Restoration of the Sieperda Tidal Marsh in the Scheldt Estuary, The Netherlands

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Abstract

Because of land reclamation, reinforcement of dikes, and the deepening of shipping channels, large areas of tidal marshes have been removed or eroded from the Scheldt estuary during the last two centuries. Tidal wetland restoration contributes toward compensating this loss of habitat. Not all restoration projects are meticulously planned, however; some are forced by nature. During a severe storm in 1990, a dike was breached in the brackish part of the Scheldt estuary and returned tidal influence to the Sieperda polder. In the 10 years since the dike breach, the former polder has changed into a brackish tidal marsh. Here we report on the geomorphologic and ecological developments that have taken place in the marsh. Tidal intrusion into the former polder turned crop fields into mudflats and changed pastures into salty marsh vegetation. The digging of a new creek improved marsh hydrology and enhanced tidal intrusion further into the marsh. Macrofauna typical of estuarine mudflats established rapidly in the developing marsh. Vegetation succession took place rapidly. Within 5 years, large areas of mudflats became covered with marsh vegetation. Birds characteristic of salt marshes were observed breeding or seen foraging in the marsh. The number of wading birds declined as areas of mudflat became overgrown. It is demonstrated that tidal flow is the engine to tidal marsh restoration. Tidal influence caused geomorphologic changes, which directed ecological developments in the former polder.

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Key words: benthic fauna, birds, geomorphology, marsh vegetation, restoration, tidal influence, wetlands.

Introduction

The Netherlands can be characterized as a low-lying river delta where the rivers Rhine, Meuse, and Scheldt flow into the North Sea. More than half of the Netherlands lies below sea level. Its history has been determined by a constant struggle against the sea. From the Middle Ages onward the Dutch started building dikes to protect themselves against floods that periodically occurred during severe autumn and winter storms. The fertile clay soil behind the dikes has been used mainly for agriculture (flax, potatoes, sugar beets, and madder). When tidal flats gained enough height and became covered with marsh vegetation, farmers started using this land. By building new dikes around it, a new polder was formed. This practice continued well into the 20th century.

Scheldt Estuary

The Scheldt River originates in northern France and flows through Belgium and the southwestern part of the Netherlands into the North Sea (Fig. 1). The Scheldt catchment area is approximately 21,000 km^2 and is inhabited by some 10 million people. The stretch from the city of Ghent (Belgium) to the North Sea (approx. 160 km) is known as the Scheldt estuary. It is a macrotidal coastal plain estuary and is important economically and ecologically. The estuary is primarily the navigation route to the port of Antwerp in Belgium, one of Europe's major ports. It contains important habitats for shellfish (cockles) and juvenile flatfish (plaice and flounder). Migratory birds use the estuary for foraging, and a number of coastal breeding birds nest along the estuary. The estuary has been in an almost continuous state of change during the 20th century. Because of land reclamation, reinforcement of dikes, and the deepening of the shipping channels, about 2,500 ha of mudflats and tidal marshes have been lost since 1900. Substantial parts of the remaining marshes have reached the final stage of succession. Sheltered areas with the potential to develop into intertidal areas and marshes have become very scarce. One way of stimulating the development of new marshes is the reintroduction of tidal influence in reclaimed polders. In addition to ecological benefits the restoration of tidal wetlands in this way may also reduce the maximum high water levels and may be beneficial to water quality, especially in the upper reaches of the estuary (Verbeek & Storm 2001). However, there is intense public distrust in the idea of allowing sea dikes

Figure 1. The location of Sieperda marsh in the Scheldt estuary.

to retreat because it is considered unsafe (Smit & Pethick 1996).

Restoration area

This article is about a pilot tidal wetland restoration project, which was made possible only because of an accidental dike breach in a remote part of the Scheldt estuary. The Sieperda area is located in the brackish part of the estuary near the Dutch–Belgian border (Fig. 1) and has experienced a number of changes over the past 35 years. Before 1966 the area was part of the much larger 2,000-ha Saeftinge marsh and was characterized by a network of small and narrow tidal creeks. By comparison, the Sieperda area is only 100 ha large. In 1966 a sand dam was constructed on the marsh parallel to the existing sea dike to accommodate gas and water pipelines. The area between the dam and the sea dike was closed off from tidal influence by the construction of a relative low (summer) dike, turning it into a polder, 85% of which was leveled and used for cattle grazing and agriculture (Fig. 2). Only the easternmost part of the polder, closest to the estuary, kept its natural geomorphologic structure. A long ditch was dug along the sand dam for drainage of rainwater and occasional floodwater. Several smaller ditches were linked onto the main drainage system (Fig. 3A). Because the summer dike was relatively low the area frequently flooded in winter. In 1976 and 1985 the dike gave way during severe storms but was subsequently repaired. After another dike breach in 1990, it was decided not to repair the dike and allow the area to be returned to tidal influence once again. The limited economic value of the polder, the high costs of repair, and pressure from nature conservation groups led to this decision. The accidental breach turned the Sieperda polder into a developing tidal marsh. This project did not have a specific restoration goal but offered an opportunity to learn how the return of tidal influence would have its effect on a stretch of reclaimed land.

During the past 10 years four independent studies were conducted, dealing with changes in hydrology and geomorphology, vegetation structure, benthic fauna, and bird populations. Because of the unplanned nature of this project few pre-breach data were available, and the studies started after the return of tidal influence into the area. Here the results of these studies are presented and the driving forces behind ecological change in Sieperda marsh are identified.

Methods

Tidal Survey

The propagation of the tidal wave (velocity and amplitude) was measured during complete neap-spring tidal cycles using pressure sensors (PTX 630, Druck, The Netherlands) at three locations (A, B, and C in Fig. 3b). A pressure sensor was placed on the bed in the center of the creek. Tidal surveys were performed in 1992, 1993 (twice), 1995, and 1996 (Sánchez Leal et al. 1998).

