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Introductory Paper

The Scheldt estuary: a description of a changing ecosystem

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Abstract

Estuaries are naturally highly dynamic and rapidly changing systems, forming a complex mixture of many different habitat types. They are very productive biomes and support many important ecosystem functions: biogeochemical cycling and movement of nutrients, mitigation of floods, maintenance of biodiversity and biological production. Human pressure on estuaries is very high. On the other hand, it is recognized that estuaries have a unique functional and structural biodiversity. Therefore, these ecosystems are particularly important for integrating sound ecological management with sustainable economics. These opportunities are explored for the Scheldt estuary, a well-documented system with an exceptional tidal freshwater area. In this article a description of the Scheldt estuary is presented, illustrating that human influence is intertwined with natural dynamics. Hydrology, geomorphology, trophic status and diversity are discussed, and possible future trends in both natural evolution and management are argued.

Introduction

Estuaries are the main transition zones or ecotones between the riverine and marine habitats. They are geomorphologically very dynamic and ephemeral systems, influenced both by sea and land changes, forming a complex mixture of many different habitat types. These habitats do not exist in isolation, but rather have physical, chemical and biological links between them, for example in their hydrology, in sediment transport, in the transfer of nutrients and in the way mobile species move between them both seasonally and during single tidal cycles. Even small estuaries are typically composed of a mosaic of between four and nine major habitat types (subtidal, intertidal mudflats, intertidal sandflats, marshes, shingles, rocky shores, lagoons, sand-dunes and grazing marshes/coastal grassland) (Davidson et al., 1991). Despite the many different habitat types, relatively large and unpredictable variations in salinity (physiological stress) and water movement or turbidity (physical stress) tend to limit the number of animal and plant species capable of adapting to these rigorous conditions (Day et al., 1989; McLusky, 1989). As a result, an estuary generally harbours less species than either the freshwater river above the tidal limit or the truly marine habitat outside the estuary. Although estuaries generally contain relatively few species, the abundance and biomass of organisms is usually very high.

Estuaries and coastal marine ecosystems are also cited among the most productive biomes of the world, and serve as important life-support systems also for human beings (Day et al., 1989; Costanza et al., 1993). Other highly productive systems, such as coral reefs and tropical rain forests, differ greatly in how their productivity is achieved. Reefs and tropical rain forests efficiently recycle the limited resources through a very diverse ecosystem. In contrast, the low diversity estuarine ecosystems achieve very high productivities through the continuous arrival of new nutrient supplies. Perhaps the most distinctive feature that contrasts estuaries from other biomes is the nature and variability of the physicochemical forces that influence these ecosystems. Within small geographic regions, many estuaries experience widely varying conditions of temperature, salinity, concentrations of a wide variety of chemicals, and plant and animal densities, many of whose are mediated by water movement over relatively short time scales (Day et al., 1989; McLusky & Elliott, 2004).

Being open systems, estuaries also serve as important connections between rivers and the sea for many anadromous (ocean dwelling but spawning in estuaries and rivers) and catadromous (freshwater dwelling but spawning in seawater) species.

Estuaries support many important ecosystem functions: biogeochemical cycling and movement of nutrients, purification of water, mitigation of floods, maintenance of biodiversity, biological production (nursery grounds for several commercial fish and crustacean species) etc. (Daily et al., 1997; De Groot, 1997; Meire et al., 1998). An estimate of the economic value of these ecosystem functions (goods and services) indicated that estuaries are among the most valuable ecosystems in the world (Costanza et al., 1997).

Human pressure and impact on estuaries is very high, as most of the urbanization is concentrated in the coastal zone. On the other hand, it is recognized that estuaries have unique functional and structural biodiversity values. Therefore, these ecosystems are particularly important for integrating sound ecological management with sustainable economics. The Scheldt estuary in NW-Europe is a typical example of such an estuary. It is situated in a very densely populated area with a very high economic activity, which is conflicting strongly with the high biological values. The papers in this special volume were presented at the ECSA local meeting "Ecological structures and functions in the Scheldt estuary: from past to future" held at the university of Antwerp from 7 to 10 October 2002. Several papers result from larger research projects that aimed at providing the necessary scientific basis for a more integrated management of the estuary. In this paper, we give a general description of the Scheldt estuary, including the hydrology, geomorphology, trophic status and biodiversity. Human impacts are briefly discussed and we also point to the need of a more integrated management of the estuary and present some tools that might achieve this in the near future. It is not an extensive review of the present knowledge about the estuary.

