Ecological Rehabilitation of the Schelde Estuary (The Netherlands–Belgium; Northwest Europe): Linking Ecology, Safety against Floods, and Accessibility for Port Development

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Abstract

The Long-Term Vision for the Schelde estuary was determined as “the development of a healthy and multifunctional estuarine water system that can be utilized in a sustainable way for human needs.” This Dutch–Flemish managerial plan sets quality targets for the condition of the estuary by the year 2030 and the management measures to achieve them. Targets were developed and integrated from three central perspectives: accessibility of the ports, safety against floods in the densely populated catchment, and ecosystem health. This study focuses on the ecological rehabilitation of the estuary and the creation of sustainable nature, seeking possible alliances with security measures against floods, navigation requisites for port activities, and enhancement of the estuary’s educational and recreational values. The estuary and its valley were subdivided into ecologically relevant zones. Key parameters were identified, and a conceptual rehabilitation model was developed, based on a problem analysis. Goals were set in a semiquantified way for most attributes of the estuarine functioning and prioritized for each zone. Rehabilitation measures with maximal contribution to the priority goals were identified for each zone. Spatial analysis of the study area indicated optimal areas for the implementation of these measures. To exemplify the array of possibilities on an ecosystem level, two different rehabilitation plans were proposed, each from a different approach. The potential contribution to the rehabilitation of the estuary was compared for both alternatives.

Key words: ecological rehabilitation, integrated management, northwest Europe, Schelde estuary.

Introduction

Estuaries, defined as parts of a river under tidal influence (Fairbridge 1980; McLusky 1993), are important contributors to the world’s biodiversity. However, estuarine environments are severely threatened. Despite their ecological importance and relative scarcity on a global level, they have suffered large losses and many have been subject to prolonged cumulative anthropogenic impacts (Davidson et al. 1991; Suchanek 1994; Gray 1997; McLusky 1999). Downstream they provide ideal settlement places for harbors, industries, and towns, and the fertile upstream areas are often claimed for agriculture. Rising high-tide levels, resulting from global climate change, incite the construction of heavy embankments for flood control in the acquired lands. Drainage of industrial, domestic, and agricultural wastes puts the remaining areas under heavy pressure. What is left of the biological productivity (e.g., shellfish and fish) is seldom harvested in a sustainable way (McLusky et al. 1992; Heip & Herman 1995).

The Schelde estuary, with its tidal flats and marshes along an uninterrupted salinity gradient from a marine to a freshwater system, is almost unique in Europe. The Port of Antwerp, situated 80 km upstream is especially important for container traffic and vital for Flanders’ economic welfare. With its very densely populated catchment basin, the estuary faces problems such as decreased retention capacity, a fragmented ecological infrastructure, peak discharges, and increased sedimentation rates, turbidity, current velocities, and tidal amplitude. These issues result from the combined effects of land reclamation, land use and water management in the catchment, discharge manipulations, canalization, channel deepening, and the general rise in sea level. These changes reduce the ecosystem’s carrying capacity and resilience, increase its contribution to the eutrophication of the North Sea, and result in impoverished biotic communities and flood hazard.

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Sectoral management of all these aspects threatened the sustainable use of the estuary, and therefore an integrated approach was required. The Long-Term Vision, a Dutch–Flemish managerial plan for the Schelde estuary (LTVS), was determined as "the development of a healthy and multifunctional estuarine water system that can be utilized sustainably for human needs." The LTVS sets quality targets for the estuary in the year 2030 and the management measures to achieve them. Goals and management measures were integrated from three central perspectives: accessibility, flood management, and ecology. The Long-Term Vision quality targets were adopted by both governments in 2001; bilateral agreements for its phased implementation were signed in March 2002. In the first phase, goals and management measures for the year 2010 are set and a bilateral integrated monitoring and research program is established. This sketch of 2010 is submitted to an integrated environmental impact assessment and societal cost benefit analysis in order to select the optimal scenario with acceptable environmental impacts and societal costs, benefits, and acceptance. This study deals with the ecological aspects of the LTVS. The generalized ecological LTVS quality goals for 2030 (to improve the estuarine ecosystem with its typical habitats and communities and to reinstate essential physical, chemical, and ecological processes) were specified and semiquantified. Restoration measures were identified and combined into two alternative rehabilitation plans. A major issue in these plans was the coupling of ecological rehabilitation and the creation of a sustainable natural environment with security against floods, navigation requisites for port activities, and enhancement of the estuary's educational and recreational values.