Geomorphologic Monitoring

The developments in creek and marsh morphology were studied by conducting field surveys and by interpreting aerial photographs. Sedimentation and erosion rates in creeks and on the marsh surface were monitored along six transects, five transects perpendicular and one transect parallel to the direction of tidal flow. Altimetry measurements were performed along the transects by leveling on an annual basis from 1992 onward (Kornman & van Doorn 1997; Sanchez Leal et al. 1998). All bed levels were measured relative to Dutch Ordnance Datum (N.A.P.). From the changes in bed levels over time sedimentation rates on the marsh were calculated. Creek and tidal flat development was also determined by analyzing aerial photographs taken in 1990 and 1995.

Monitoring of Vegetation Succession

The monitoring of developments in vegetation succession commenced in 1993. At the start of the study 29

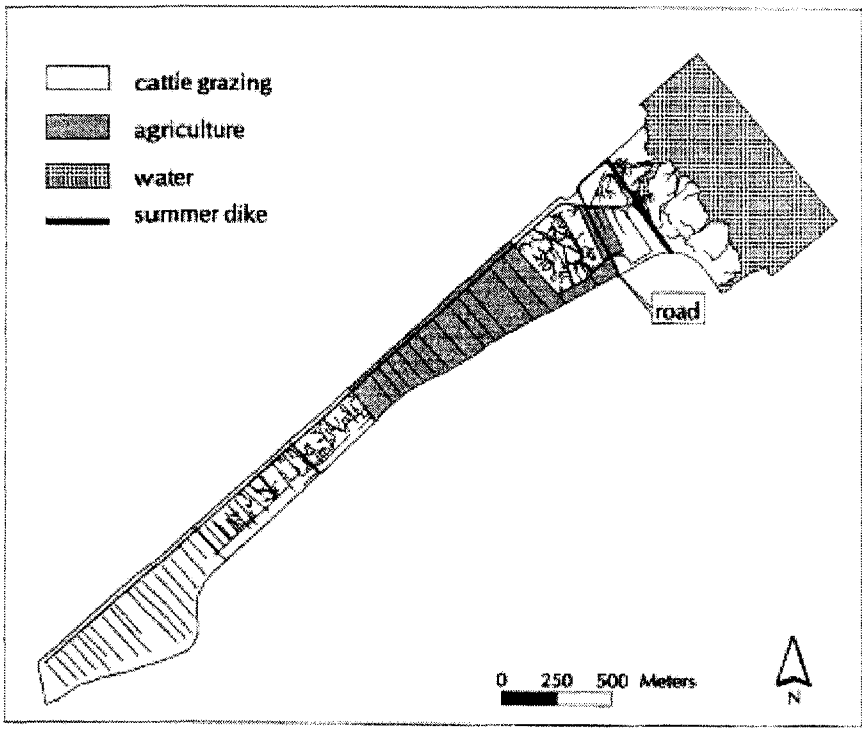


Figure 2. Land use in the pre-1990 Sieperda polder.

permanent quadrats (PQs, 2 × 2 m) were marked along seven transects, which were evenly distributed across the marsh (Fig. 6a). The composition of the vegetation within each PQ was surveyed annually in September. For each plant species the percentage cover was estimated using the following scale: 0.1, 0.5, 1, 2, 3, 4, and 5, continuing with increments of 5% up to 100%. The total percentage cover for each PQ could exceed 100% because ground covering and taller plant species could cover the same surface area. Additionally, the vegetation cover was mapped separately on basis of false color aerial photographs, making use of the different reflectance properties of vegetation and soil. Marsh areas reflecting less than 25% of maximum reflectance were considered uncovered or sparsely covered with vegetation.

Benthic Fauna Monitoring

The sampling of benthic macrofauna started in 1995 and was performed annually in September, the end of the growth season when maximum biomass was expected. Ten sampling sites were selected that were evenly distributed over those parts of the marsh not covered with vegetation. Six sites were situated on mudflats and four in shallow supralittoral pools. In the supralittoral pools (Fig. 6a) both infauna and hyperbenthos were examined. Through the years some sampling sites became overgrown with vegetation, and these sites were excluded from the study. Infauna was sampled by taking ten, 30-cm deep sediment cores at each site (mudflats and pools) with a round metal corer (diameter 4.5 cm). The cores were sieved over 1-mm round mesh and stored in 4% neutralized formalin. Hyperfauna, in this case the fauna living near the bottom and in the shallow water of the pools, was sampled with a hyperbenthic sampling net (width 25 cm, mesh 1.25 mm). Each sample was the result of a 20-m haul. The residue was preserved in 4% neutralized formalin. Each sample was colored with Bengal Rosa and analyzed in the laboratory to species level, where possible, using a binocular microscope. Biomass (ash free dry weight) was determined by drying (80°C, 48 hr) and ashing (570°C, 2 hr) each sample (Stikvoort 2000).

Bird Monitoring

The significance of the developing marsh for breeding birds was studied by monitoring and mapping the exact nesting sites in 1991, 1994, 1997, and 1999 using standard procedures (Hustings et al. 1985). During the breeding season the area was visited at least six times, and all observations of breeding were recorded. At the end of the season all data collected were transformed into numbers of breeding pairs following criteria that differ for each species. All water birds in the marsh were monitored on a monthly basis as part of an existing long-term monitoring program. The number of water birds (grebes, herons, geese, ducks, and waders) were counted or estimated around high tide, using bin-