The Scheldt estuary: some characteristics

General characteristics

The river Scheldt has a length of 355 km from source to mouth. The source is situated in the north of France (St. Quentin) about 110 m above sea level and the river flows into the North Sea near Vlissingen (The Netherlands). The total catchment area is approximately 21.863 km^2. About 10 million people (477 inhabitants km^{-2}) live in the river basin. The Scheldt is a typical rain fed lowland-river.

The estuary of the river Scheldt extends from the mouth at Vlissingen (km 0) to Ghent (km 160), where sluices impair the tidal wave (Fig. 1) in the Upper Scheldt. The tidal wave also enters the major tributaries Rupel and Durme, providing the estuary approximately 235 km of tidal river. The Zeeschelde (105 km), the Belgian part of the estuary, is characterized by a single ebb/flood channel, bordered by relatively small mudflats and marshes (28% of total surface). The surface of the Zeeschelde amounts to 44 km^2.

Human activities are mainly concentrated in the Zeeschelde, where agglomerations and industries historically developed close to the riverbanks. The intertidal zone is often absent (e.g. quays, wharfs) or very narrow. Upstream of Dendermonde, the estuary is almost completely canalized (Hoffmann & Meire, 1997). The Zeeschelde is sometimes further subdivided into the 'Beneden Zeeschelde' between the Dutch/Belgian border and Antwerpen and the 'Boven Zeeschelde' between Antwerpen and Ghent. The middle and lower estuary, the Dutch part of the estuary called the Westerschelde (58 km), is a well mixed region characterized by a complex morphology with flood and ebb channels surrounding several large intertidal flats and salt marshes. The surface of the

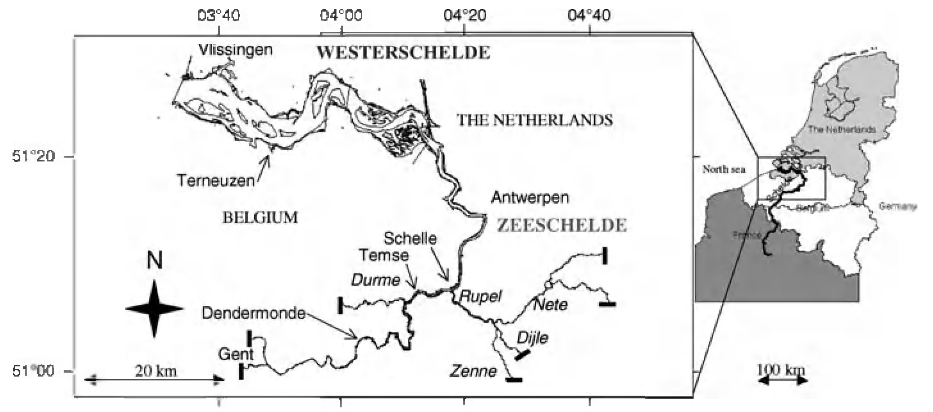

Figure 1. Map of the Scheldt estuary.

Westerschelde amounts to 310 km^2, with the intertidal area covering 35%. The average channel depth is approximately 15–20 m (Table 1).