Integrated estuarine ecosystem management, goal setting, and long-term planning are not new concepts. In the United States several estuary project plans, involving one or more states, were initiated in the 1980s, with the Chesapeake Bay project as the best known example (http://www.chesapeakebay.net/). The primary aim of these projects is to restore and sustain the estuary's "health": its living resources, habitats, and ecological relationships. They operate from a watershed approach, acknowledging public awareness and commitment as essential assets for success. The LTVS on the other hand operates strictly within the boundaries of the estuary; ecosystem health is only one of its three pillars, in addition to flood control and port

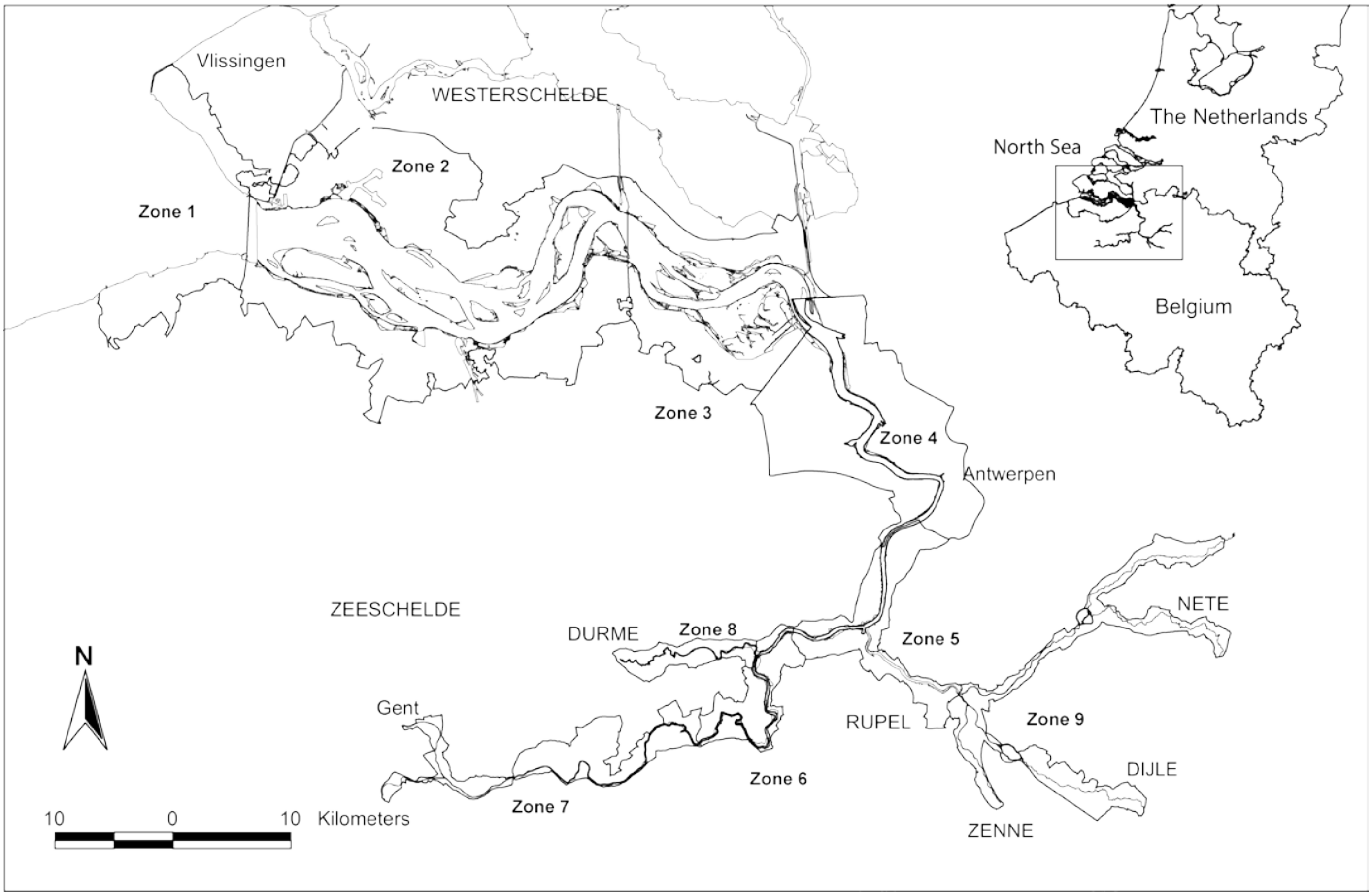

Figure 1. The Schelde estuary and its valley: study area, subdivided into nine zones.

accessibility, and less effort is dedicated to achieving public involvement and commitment.

The Study Area

The Schelde River begins in the north of France and flows into the North Sea near Vlissingen (The Netherlands) (Fig. 1). It is a lowland river with a total length of 355 km and a fall of 100 m at most. Its catchment area, approximately 21,000 km^2, has around 10 million inhabitants. This study focuses on the estuary which extends to Gent, 160 km from the mouth, where tidal influence is stopped by sluices. The tributaries of the Durme and Rupel, with the Nete, Dijle, and Zenne, are also under tidal influence and considered part of the estuary (total length of 77 km). The Dutch part of the estuary (Westerschelde) is characterized by flood and ebb channels, separated by intertidal sand and mudflats. Where the Zeeschelde (the Flemish part) starts, it changes quite rapidly into a one-channel system. Due to the funnel shape of the estuary the maximum vertical tidal range is about 100 km upstream, in the freshwater zone. The mean tidal amplitude varies from 3.8 m near the mouth to a maximum of 5.33 m and back to 2 m near Gent. The estuary is well mixed with a smooth transition between salt and fresh water. The polyhaline zone is 40 km long, and the mesohaline and oligohaline sections are 40 and 10 km, respectively. The freshwater part, including the tributaries has a total length of 135 km. For the purpose of this study the estuary and its valley were subdivided into nine ecologically relevant zones, each with specific prevailing morphological, hydrological, and salinity conditions (Fig. 1).