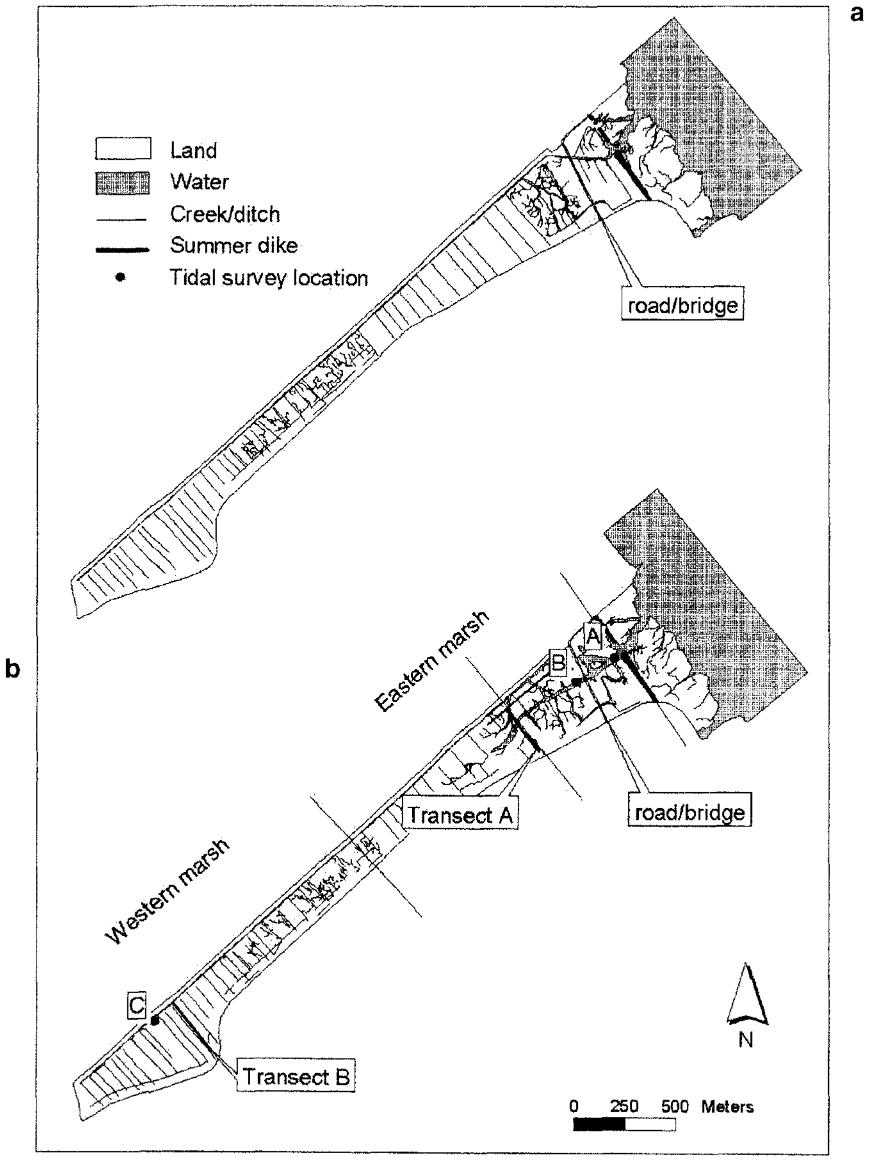


Figure 3. Map of creeks and drainage system in Sieperda marsh in 1990 (a) and 1996 (b). B also shows the two geomorphologic zones, two of the transects along which the geomorphologic developments were studied, and the three tidal survey locations.

oculars and telescopes, when the birds concentrated at high-tide roosts.

Results

Hydrodynamic Developments

After the dike breach in 1990 the tidal flow into the polder was restricted at first due to the existing drainage network. Figure 3 shows creek development in the eastern part of the marsh between 1990 and 1995. In 1993 a new wider creek was dug in the center of the area, enhancing tidal influence into the developing marsh (Fig. 3b). Although tidal influence into the marsh improved, the distal part of the marsh experienced tidal influence only during spring tides and showed a spring to neap tidal cycle instead of a diurnal cycle as observed in the proximal part of the marsh (Fig. 4). A typical tidal curve shows a slightly asymmetric sinusoidal wave, with a shorter flood than ebb duration. The tidal range in the estuary near Sieperda marsh, including the easternmost part of the marsh, varied from 4 to 6 m (site A). After the construction of the new creek and bridge in 1993, the average tidal range behind the bridge increased from 0.75 to 1.75 m (site B). Three years later the average tidal range had increased to 2.3 m (site B). Tidal influence further into the marsh is hampered by the width of the bridge acting as a bottleneck and the very

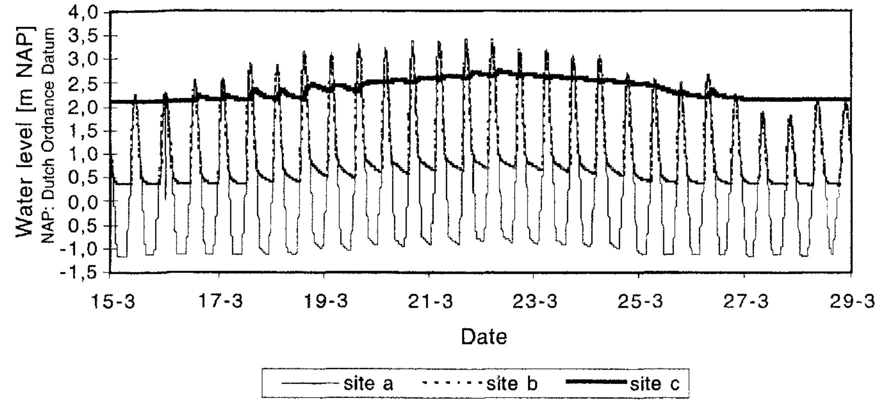


Figure 4. Tidal patterns in Sieperda marsh in 1996. Measuring sites a, b, and c are shown in Figure 3b.

slow growth of the creek in the central part of the marsh due to the presence of a solid surface layer of clay. As a result there is no creek penetration into the western part of the marsh and tidal volumes in this area are small (site C).

Geomorphologic Developments

The geomorphologic developments in the marsh are the result of the return of tidal influence combined with the area's contour and history. The extent of tidal influence is being determined by the volume of tidal flow into the long and narrow marsh, the area's elevated position (approximately N.A.P. + 2.3 m) relative to mean high water level, as a result of Sieperda being part of a much larger marsh before 1966, and the old drainage and creek system. Sieperda marsh can be divided into two distinct geomorphologic zones: an eastern zone (closest to the estuary) and a more distant western zone (Fig. 3b).