Freshwater flow and tidal influence

The long term yearly averaged river discharge at Schelle (where the Rupel enters the Scheldt,), amounted to 104 m^3 s^{-1}, with a maximum recorded value of 207 m^3 s^{-1} (in 1966) and a minimum of 43 m^3 s^{-1} (in 1949) (Taverniers, written communication). Being a typical rain-fed river, river discharge varies among seasons (Fig. 2). During winter, the mean river discharge amounts to 180 m^3 s^{-1}, with exceptional values up to 600 m^3 s^{-1}. Average summer values decrease to 60 m^3 s^{-1}, with minimal values down to 20 m^3 s^{-1} (Baeyens et al., 1998). On average, only 39% of the discharge coming from the (non-tidal) Upper Scheldt enters the estuary in Ghent. The remainder is deviated to canals, mainly the Ghent–Terneuzen canal. This canal empties in the Westerschelde near Terneuzen, discharging the fresh water much more downstream in the estuary. As a consequence of this depletion, the share of the Rupel increased to about 42% of the total Scheldt discharge in Schelle. During peak discharges near Ghent, a much larger proportion of the water is deviated towards the Zeeschelde. At low discharges on the contrary, most water is going to the canals to guarantee a minimum discharge and water level for the shipping. In these circumstances, the Rupel discharge can be twice the discharge of the Upper Scheldt discharge entering the estuary. The residence time of the water ranges from one to three months, depending on the river discharge (Soetaert & Herman, 1995).

Due to the funnel-shaped morphology of the estuary, the mean vertical tidal range is maximal in the freshwater tidal reaches (average tidal range at Schelle: 5.24 m) (Claessens, 1988) (Table 1). The ratio between the duration of rising and falling tide decreases from 0.88 at Vlissingen to 0.75 at Schelle and 0.39 at Ghent (Fig. 3). The maximum tidal velocity during an average tidal cycle at the mouth is about 0.9 m s^{-1}, in the Beneden Zeeschelde 1.1 m s^{-1} and between Antwerpen and the Rupel is 1.2–1.3 m s^{-1} (Baeyens et al., 1998).

Salinity

The longitudinal salinity profile of the Scheldt estuary is primarily determined by the magnitude of the river discharge (Fig. 2), with the transition between fresh and salt water being particularly variable (Soetaert et al., 2005; Van Damme et al., 2005). The estuary is well mixed (except during peak discharges), which means that vertical salinity gradients are small or negligible.

A polyhaline zone stretches out from the river mouth (km 0) to the vicinity of Hansweert (km 40). Between Hansweert and the Dutch–Belgian border (km 58) a mesohaline zone is located. The section between the border and the vicinity of Antwerpen is characterized by a steep salinity gradient. Upstream of the Rupel is the fresh water tidal zone. Salinity there varies between 0 and 5 PSU.

The spatio-temporal evolution in salt content is very sensitive to the seasonal changes in river

Table 1. Some characteristics of the Scheldt estuary at several locations (based on data of the Maritime Access Division of the Flemish Government). For positions of the locations see Figure 1

	Vlissingen	Terneuzen	Hansweert	B-NL border	Kruibeke	Temse	Dendermonde	Melle
Distance from the mouth (km)	0	23	36	49	82	97	120	154
Mean tidal range (m)	3.82	4.19	4.48	4.85	5.20	5.14	3.74	1.96
Mean depth (m)	25	55	25	20	13	10	6	15
Width (m)	5000	5500	4300	2500	350	250	100	50
Flood volume (10^9 m^3)	1.04	0.67	0.40	0.14	0.04	0.03	0.006	0.006