General Approach

Restoration goals and objectives are often derived from a described historical and/or geographical reference condition. In the Schelde estuary, anthropogenic impact has been almost continuous since the ninth century; therefore, it is scientifically impossible to trace how an unimpaired Schelde estuary would have developed. Knowledge on historical developments is analyzed for a better understanding of the current functioning rather than to establish reference conditions. Specific conservation issues (e.g., rare, red listed or vulnerable species and habitat types) could also serve to set the goals, but with the current deterioration of the estuary more fundamental issues are at stake. Therefore, the ecosystem health concept was adopted; the primary goal was to reestablish the estuary's autogenic processes and to reinstate its organization, vigor, and resilience. In an analysis of the problem, research results helped to trace dysfunctional patterns in habitats and community structure back to anthropogenic impairments of estuarine processes. Key parameters were identified and a conceptual rehabilitation model was developed (following Pastorok et al. 1997).

Problem Analysis

The Estuarine Food Web

Due to the high content of allochthonous and autochthonous detritus, microbial activities in the Schelde estuary are intense. Oxygen depletion occurs frequently and annual gross bacterial production exceeds net primary production even in the marine part (Goosen et al. 1995, 1999; Heip et al. 1995). However, bacterial production and detritus are not passed on to higher trophic levels (Herman et al. 2000); the establishment of the food web in the Schelde estuary relies on primary production. There are no records of extended submersed aquatic vegetation in the past or the present, probably due to the combination of high current velocities and turbidity. This leaves phytoplankton and phytobenthos as the base of the food web. Primary production in the Schelde is extremely light limited (Fig. 2; Heip et al. 1995); in zones 2–4 there is even no net primary production. Other threats to the phytoplankton population are peak river discharges, causing mortal shifts toward higher salinity zones (Muylaert et al. 2000, 2001). When dissolved silica (DSi) becomes limiting, nuisance nondiatom blooms of foam and toxic algae take over from diatoms (Billen & Garnier 1997).

All higher trophic (faunal) levels are sensitive to oxygen depletion. Zooplankton, food for macrobenthos and fish, faces problems in selecting suitable food particles from the high concentrations of suspended particulate matter (Herman & Heip 1999; Tackx et al. 2003). The role of macrobenthos is multiple. It transmits energy to fish and birds. Bioturbating deposit feeders affect benthic oxygen and nitrogen cycling. Filterfeeder grazing controls phytoplankton populations and algal blooms in eutrophic conditions, especially in shallow well-mixed estuaries (Herman et al. 1999). Distribution patterns of macrobenthic populations are influenced by salinity, tidal regime, current velocity, and sediment texture and quality. Filterfeeders need intertidal or shallow habitat and have narrow tolerance ranges for current velocities (Ysebaert et al. 2002). Cockles (*Cerastoderma edule*) and mussels

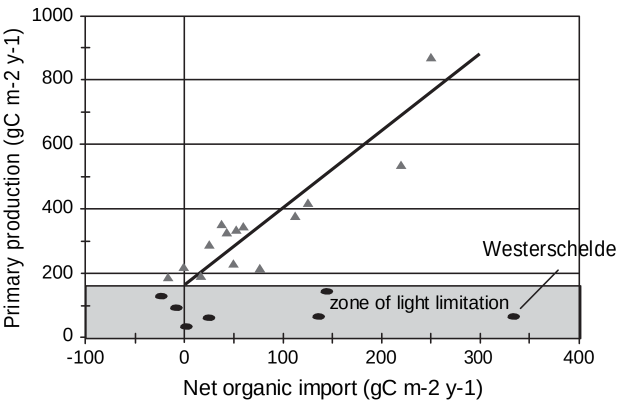

Figure 2. Primary production as a function of net organic import for several estuaries worldwide (after Heip et al. 1995).

(*Mytilus edule*) previously were abundant up to the Dutch–Belgian border. Cockles are now restricted to zones 1 and 2, and mussels have almost disappeared from the estuary. Their retreat to a narrower habitat range might be related to salinity extremes, caused by freshwater discharge manipulations near the Dutch–Belgian border. Macrobenthic diversity in the freshwater area is expected to be higher than in the brackish sections (Remane & Schlieper 1971); however, in the upper Zeeschelde only opportunistic oligochaete species survive the current water and sediment quality (Ysebaert et al. 1998).