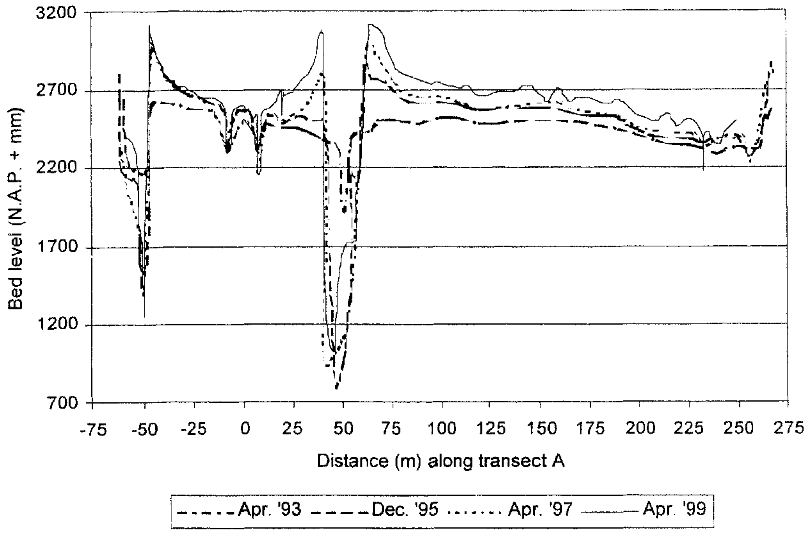
In the eastern part geomorphologic changes were very pronounced. Figure 5a illustrates the geomorphologic changes along a transect in the eastern part of the marsh. It shows that creeks became wider and deeper over time and that levees developed. Table 1 shows the sedimentation rates on creek levees and floodplains over contiguous 3-year periods. The sedimentation rate on creek levees is high and constant in time. The sedimentation rate in the floodplain areas of the marsh changed in time. The sedimentation rate during the first years after the construction of the creek was higher (3 cm/yr) than average for Scheldt estuary marshes, which approximates 1.5 cm/yr (Krijger 1993). The new creek allowed larger tidal volumes into the developing marsh, causing increased creek erosion and enhanced sediment availability. After this period of strong sedimentation the sedimentation rate on the floodplains approached values characteristic for the estuary. The period 1997–1999 was characterized by the strong growth of *Phragmites australis* (common reed), a dense and high vegetation very capable of sediment trapping. This is thought to be the main cause for the increased sedimentation rate observed during this period.

In the western part of the marsh hardly any geomorphologic changes occurred. The sedimentation rates were less than 0.5 cm/yr (Table 1) and creeks did not develop. Figure 5B shows the very limited changes in bed levels along a transect in the western half of the marsh. The large difference in development between the eastern and western marsh is caused by the weak tidal influence (Fig. 4, site C) in the western marsh, which was unable to alter the geomorphology.

Ecological Developments

Vegetation. Before the dike breach in 1990 the then existing polder was divided into areas used for agriculture and cattle grazing (Fig. 2). After the reintroduction of tidal influence, the former crop fields, as well as those parts of the former pastures with poor drainage, turned into bare mudflats or areas very sparsely covered with vegetation (Fig. 6a). Figure 7 shows the vegetation succession in four representative PQs spread over the marsh from west to east from 1993 onward.

Vegetation succession on the mudflats was initiated with the establishment of the salt marsh species *Aster tripolium* and *Puccinellia maritima* (Fig. 7a), followed after several years by *Scirpus maritimus* and *Atriplex prostrata*. The former pastures were initially characterized by common grasses such as *Agrostis stolonifera*, *Elymus pycnanthus*, and *E. repens*. In the low-lying and moist areas, *A. stolonifera* was replaced almost completely by the salt marsh species *P. maritima* and *A. tripolium* after the return of tidal influence (Figs. 7b and 7d). In the higher and drier parts of the former pastures, *A. stolonifera* and *E. pycnanthus* could survive and were accompanied by marsh plants such as *P. maritima*, *A. tripolium*, and *Juncus gerardi* (Fig. 7c). In closely cropped areas in the westernmost distant part of the marsh with insufficient drainage, pioneer species such as *A. tripolium*, *Salicornia* spp., *Spergularia marina*, and *Glaux maritima* could flour-



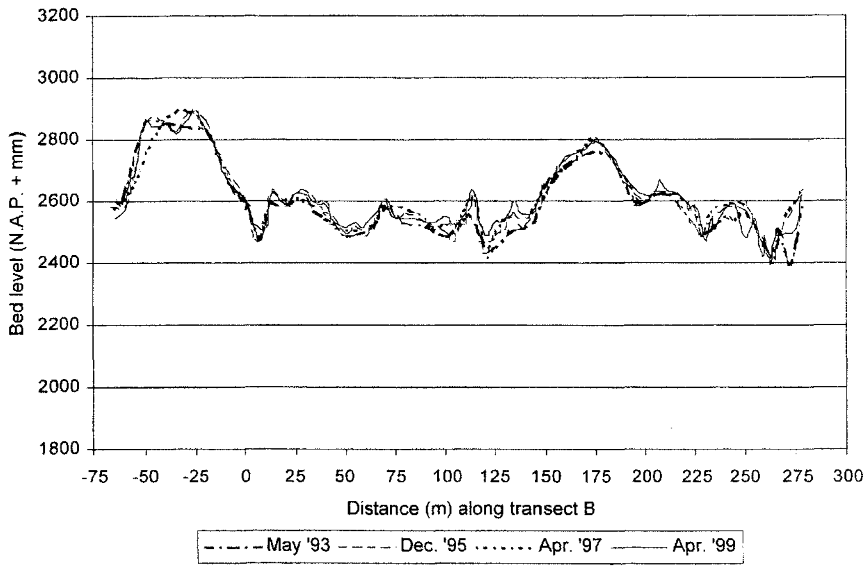


Figure 5. Geomorphologic developments along two transects in the eastern and western part of Sieperda marsh. The location of transects A and B on the eastern and western marsh respectively is shown in Fig. 3b.

ish. From 1995 onward the colonization of the mudflats progressed rapidly (Figs. 6b and 8), probably as a result of improved drainage after the construction of the new creek in 1993. In recent years *Phragmites australis* became established in the marsh and expanded rapidly.