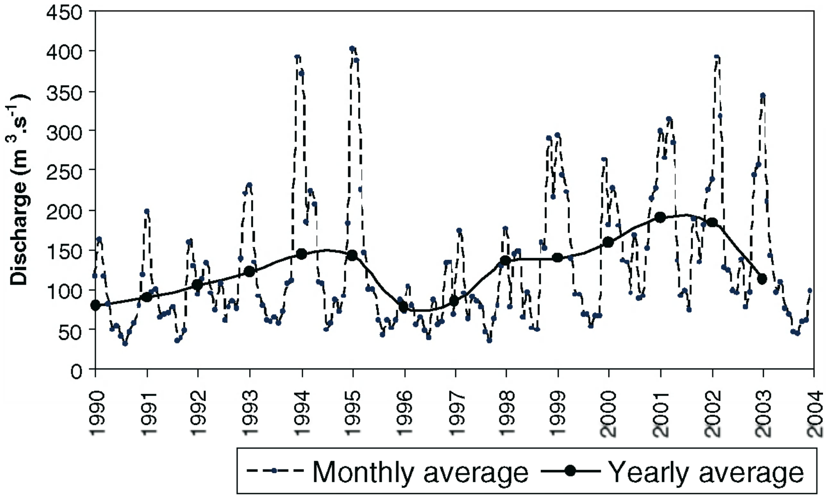

Figure 2. Fresh water discharge in the Scheldt estuary at Schelle (period 1990–2004) (source data: Maritime Access Division, Flemisch Government).

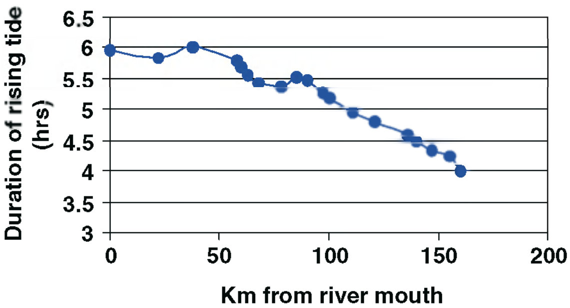

Figure 3. Duration of the period of rising tide along the longitudinal gradient of the Scheldt estuary (based on data of the Maritime Access Division of the Flemish Government).

discharge and to a lesser extent to the fortnight tidal oscillation, which is of smaller amplitude. In the mesohaline zone, discharge has a maximal effect on salinity. Here salinity-shifts over a distance of 20 km are normal (Van Damme et al., 2005).

Maximum turbidity zone

Temperate, well-mixed, tidal estuaries are generally characterized by the presence of a maximum turbidity zone (MTZ) in the region of low salinity. The MTZ consists of an area where a large amount of cohesive sediments are accumulated and where these sediments are continually deposited and resuspended by the tidal flow. The distribution of suspended matter is influenced by a range of interrelated processes (e.g. temperature and biological activity, fresh water discharge and salinity, hydrodynamic conditions and turbulence, mineralogical composition, chemical conditions, aggregation and flocculation). In the Scheldt estuary, the turbidity maximum is situated at about 110 km from the mouth during dry periods and at about 50 km during wet periods (Wollast, 1988). Two MTZ might be observed, one at the freshwater/seawater interface, and a second one originating from tidal asymmetry (Baeyens et al., 1998; Fettweis et al., 1998; Herman & Heip, 1999).

Table 2. Habitat surface (ha) in the Scheldt estuary

	1900	1960	1990
Westerschelde			
Total surface	36.922	32.880	30.930
Sand flat, mudflat & marsh	13.500	7.880	5.880
Shallow water	7.500	4.470	3.170
Zeeschelde			
Total surface	5.704		4.923
Mudflat & marsh	2.192		1.411

The combination of favourable hydrodynamic conditions, several fine suspended matter sources, and the flocculation process, led in the salinity

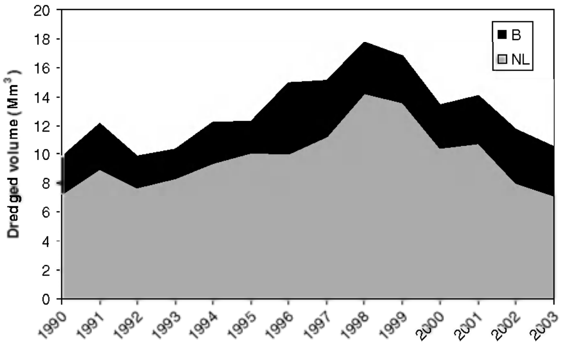

Figure 4. Amounts of dredged volume in the Scheldt estuary in Belgium (B) and the Netherlands (NL) (period 1990–2003) (source: Maritime Access Division of the Flemish government).