The Schelde estuary is important as a wintering and stopover place for migrating waterbirds along the East Atlantic flyway. Waders feed mostly on sheltered mudflats with moderate mud content; the sandy exposed flats and plates with poorly established benthic communities function as resting places. The decline of diving ducks in the Westerschelde might be linked to evolutions in the shellfish supply. Water transparency and fish are limiting factors for piscivorous birds (Arts, unpublished study; Ysebaert 2000). Pollution, overfishing, and habitat destruction heavily reduced fish populations in the Westerschelde, and fish disappeared altogether in the Zeeschelde by the 1970s. Some species are recovering, but many migratory species are still unable to complete their life cycle. Temporary anoxia in the Zeeschelde, the sluice complex in Gent, and embankments prevent them from reaching suitable spawning grounds upstream and in the catchment. The Zeeschelde itself lacks suitable spawning habitats; in the Westerschelde shallow sheltered refuges, which serve as nursery grounds for juvenile marine fishes, have reduced in surface area (Maes et al. 1997, 1998; Maes 2000). Common seal (*Phoca vitulina*) and Harbor porpoise (*Phocoena phocoena*) used to be quite common in the Westerschelde. In present times the combination of polychlorinated biphenyls, cadmium, and organotin compounds hinders seal reproduction; the current fish stock, especially herring (*Clupea harengis*), is inadequate, and their resting is disturbed (Meininger , unpublished study).

Habitat Structures

In the past century 15% of the estuarine habitat was lost. Embankments and infrastructure works fragmented the remaining habitat and disrupted continuity with the valley. In the Westerschelde the surface of deep subtidal areas increased at the expense of shallow habitat. The total surface area of intertidal mudflats decreased and the ratio of sheltered-to-exposed flats decreased. Sand flats gained area and elevation and became steeper (Vroon, unpublished study). Brackish marshes are well represented (Table 1) due to the extended marsh of Saeftinge. In the Zeeschelde a relatively large surface of freshwater tidal marshes, a rare habitat in Europe, is present, but the most upstream sections are completely void of intertidal habitat. Representation of salt marshes is rather limited. The habitat quality of the tidal marshes is generally poor; many are nearly supratidal and in the last stages of marsh development. In the current setting there is no space for new marsh development, and catastrophic events, which could set back the succession of the old marshes, are prevented by control measures.

Table 1. Spatial distribution of habitat types along the Schelde estuary (ha).

Habitat Type	*Shallow Water*	*Mudflats*	*Marshes*
Zone 1	?	?	100
Zone 2	2,142	5,299	132
Zone 3	755	2,819	2,367
Zone 4	<20	524	188
Zone 5	0	126	128
Zone 6	0	59	189
Zone 7	0	9	30
Zone 8	0	35	113
Zone 9	0	0	8

Rehabilitation Hypothesis

In this conceptual model the dysfunctional patterns in habitat and community structures were traced back to anthropogenic changes in the physical and chemical processes. Key parameters were identified, and rehabilitation measures were proposed. The key points are presented in Figure 3 and Table 2.

Physical Processes

Land reclamation, embankments, channel widening and deepening, sand exploitation, and sea level rise affected the morphological and hydraulic evolution of the estuary. Their effects interfere with one another and, except for habitat loss, are hard to distinguish from natural developments. Therefore, we focus on identification of changes that have impaired ecological functions and propose measures to reverse them. In the past century the flood wave moved increasingly faster into the estuary; its celerity increased by one-third. This enhanced the tidal range, and the amplitude increased by 0.8 m (Fig. 4; Claessens , unpublished study). The current physical organization of the estuary, with its high current velocities and turbidity, puts the food web under pressure. Tidal energy should be dissipated and returned to more natural levels. Flood wave celerity is a function of cross section and channel width (Winterwerp et al. in press); hence, the effects of channel deepening and widening could be compensated for by the creation of shallow and intertidal areas. In the wider system of the Westerschelde this measure would probably not affect the energy of the flood wave but created sites could function as side pockets or “mini-estuaries” with their own favorable physical organization.

The freshwater discharge to the estuary is manipulated at different points along the gradient. Moreover, the