Benthic fauna. In 1995, the first year of monitoring and 5 years after the dike breach, estuarine benthic fauna was well established in the newly developed marsh. Table 2 gives an overview of species diversity in the marsh. A total of 19 taxa was observed in the marsh over the period 1995–1999. The observed insects and fish (goby) inhabited the supralittoral pools. The 10 sampling sites changed over time, sometimes dramatically. At the start of the monitoring program large areas of mudflats were still present in the eastern part of the marsh. As the intertidal mudflats were situated above mean high water neap, they progressively became overgrown with marsh vegetation and the sampling sites that were located here were excluded. The supralittoral pools in the distant part of the marsh became shallower and smaller and in one case became overgrown with vegetation. Species diversity between years varied from 14 to 17 taxa. Species densities fluctuated between 4,000 and 40,000 individuals/m^2, with an average of some 10,000 individuals/m^2. Total biomass fluctuated between sampling sites and years and varied between 1 and 27 g ash free dry weight/m^2 (Fig. 9). Relative species abundance also fluctuated over time, although the two most abundant species (*Corophium volutator* and *Nereis diversicolor*), often accompanied by several oligochaete spp., constituted more than 80% of total species density at most sampling sites (Fig.

Table 1. Sedimentation rates in Sieperda marsh.

		1993–1995	1995–1997	1997–1999
Eastern marsh	Levee	8 cm/yr	8 cm/yr	8 cm/yr
	Floodplain	3 cm/yr	1.5 cm/yr	4 cm/yr
Western marsh		0.5 cm/yr	0.5 cm/yr	0.5 cm/yr

10). Because the oligochaetes contributed only modestly to total biomass, *C. volutator* and *N. diversicolor* alone accounted for more than 80 to 90% of total biomass at most sites. The species composition and biomass did not differ profoundly between 1995 and 1999. There appears to be a small shift in relative biomass in favor of *C. volutator* and at the expense of *N. diversicolor* in 1999.

Birds. The return of tidal influence in Sieperda marsh appears to have affected breeding birds, because breeding habitats changed as a result of vegetation development and succession. Evaluation of monitoring data was complicated by the fact that pre-breach data were not available. Not surprisingly, a number of bird species that breed on salt marshes, such as *Anser anser, Tringa totanus,* and *Luscina svecica,* have taken advantage of the new situation (Table 3). *Acrocephalus scirpaceus,* a species breeding on marshes or reed beds, was also able to benefit. These species either nest aboveground in reed vegetation or on the ground in elevated nests and are therefore less susceptible to tidal influence. Reed beds developed strongly in the late 1990s. However, the number of breeding Oystercatchers decreased as a result of a gradually declining breeding

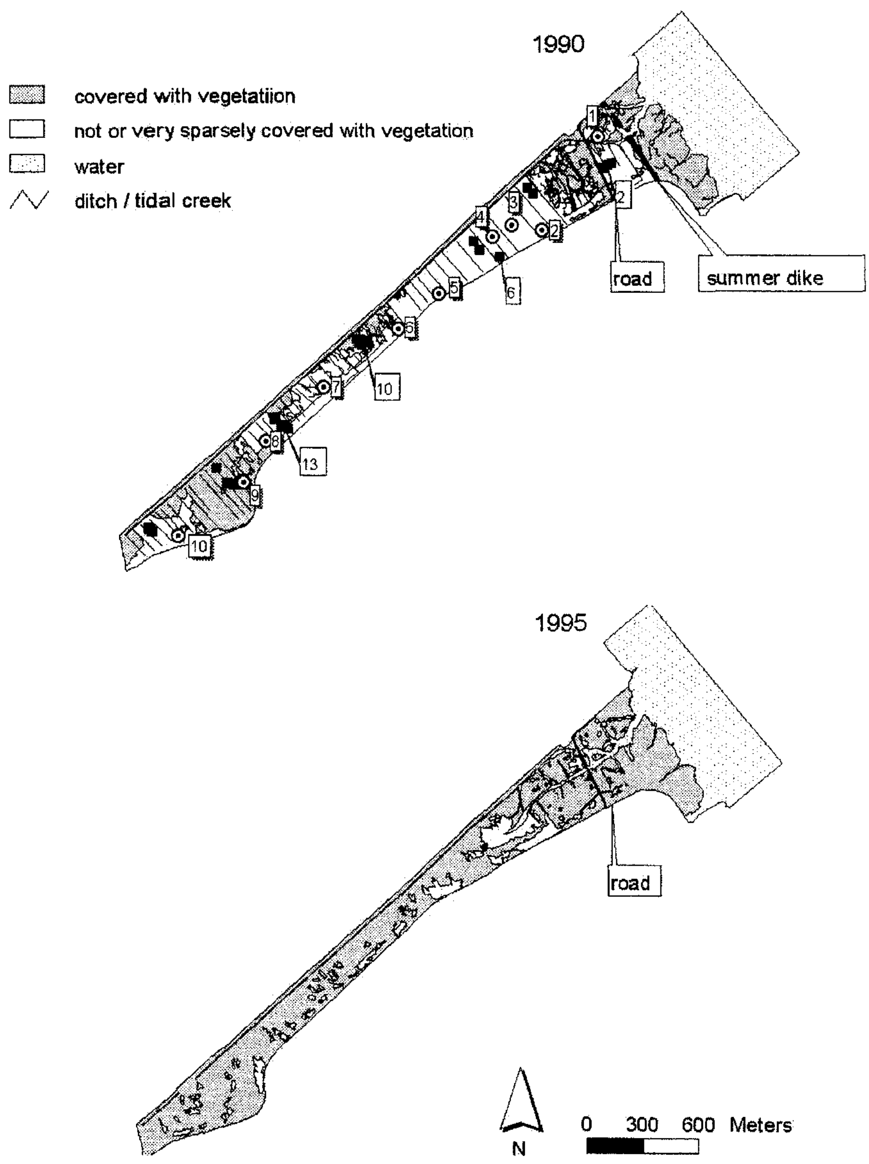


Figure 6. Map of vegetation zones in Sieperda marsh in 1990 (A) and 1995 (B).