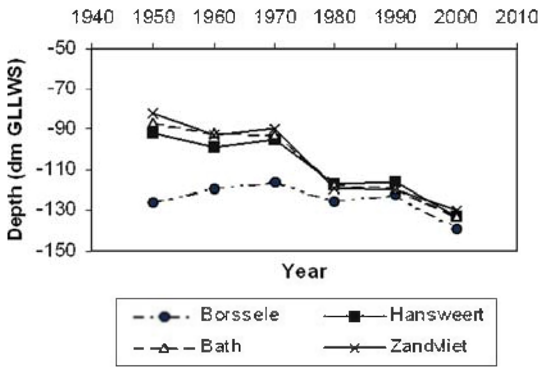

Figure 5. Channel depth at 4 locations in the Westerschelde (GLLWS = level at averaged minimal low spring tide) (based on data of the Ministry of Transport, Public Works and Water Management of the Netherlands).

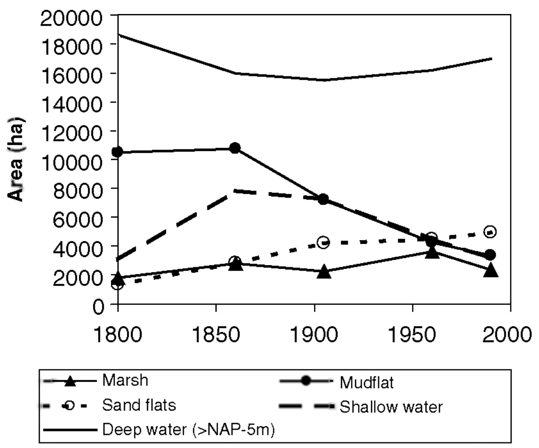

Figure 6. Habitat area evolution in the Westerschelde over the last centuries. NAP = the Dutch standard altitude reference level, the relation with the Belgian TAW standard is: NAP (m) + 2.33 m = TAW (m) (source: Ministry of Transport, Public Works and Water Management of the Netherlands).

zone 2–10 PSU to a bottom sediment that contains locally a high percentage of fine material (fine sand to mud, sometimes even a non-compacted, mobile hyperpycnal or fluid mud layer) (Baeyens et al., 1998). Bottom sediments of the Westerschelde in general consist of sand (coarse, medium-coarse and medium-fine) except on the tidal flats where also muddy sediments occur.

How did the Scheldt estuary change from past to present and what are further expected changes?

Geomorphology

Major changes in the morphology of the estuary occurred during the last centuries. Since the early middle ages tidal marshes were reclaimed by embankment to create agricultural land, since the middle of the 20th century for industrial and urban developments. The last century still about 16% of total surface was lost (Table 2). As mainly mature marshes are embanked, the relative contribution of intertidal areas decreased in the same period from 27 to 19% (excl. sand flats), or from 37 to 30% (incl. sand flats).

Intertidal habitat was also lost due to dike building. In order to protect the land against storm floods from the North Sea all dikes along the estuary (more than 700 km) have been heightened and strengthened. Therefore, the base of the dikes needed to be widened, which was mostly done on the marshes and not on the landside of the dike. By now, over more than 50% of the total length of the estuary lacks tidal marshes in front of the dike. This disrupted the connectivity of marshes along the salinity gradient.

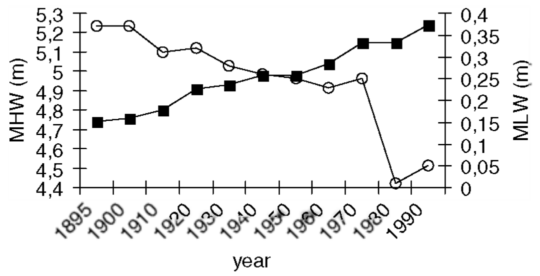

Figure 7. Evolution of mean high water level (MHW, squares) and mean low water level (MLW, open circles) in the Scheldt estuary near Antwerpen (based on data of the Maritime Access Division of the Flemish Government).