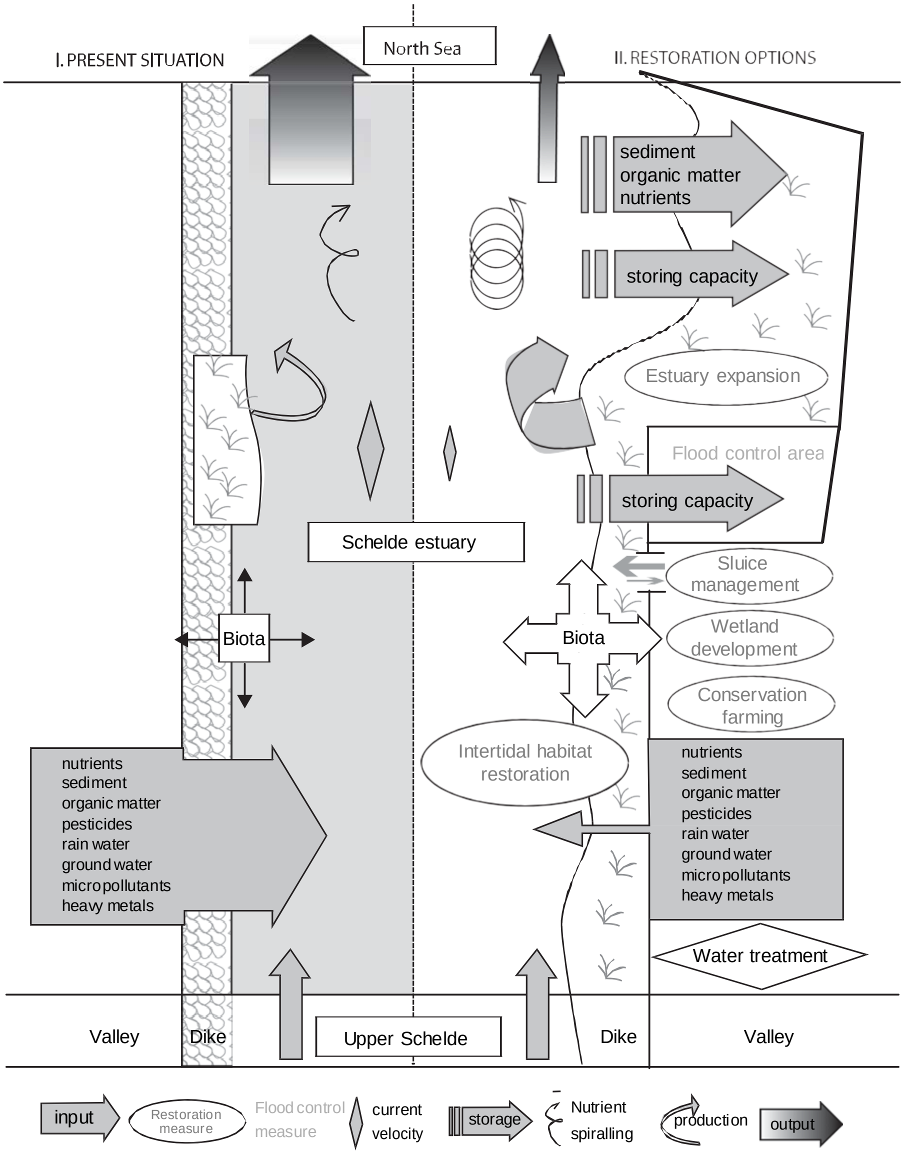

Figure 3. Conceptual rehabilitation model for the Schelde estuary.

discharge fluctuations have become unnaturally high due to the reduced retention capacities of the valley and upper estuary. This affects the salinity regime, the retention time, and internal nutrient spiraling. To buffer discharge, energy retention areas have to be created in the valleys.

A simple conceptual model describes the total energy (wave, tidal, and fluvial) distribution along an estuary (Dalrymple et al. 1992). Its application to the Schelde estuary (Fig. 5; Chen 2003) revealed that tidal energy dissipation is most needed in zones 2–5 (as defined in Fig. 1); discharge buffering is most useful in zones 7 and 9, upstream from the fluvial energy peak. Turbidity in the estuary relates to total energy and to the composition of the water (Chen 2003); consequently, rehabilitation measures for both would improve light penetration in the water. Sheltered intertidal areas can trap suspended solid matter and reduce turbidity in the channel.

Biochemical Processes

The estuary and its tributaries are used as a major drain for industrial and domestic wastes, a substantial part of which is untreated. The city of Brussels still discharges untreated wastewater through the Zenne and Rupel in the Schelde estuary. The estuary's performance as a biochemical filter between the land and the North Sea relies on both the received loads and its internal organization to process them. Rehabilitation efforts should address both aspects. All biochemical processes would benefit from reduced discharges from inland water treatment and creation of buffer

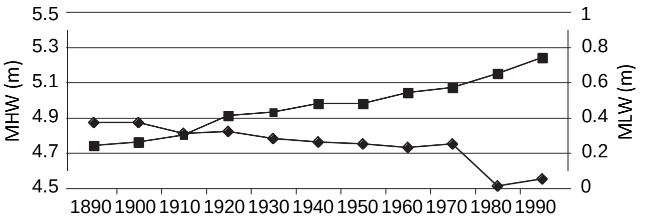

Figure 4. Evolution of mean high tides (*n*) and mean low tides (¤) in the Scheldeestuary.

areas for retention. Organic carbon input to the Schelde estuary exceeds 100,000 ton/year and most of it is cycled inside the estuary, causing a high oxygen demand (Frankignouille et al. 1996, 1998). High loads of ammonium enter the estuary through diffuse discharge from agricultural areas. The oxygen demand for its nitrification is equally high (Van Damme et al. in press). Aeration is the most important oxygen source in the estuary. It can be improved by the creation of more intertidal and shallow areas, where the surface-to-volume ratio is high. Removal of nitrogen through anaerobic denitrification is most effective in low intertidal mudflats; bioturbation by deposit feeders enhances the process. Phosphorus enters the estuary through point sources from domestic waste, doubling the natural concentrations (Zwolsman 1994); however, there is no process to eliminate it from the system. If it is not assimilated, it is eventually buried through deposition in sheltered areas, but this is not a sustainable solution because it can always be remobilized. Dissolved silica concentrations in the estuary do not increase anthropogenically. However, the N-to-P-to-Si ratio is the determinant for algal blooms. Creation of freshwater tidal marshes would reduce the danger for Si limitation; they are important production sites for DSi and have much higher Si fluxes compared to North Sea sediments (Vanderborght et al. 1977; Struyf et al. 2004). More research is needed on Si fluxes in brackish and polyhaline tidal marshes.