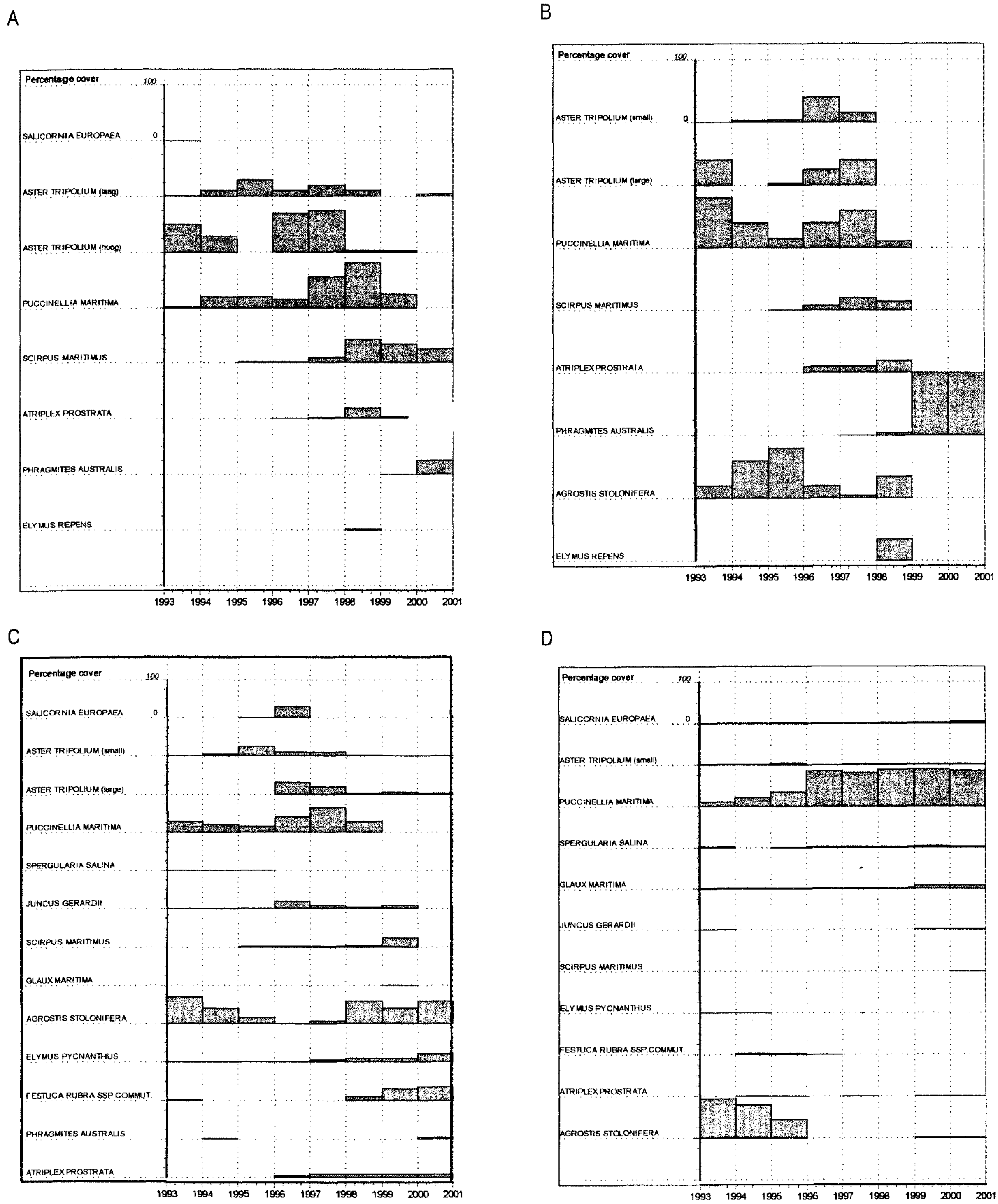


Figure 7. Vegetation succession in 4 of the 29 investigated PQs. The location of the PQs is shown in Figure 6a. A: PQ2, B: PQ6, C: PQ13, and D: PQ10.

habitat, which consists of sparsely vegetated areas. Meadow birds also breed in Sieperda marsh, but they are restricted mainly to the western and elevated parts of the marsh, where tidal influence is less frequent and grazing cattle keep the vegetation short.

Sieperda marsh is used for feeding by numerous bird species that do or do not breed in the marsh. Their numbers fluctuated considerably over the years (Table 3). It should be considered that Sieperda marsh is located adjacent to the much larger Saeftinge march (2,000 ha) and

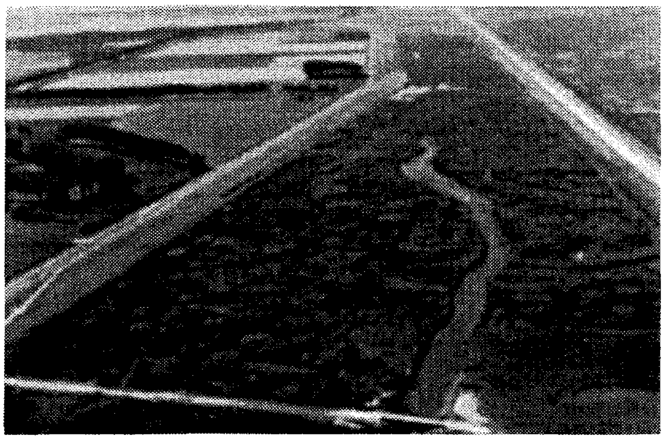


Figure 8. Aerial photograph of Sieperda marsh in 1996.

birds migrate between the two marshes. It was observed clearly that species whose feeding habitat is restricted to mudflats (such as Dunlin) declined in numbers as vegetation succession progressed (Table 4). Other species are less specific with regard to their feeding habitat and their numbers declined, remained unchanged, or even increased (Castelijns et al. 1997, 2000). It remains unclear whether the restoration of the marsh influenced their numbers.