To guarantee the safe access to the ports along the estuary, but mainly to the port of Antwerp, for ever larger ships, large scale dredging of the maritime access routes in the Westerschelde and in the lower Zeeschelde is required (Fig. 4). Most dredging takes place at the bars where ebb and flood channels merge and at the port sluices. Some bars have been deepened more than 5 m and a further deepening is required (Fig. 5). Although some sand is extracted from the estuary, most dredged material is relocated within the estuary at some specified dumping locations. In the Zeeschelde, about 367,000 tons dry weight of polluted fine sediments are removed yearly from the system (OVAM, oral communication, 2003).

The recent evolution of habitat area in the Westerschelde (Fig. 6) is characterized by a decrease of low dynamic area (e.g. mud flats and shallow water characterized by low physical stress) and an increase of high dynamic area (e.g. deep water and sand flats characterized by high physical stress). Total volume of the channels increased (partly due to dredging) but also the total volume of the tidal flats increased partly by an increase in area, partly by sedimentation. Tidal marshes in the Scheldt estuary rise with rising mean high water level (MHWL), whereby a faster sea level rise will result in a more pronounced elevation difference between levees and adjacent basins (Temmerman et al., 2004a). The marshes are predicted to be able to keep up with the rising MHWL, unless MHWL rise would increase and the suspended matter concentrations would decrease (Temmerman et al., 2004b). This confirms a noted tendency that young marshes accrete to erosion-sensitive high marshes. In the Scheldt young marshes become scarcer.

Future evolution of habitat morphology will depend on a series of factors. Sea level rise, lowering of the sea bottom (subsidence), dredging and reclamation can all influence the tidal regime. A clear trend is already visible: tidal amplitude near Antwerpen increased substantially, about twice as much than at the mouth of the estuary (Fig. 7). Water, and especially sediment management in the catchment can have an effect on discharge. The interaction between these impacts and restoration measures will eventually result in one or another tendency in habitat shape.

Trophic status

Due to high input of allochtonous organic matter and nutrients in the upper and freshwater tidal estuary, microbial activities are intense and oxygen depletion occurs frequently. Under unfavourable conditions, i.e. high temperatures and low river flows, the entire upper estuary became often anoxic in the late seventies (Van Damme et al., 1995). Thanks to wastewater treatment, dissolved oxygen concentrations increased during the eighties, and this improvement continued in the 1990's (Van Damme et al., 1995; Soetaert et al., 2005). However, oxygen conditions are still low in the upper estuary, especially during summer (Van Damme et al., 2005). The improvement also proved to be related to variation in discharge (Struyf et al., 2004). Along the longitudinal axis, oxygen conditions improved considerably towards the Dutch/Belgian border, and in the Westerschelde the water column became fully oxygenated.

Still an important source of pollution remains, as the city of Brussels still discharges untreated wastewater through the Zenne and Rupel in the Scheldt estuary. In 2000, a first, small, wastewater treatment plant became operational; a second bigger one is tendered. The huge amount of respiration suggests a heterotrophic system (Heip & Herman, 1995). Indeed, annual gross bacterial production exceeds net primary production, even in the marine part, although differences there become rather small (Goosen et al., 1995, 1999). The improvement in water quality resulted in a first recovery of fish life in the Zeeschelde, mainly near the Dutch/Belgian border (e.g. Maes et al., 1998).

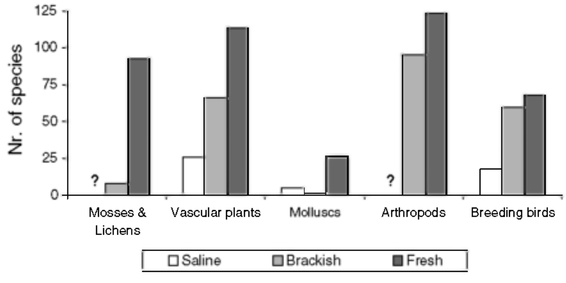

Figure 8. Diversity (number of species) along the salinity gradient of the Scheldt estuary (after Van den Bergh et al., 2001).