Toxic substances of different types enter the estuary from industries, towns, and agricultural areas. Little is known about their bioavailability and impacts on the ecological functions.

Habitat and Community Structure

More intertidal and shallow habitat, inland water treatment, and retention areas are necessary to reinstate the physical and chemical processes. These measures will solve most problems in the habitat and community structures and enhance the estuary's functions, including production and internal nutrient spiraling. However, some aspects are preconditioned and need special attention. To increase the surface of estuarine habitat, reclaimed land should be returned to the river through managed realignment, preferably in places where old creek remnants still exist. If the area is big enough and has the right topography, it will develop into a diverse habitat with all essential elements. Inland wetlands and upstream winter beds would be excellent retention areas. But space is scarce; it should be claimed sparingly and serve multiple purposes if possible. This is most efficiently achieved in flood control areas (FCA). These constitute extra storage capacity for water during storm surges. They truncate the flood wave when water flows over the lower river dike, avoiding floods in residential and industrial areas (Fig. 6A). Possible measures to serve several purposes in FCAs, without reducing storage capacity, are to install reduced and controlled tidal regimes through sluice management (Fig. 6B), to develop tide-independent wetlands, or to establish conservation farming agreements with farmers. Old dumping sites for dredged material or domestic and industrial waste on the riverside of the dike can be restored to intertidal marshes by leveling. Typical shoreline defenses with boulders can be replaced by terraces made of piles and willow wicker along stretches with moderate hydraulic pressure. Both measures increase intertidal habitat surface

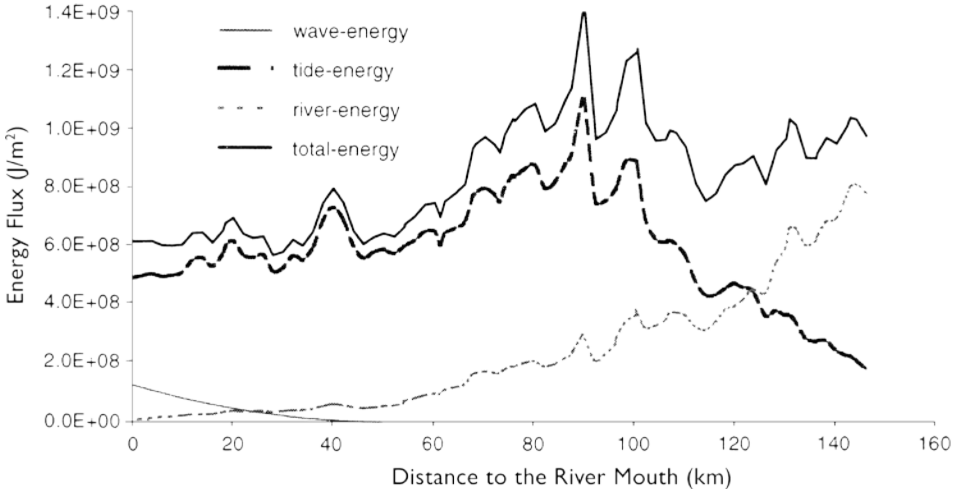

Figure 5. Energy distribution along the Schelde (Chen 2003).

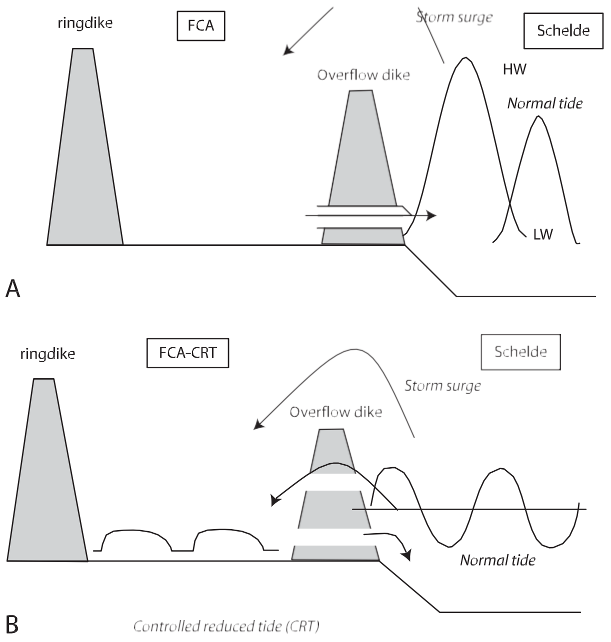

Figure 6. (A) Functioning of an FCA; (B) functioning of an FCA under controlled reduced tide.

and enhance continuity along the estuarine gradient. To restore the connection with the valley, drainage sluices should be adapted or managed to allow limited flow rates from the estuary back to the valley. Not only would fish benefit, but this exchange would also establish plankton communities in the inland watercourses that could colonize the estuary after a discharge flush. If expansion of the estuary is not accepted, young marshes, shallow areas, and sheltered mudflats will have to be created within the current boundaries of the estuary. Old marshes can be leveled to set back the succession, silting marsh creeks can be scoured or side channels can be dammed to create shallow waters, and breakwaters can shelter exposed mudflats. However, these measures are not sustainable.