Discussion

Ten years have passed since the natural restoration of Sieperda marsh started. Some lessons can be learned from the joint monitoring data collected. First, tidal flow was demonstrated to be the engine for tidal marsh restoration. The decreasing gradient in tidal influence in the marsh is reflected in the marsh geomorphology; the further away from the engine (the estuary), the smaller the geomorphologic changes. The reintroduction of tidal influence and the geomorphologic changes directed the ecological changes in the former polder. The monitoring program has demonstrated that although ecological restoration commences rapidly, ecological changes in the marsh were still in progress after 10 years, albeit at a slower pace. After the return of tidal influence, the bare crop fields turned into mudflats that were colonized quickly by macrobenthic species, who themselves serve as food sources for wading birds. The existing meadow vegetation was largely replaced by brackish marsh species, except for the elevated pastures where common grasses could survive. The changes observed in the population of breeding birds reflect the process of establishment of vegetation and subsequently the development in vegetation succession in the tidal marsh. During the early years after the breaching of the dike, about 75% of the area under renewed tidal influence consisted of mudflats, a foraging habitat favored by waders such as the Oystercatcher. In 1995 the mudflats had declined to about 10% of the area due to the establishment and growth of marsh vegetation. Especially bird species that breed in marshes took advantage of the progressing vegetation cover and growth in the developing marsh. Species preferring bare or sparsely vegetated breeding habitats, such as the Oystercatcher, showed a decline in numbers.

It can be concluded that the restoration of the Sieperda marsh has been successful, at least in the eastern (seaward) half of the marsh. Developments in the western half of the marsh, both geomorphologically and ecologically, were less pronounced due to a hampered tidal influence as a result of (1) the limited width of the bridge subduing the tide, (2) the very slow growth of the creek in the central part of the marsh due to the presence of a solid surface layer of clay, and (3) the relatively elevated position of the marsh. Widening the bridge and enlarging the creek through the clay layer would improve tidal influence into the western marsh. Because Sieperda

Table 2. Benthic taxa observed in the developing marsh.

Category/Taxon	*Habitat*	*Category/Taxon*	*Habitat*
Oligochaetes		**Crustaceans**	
Various unidentified species	mf/sp-i	*Carcinus maenas*	mf
		Corophium volutator	mf/sp-i
Polychaetes		*Crangon crangon*	sp-h
Heteromastus filiformis	mf/sp-i	*Gammarus* sp.	mf/sp-i
Manayunkia aestuarina	mf/sp-i	*Mesopodopsis slabberi*	sp-h
Nereis diversicolor	mf/sp-i	*Neomysis integer*	mf /sp-i,h
Pygospio elegans	mf	*Palaemonetes varians*	sp-h
		Sphaeroma rugicauda	mf/sp-i,h
Mollusks		**Insects**	
Cerastoderma edule	mf	*Chironomus* sp. larvae	sp-i
Hydrobia ulvae	mf/sp-i	*Dolichopodidae* larvae	mf/sp-i
Macoma balthica	mf/sp-i	*Sigara* sp.	sp-h
Fish			
Pomatoschistus sp.	sp-h		

mf, mud flat; sp-i, supralittoral pool—infauna; sp-h, supralittoral pool—hyperbenthos.

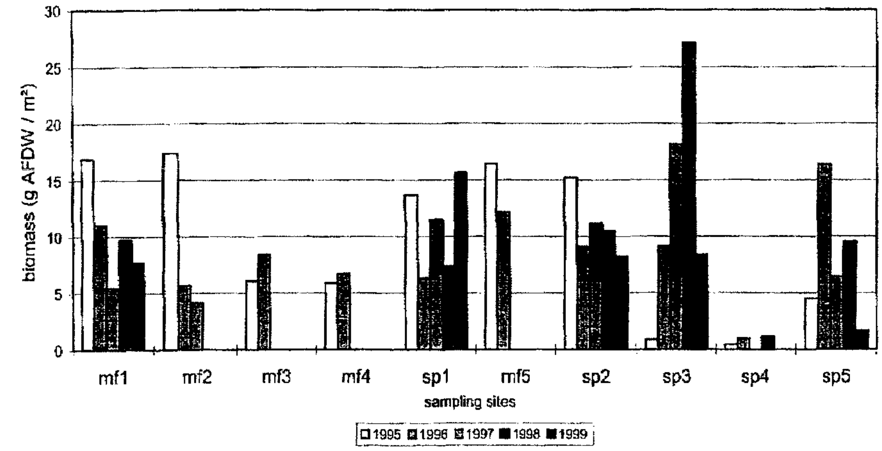


Figure 9. Developments in total biomass of benthic fauna at the, initially, 10 study sites. Habitat codes: mf, mudflat; sp, supralittoral pool.

marsh once was part of the adjacent Saeftinge marsh, the marsh surface level (more than mean high water level) at the time of the dike breach was typical of an old salt marsh. Therefore vegetation succession commenced rapidly and within 10 years reached the stage of the emergence of common reed (*P. australis*). A more gradual and natural rate of succession could be achieved by leveling elevated parts of the marsh, which would rejuvenate the process of marsh development and stimulate the settlement of pioneer vegetation. The responsible management and conservation authorities will have to deal with these questions.