Table 3. River bank characteristics of the Zeeschelde between the Dutch Belgian border and Ghent (after Hoffmann & Meire, 1997)

	Length (km)	% Of total length
Bank characteristics		
Unfortified	34	13
Vertical construction	33	13
Fortified dike	186	74
Tidal marshes	80	32
Tidal mudflats	100	39
Distance between marshes	Frequency	%Frequency
< 500 m	52	56
> 5 km	6	6
Surface of marshes		
< 5 ha	67	73
> 40 ha	3	3

Biodiversity

It is clear that the hydrological, geomorphological and biogeochemical changes in the estuary had important consequences for the biodiversity. Bad water quality severely impacted benthic invertebrates and fish. According to Remane (1958), diversity in estuaries is lowest in the brackish part, due to the large variation of salinity. In the brackish part, less macrobenthic species were indeed found than in the marine part (Ysebaert et al., 2003). Functional groups changed also along the salinity gradient, with suspension feeders dominating the biomass in the marine part and deposit feeders in the brackish part (Ysebaert et al., 2003). In contrast, the freshwater part harboured less species than the brackish part, as the benthic community was almost exclusively restricted to oligochaetes (Seys et al., 1999). Until recently, fish was nearly absent in the fresh water tidal area and very scarce in the brackish part. On the contrary, in the marshes along the estuary however, a higher diversity of plants, molluscs, arthropods and breeding birds was observed in the freshwater part (Fig. 8).

The Scheldt estuary is one of the most important estuaries along the NW-European migration route for water birds, maximum numbers reaching up to 230,000 individuals. For 21 water bird species, the Scheldt has international importance (Ysebaert et al., 2000; Van den Bergh et al., 2005). A clear shift in species and functional groups is observed along the salinity gradient of the Schelde estuary (Ysebaert et al., 2000).

Lack of data makes it very difficult to estimate the impact of geomorphological changes on distribution and abundance of benthos, fish and birds. However, due to the gradually improving water quality the reproduction cycle of some migrating species (e.g. *Lampetra fluviatilis*) is restored, and numbers of a previously very abundant species, *Allosa fallax*, are raising, although they have by far not yet attained their former abundance (Maes et al., 1998). Also increasing numbers of water birds, especially in the Zeeschelde, might also be attributed to the improving water quality, as there is circumstantial evidence that benthic biomass did increase in the Zeeschelde.

Different phytoplankton communities can be distinguished in the estuary, not only on either side of the salinity gradient, but even within the freshwater reaches. Riverine phytoplankton, which is imported in the more turbid estuarine waters, undergoes a shift in species composition from green algae to diatoms (Muylaert et al., 2000), which are better adapted to low light climate. Zooplankton populations in the Zeeschelde are dominated by calanoid copepods in the saline and brackish part, and rotifers in the freshwater part (Soetaert & Van Rijswijk, 2003; Tackx et al., 2005). A gradual recovery of some species like *Eurytemora affinis* is observed (Appeltans et al., 2004). It is very difficult how the changes in water quality and potentially also in water residence time will impact the plankton populations.

The future

Estuaries are nowadays recognized as specific and valuable systems. Only the freshwater tidal zones still face a lack of interest, despite or due to their rareness. With the recognition of the value of estuaries came a turning point in the history of decline. For the Scheldt estuary, some evolutions may herald a start of recovery. However, the pressure on the estuary will remain or even increase: further deepening of the fairway is necessary from an economic point of view, further infrastructure for flood protection is necessary for safety. This inevitably will have impacts on the system. In an ever-changing system, it is a challenge to investigate if this will have effects on hydrology and geomorphology and if yes which effects and on what time scale they will occur. On the other hand, we are confronted with a further sealevel rise, changes in the fresh water discharges to the estuary with potential impacts on nutrient, pollutant and sediment loads. In the catchment area, the number of sewage treatment plants is increasing. The water quality of the Scheldt shows clear signs of improvement (Van Damme et al., 2005). The wastewater of Brussels, which eventually reaches the Scheldt estuary, will be treated from 2006 onwards. A further improvement of the water quality is up to some degree expected. However, the impact of non-point source pollution will probably remain high (Struyf et al., 2004) and there are now already indications of major changes in the relative availability of nutrients (Soetaert et al., 2005). How will this affect estuarine functions such as nutrient retention, primary productivity etc.? The opportunity will arise to investigate how water quality restoration will affect the trophic status of the estuary, biodiversity and carrying capacity for species and communities. Species composition may change either because some extinct species are unable to recolonize the estuary, due to the immigration of exotic species or due to the changed hydrodynamic and geomorphological conditions. What will be the effect of an increased diversity on estuarine functioning?