Quality Goals

Goals were set to evaluate the rehabilitation process for essential attributes (Table 2). In the Schelde estuary, official quality goals existed for chemical water quality parameters in the Dutch and Flemish legislation. For the implementation of the European Water Framework Directive (2000/60/EC), goals, based on community and habitat structure, are being set for some biological quality elements. Conservation goals for birds are required for the European Bird and Habitats directives (79/409/EC; 92/43/EC). To enhance coherence in the estuarine management these were also adopted as goals for ecological rehabilitation. Quality goals for Si, turbidity, and zooplankton were drawn from critical values as described in existing research results. Further research is needed to define critical ranges for river discharge buffering and tidal energy. At this stage it is also impossible to set required surface areas for each habitat type.

In each zone where different conditions prevailed, different aspects needed prior attention. This was an important aspect for the selection of rehabilitation measures in the proposed plans. The relative attention to be paid to each attribute along the estuary was determined in a semi-quantified way (Table 2). The catchment basin was added as zone 10 because discharge reduction should also be addressed there.

Practical Planning

Spatial Analysis: The Selection of Sites

Potential nature development and rehabilitation sites were identified through spatial analysis of the study area. Sites with potential to improve the ecosystem functioning after implementation of specific measures were selected. Based on aspects of land use, regional zonation planning, and current nature value, some areas were excluded (highly valued areas were excluded). The remainder of the study area was divided into relevant polygons as basic units of a Geographic Information System (GIS)-linked database. For each polygon the database contains information concerning juridicial issues, abiotic characteristics, ecology, possibilities for rehabilitation measures, and an appreciation of their probable contribution toward the different aspects of estuarine functioning; information is still being added. The database was intended as a tool in the sequel of this rehabilitation plan and the LTVS. It should allow quick valuation of a total plan or changes in the plans.

Rehabilitation Plans: The Selection of Measures

Two total plans of comparable ambition were proposed. Both plans had some measures in common: the restoration of impaired marshes under the dumping sites, ecological adaptations to embankment defenses, and adapted sluice management to old inland creek remnants. They were considered important for strategic reasons. Existing habitats should be restored and optimized prior to the construction of new ones. Moreover, all these projects involved government property; their implementation would show the governments' own commitments and catch public interest for the plan without too many "not in my back yard" complications.

The other measures were chosen to exemplify the array of possibilities as much as possible. The total surface area of restored/created habitat was comparable for both plans (Table 3), but ecological benefit and societal implications differed. Plan I aimed at the creation of complete and diverse habitats. Only a few but very large managed retreats were proposed. In the lower and middle estuary, this would result in the creation of "mini-estuaries" of a specific salinity range. In the upper estuary, dike

Attribute	*Goal*	*Measures*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Tidal energy	optimize dispersion	shallow and intertidal area	1	11	11	11	11	1	1	1	1	0
Discharge	buffer (min–max)	retention area	0	0	0	0	1	1	11	1	11	11
Turbidity	Md/Pd < 5.5 Zeeschelde	E, SPM, and POC reduction	0	1	1	11	11	11	1	11	1	0
	Md/Pd < 5 Westerschelde		0	1	1	11	11	11	1	11	1	0
Salinity	moderate stress	investigate discharge manipulations retention areas	0	1	1	11	11	11	1	11	1	0
Oxygen	surface water quality goals	shallow and intertidal habitat	0	0	1	1	11	11	1	11	1	11
BOD	surface water quality goals	water treatment/buffer strips	0	0	0	0	0	0	0	0	0	11
Nitrogen	surface water quality goals	buffer strips/low mudflats	0	0	1	1	1	11	11	11	11	11
Phosphor	surface water quality goals	water treatment/buffer strips	0	0	0	0	0	0	1	1	1	11
Si	DSi > 0.15 mg in zone 1 N/P/Si; 16:1:16	freshwater tidal marshes	1					11	11	11		0
Toxic substances	surface water quality goals	water treatment/buffer strips	1	1	1	1	0	0	0	0	0	11
Phytoplankton	WFD	transparency, discharge, N/P/Si	0	1	1	11	11	11	1	11	1	0
Zooplankton	phyto POC/POC > 0.03	POC reduction, discharge, aeration	0	1	1	1	11	11	11	11	11	0
Macrobenthos	WFD	diverse intertidal habitat	1	11	11	11	11	11	11	11	11	0
Fish	WFD	migration barriers, shallow area	0	1	1	1	1	1	1	1	1	11
Birds	Bird Directive	diverse intertidal habitat, roosts	11	11	11	11	1	1	1	1	1	0
Sea mammals	enhance habitat	disturbance, toxins, fish	11	11	11	1	0	0	0	0	0	0
Shallow water	increase surface	expand estuary/(scour marsh creek)	1	11	11	11	11	11	11	11	11	0
Tidal mudflats	increase surface	expand estuary	1	11	11	11	11	11	11	11	11	0
Tidal mudflats	reduce dynamics	expand estuary/(groins)	0	11	11	0	0	0	0	0	0	0
Tidal marsh	increase surface	expand estuary	1	11	1	1	11	1	11	1	11	0
Tidal marsh	complete succession range	expand estuary/(level old marsh)	1	11	11	11	11	11	11	0	0	0
Wetland	increase surface	management measures	0	0	0	1	1	1	11	1	11	0

