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In the framework of the SIGMA plan, Flemish authorities (Waterways and Maritime Affairs Administration, division Sea Scheldt) plan a large controlled inundation area (CIA) in polders (Kruibeke-Bazel-Rupelmonde, 578 ha) along the freshwater - oligonaline border of the Scheldt estuary. Beside fulfilling an important role in enhancing safety against flooding, a CIA could contribute to the restoration of degraded ecosystem functions and habitats by implementing specific management options. However, as the outcome of some management types on ecosystem structures and functions are still uncertain, preliminary projects on a smaller scale must yield adequate information to allow, if necessary, appropriate adaptations. In the pilot project 'Lippensbroek', a management scenario for the northern part of the future Kruibeke-Bazel-Rupelmonde CIA will therefore be tested beforehand on an innerdike area of 10 ha. Carefully designed sluices will allow the exchange of limited amounts of Scheldt water, causing a semidiurnal submersion of ca. 0.5 m. Additionnaly, submersions with larger water quantities will occur on a less regular base during storm floods. We discuss the present and future hydrologic regime of the Lippensbroek polder, together with the necessity of a multidisciplinary program to monitor the restoration of ecosystem structures (fresh water tidal marshes, mudflats, creeks, etc.) and functions (nutrient cycling, storage capacity enhancement, sediment retention, biodiversity and habitat support, etc.).

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