It is clear that the future status of the estuary will depend on the very complex interactions between all these anthropogenic and natural factors. Therefore, more than ever an integrated management plan for the estuary is necessary. Several national and international legislations provide a basis for such a management plan. The European Water Framework Directive (2000/60 EG) requires a good ecological status or a good ecological potential and all measures should be integrated in a river basin management plan. Also large parts of the Scheldt estuary are designated as special protection areas or special areas of conservation under the European Bird (79/409/EEC) and Habitat Directive (92/43/EEC), respectively. They require the development of conservation objectives which indicate the favorable conservation status. Questions as "how much habitat of which kinds is needed to sustain which populations of how many individuals?", "what are the restoration possibilities?" need to be answered and demand a huge integrated effort of scientific research. Estuaries are characterized by an ever changing history, mostly one of deterioration in many aspects, extending further back than the dawn of estuarine ecological research. Reference conditions are unavailable. Thorough understanding of estuaries therefore requires a careful reconstruction of the pristine state of estuarine functioning. On the other hand, it is clear that restoration of a pristine estuary is impossible. The elaboration of ecological quality objectives covering both the structural and the functional aspects of biodiversity is therefore a major challenge for the future. The water framework directive requires criteria to classify the system into 5 classes from very good to bad, based on benthic invertebrates, phytoplankton and angiosperms. This takes only structural aspects into account. Can we define functional goals and elaborate e.g. minimal capacities of the estuary to reduce organic loads, remove nutrients, achieve minimal levels of primary productivity?

Another important new development is the restoration of intertidal habitat. Although there is a long history of habitat restoration and creation in the United States as part of compensation schemes (Zedler & Adam, 2002), in Europe only recently some projects are ongoing. In managed realignment, the dike is put back for tens to hundreds of meters returning previously reclaimed habitat to the estuary. In other occasions, culverts are placed in the dike which allow a limited exchange of water. Along the Scheldt, estuarine restoration is combined with the safety against inundations. The Sigmaplan, a plan to protect Flanders against stormfloods in the Zeeschelde, is in an advanced phase of realization. The original plan consisted of the construction of a storm surge barrier, the heightening of dikes and the construction of controlled inundation areas (CIA's). These are low laying polders surrounded by a dike. The river dike is lower and during a storm surge water flows in the polder reducing high water levels upstream. During the next low water, the polder drains again to the estuary restoring the storage capacity. It was decided not to build the storm surge barrier and instead to increase the number of CIA's and add some realignment projects. Controlled inundation areas with controlled reduced tide (CIA-CRT) are new options were a limited tidal range is realized in the CIA's through exchange of water between estuary and CIA through the sluices, as such creating new intertidal habitats such as mudflats and marshes. These systems have peculiar ecological boundary conditions (Maris et al., submitted) but can most probably restore ecosystem functions and hence combine ecological restoration with flood control.

An integrated management plan needs to integrate all the necessary measures to reach the different goals. However, a crucial factor of uncertainty is how the hydrodynamic features of the estuary can be influenced by changing the geomorphology by adding intertidal areas or shallow water areas to the system. Under what conditions does the effect of energy dissipation prevail on possible stronger currents due to an increase of estuarine storage capacity, if habitat is added? What is the impact on water residence time and hence on the biogeochemical functioning?

The above mentioned symposium and the papers in this special volume all add to a better understanding of the Schelde estuary in particular and estuaries in general. They deal with water and sediment quality, sediment dynamics, the biogeochemical functioning, zoo- and phyto-plankton, benthos, birds, fish and marsh vegetations. They all form building blocks for an integrated management plan.

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