Md, mixing depth; Pd, photic depth; E, energy; SPM, suspended particulate matter; POC, particulate organic matter; DSi, dissolved silica; surface water quality goals refer to national legislation; WFD, European Waterframework Directive.

Table 3. Surface of created/restored habitat (ha) in plans I and II.

Measure	*Zone 1*	*Zone 2*	*Zone 3*	*Zone 4*	*Zone 5*	*Zone 6*	*Zone 7*	*Zone 8*	*Zone 9*	*Total*
Total plan I										
Groins		50								50
Level mature marsh	400									400
Level dump site				43	45					88
Realignment	750	2,000	694	682	252	366	74	804	372	5,993
FCA-CRT					454					454
Sluice management				168		152	71		717	1,108
Dike relocation								152	1,376	1,529
Wetland					64	970	1,498	283	333	3,148
Total	1,150	2,050	694	892	815	1,488	1,643	1,239	2,799	12,770
Total plan II										
Fill side channel		50	330							380
Groins		60	60							120
Level mature marsh		10	420							430
Level dump site				43	45					88
Realignment	230	1,035	1,285		23	38		74	27	2,712
FCA-CRT			294	159	344	245	74	194		1,310
Sluice management				112		152	41	33	540	878
Dike relocation									790	790
Wetland				455	387	575	1,509	797	616	4,338
Conservation agriculture						477		135	118	730
Total	230	1,155	2,389	769	799	1,488	1,624	1,232	2,090	11,776

FCA-CRT, flood control area under controlled reduced tide; realignment, tide dominated; dike relocation, fluvial dominated.

relocations would create large winter beds. These habitats would grant the estuary resilience and resistance despite the limiting conditions set on its channel morphology to fulfill its navigation function. They would serve as “gene pools” from where the main channel could repopulate after catastrophic events. From a societal point of view, fewer communities and citizens would be involved but negotiations and planning would be far-reaching. Plan II opted for a higher number of small-scale realignments. The total area of full tidal restoration was much less than in plan I, but it contained more FCA under reduced tide or designed as wetland. Also, more measures were proposed to convert one estuarine habitat type into another: groins, leveling of old marshes, and filling of side channels to create shallow habitat. In the upper estuary, some areas for conservation farming and more wetland development were proposed. Plan II would result in a less resilient estuarine ecosystem, and proposed measures were less sustainable. Implementation of the plan would have involved more communities and citizens. Both plans proposed to enhance the educational and recreational values of the created sites. Plan I offered more interesting options for visitors, and the sites would be less affected by disturbance.

Implementation

The ecological rehabilitation of the estuary still has a long way to go. At this stage a selection of the proposed measures is being submitted to an integrated environmental impact analysis and societal cost benefit analysis, together with the plans for safety measures and accessibility. Information sessions and workshops have been organized to involve the public and determine public perceptions and opinions on the general concept of ecosystem rehabilitation and on specific types of projects. The proposed plans show some possibilities; the communication process and more detailed research on the proposed sites, including societal aspects, should ultimately result in a feasible and accepted plan. Once the plans are ready, the political decision process and administrative planning will have to implement the bilateral LTVS agreements.

Conclusions

In this study an ecological rehabilitation hypothesis for the Schelde estuary was proposed, based on our current understanding of the ecosystem, leading to the design of a plan to restore organization, vigor, and resilience to the estuary. Integration with other societal aspects increased its relevance and created opportunities for mutual reinforcement.

However, many uncertainties had to be dealt with, which impeded the prognosis of its benefits. Moreover, the semiquantitative estimations need refinement to a fully quantitative approach. Continued monitoring and ecological modeling will be necessary to test the hypothesis, to increase our understanding of cause–effect relationships, and to improve quantification.

Good communication, information, and public involvement are equally critical assets to achieve the ecological restoration goals. However, estuarine processes are not subject to great public interest and people will not readily see the necessity to give up their land for them. Translation of the defined goals into more relevant societal goods and services would greatly aid the communication process and improve public support. Finally, successful and sustainable rehabilitation of the Schelde ecosystem will require an integration of ecology and the social sciences.

Acknowledgments

This project was funded by ProSes and by the Flemish Administration for Waterways and Maritime Affairs, division Zeeschelde. Research results were mostly extracted from the MOSES (Netherlands Institute of Ecology, Centre for Estuarine and Coastal Ecology) and OMES (University of Antwerpen, Belgium) research projects, which jointly built the ecosystem model for the Schelde estuary. We thank all members of the steering committee for valuable suggestions and critical evaluations of the plan.

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