Relevance to Wetland Management

The surface area of mudflats and marshes has declined continuously in the Scheldt estuary during the 20th century. These biotopes are important components of the estuarine ecosystem, because they provide habitats for benthic fauna, fish, and a large variety of waterfowl. Additionally, these tidal wetlands can contribute to the damping of tidal and wave energy in a fringed estuary and form a natural filter for surplus nutrients. The restoration of the Sieperda marsh did not start as a well-planned restoration project but was made possible by a coincidence of circumstances. From an economic point of view the pre-1990 Sieperda polder was of limited value, and repair costs for the summer dike after a breach were high. Additionally, conservation groups pressed for a return of tidal influence into the polder. From a managerial point of view the restoration of the Sieperda marsh fit into the concept of enlarging the basin storage capacity of the estuary that had gained momentum by the eary-1990s. Enlarging the basin storage capacity was seen as a way to solve problems caused by sea level rise (Storm et al. 1997). In the 1990s ecological restoration became a po-

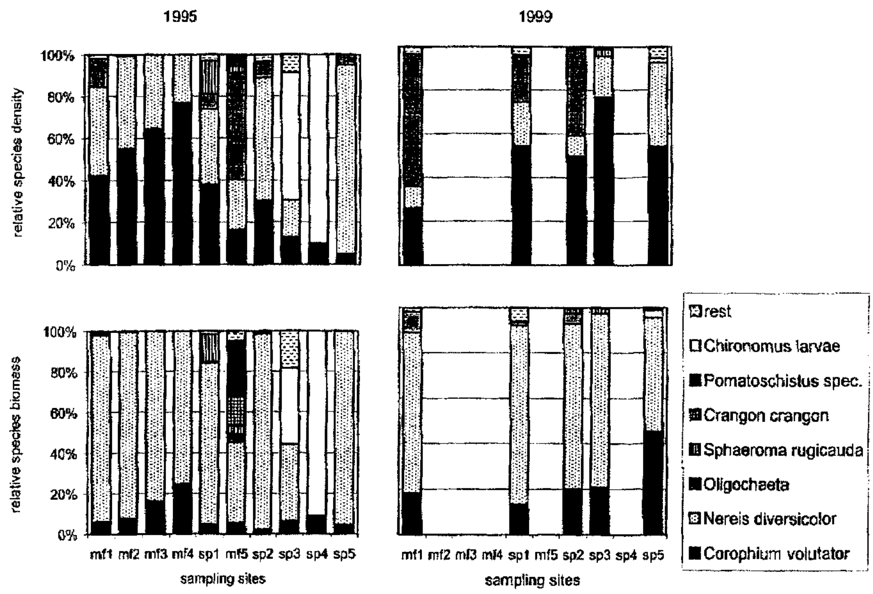


Figure 10. Developments in relative species density and biomass at the, initially, 10 study sites. Habitat codes: mf, mudflat; sp, supralittoral pool.

Table 3. Number of breeding pairs of main bird species in Sieperda marsh.

Species	*Common Name*	*Breeding Habitat*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*	*1998*	*1999*	*Trend*
Anser anser	Greyleg goose	Marsh	1	3	2	3	1	4	3	10	>10	17	+
Tadorna tadorna	Common shellduck	Burrows	11	25			30			11		33	0
Fulica atra	Common coot	Pool	2	1			10	5	4	3	4	4	+
Haematopus ostralegus	Oystercatcher	Meadow	16	15			13			12	4	6	−
Recurvirostra avosetta	Pied avocet	Salty meadow	13	31	24	26	10	6	0	48	16	9	0
Vanellus vanellus	Northern lapwing	Salty meadow		12		9	5	6	8	17		7	0
Tringa totanus	Common redshank	Salty meadow	2	13		>10	21			38		27	+
Anthus pratensis	Meadow pipit	Meadow		10			26			14		18	0
Luscina svecica	Bluethroat	Marsh	2	8		>5	>2			10		20	+
Acrocephalus scirpaceus	Reed warbler	Marsh and reed bed		26						75		88	+
Emberiza schoeniclus	Reed bunting	Marsh and reed bed	14	12						16		12	0

litical issue that was incorporated into water management policy. In retrospect the restoration of the Sieperda marsh has taken advantage of a turning tide. In future Dutch–Belgian policy plans for the Scheldt estuary three topics will play an important role: (1) *safety* or flood control, (2) *transport* or passage of ships to ports, and (3) *resilience* or the restoration of natural dynamics. Maintaining coastal safety and facilitating the transport of ocean-going vessels, which requires the continuous deepening of the main shipping channel, have an increasing effect on estuarine hydrodynamics and negatively affect the resilience of the estuarine ecosystem. Returning polders to tidal influence, referred to as "depoldering" in the Netherlands or managed realignment in the United Kingdom (Pethick 2002 this issue), could compensate this loss of resilience by increasing the basin storage capacity and restoring the natural dynamics. However, managed realignment has insufficient public support at the moment (Verbeek & Storm 2001). The public is still very much used to the idea of taking land from the sea (estuary) rather than giving it back. Furthermore, local farmers do not value tidal marshes highly as crop fields. Because of a severe flood in 1953 in which more than 1,800 people died, managed realignment is also considered to be unsafe and not to be a safeguard against a rising sea level. Therefore, the challenge will be to convince the public that managed realignment is a necessary means of improving coastal defense rather than a measure to restore marshes. This will be a difficult task.

Acknowledgments

We are grateful to D. J. de Jong for critically reading the manuscript and to Ms. A. van der Pluijm and B. Willemse for preparing the GIS maps.

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Table 4. Maximum number of waterbirds during bird season (July–June) in Sieperda marsh.

Species	*Common Name*	*1989/ 1990*	*1990/ 1991*	*1991/ 1992*	*1992/ 1993*	*1993/ 1994*	*1994/ 1995*	*1995/ 1996*	*1996/ 1997*	*1997/ 1998*	*1998/ 1999*	*1999/ 2000*	*Trend*
Anser anser	Greyleg goose	11	1,500	1,180	485	800	2,500	1,150	607	920	660	771	0
Tadorna tadorna	Common shellduck	395	510	575	265	100	215	140	152	152	103	9	−
Anas penelope	Eurasian wigeon	41	300	520	350	120	480	1,100	950	850	1,400	817	+
Recurvirostra avosetta	Pied avocet	36	395	72	160	450	96	47	35	119	105	34	−
Vanellus vanellus	Northern lapwing	120	2,800	630	1,350	202	750	990	1,380	540	479	1,130	0
Calidris alpina	Dunlin	7	2,600	650	1	0	67	52	425	40	113	41	−
Tringa totanus	Common redshank	30	95	120	205	250	45	118	50	68	102	35	0
Tringa erythropus	Spotted redshank	19	28	280	860	390	535	730	104	185	138	62	−
Actitis hypoleucos	Common sandpiper	0	12	42	3	41	20	25	16	26	36	21	0

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