4. NATURE

The sluices of the Bergenmeersen FCA-CRT were opened for the first time on 25 April 2013. At the time of writing, the natural development of the area was still in a primordial stage. Therefore the actual observed nature development in Bergenmeersen could not be described in this book (although some actual results are given in Chapter 8). Therefore, this chapter explains the expected nature development with relation to similar environments along the river Scheldt.

The nature target scenario was defined in the objective of the updated Sigma Plan. In this plan, just one coordinating objective was set out for Bergenmeersen: the development of 40 ha of estuarine nature. What this precisely implies is described below.

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4.1 Freshwater tidal area: a dynamic environment

Freshwater tidal mud flat and marsh areas are among the rarest habitats in Europe. Many estuaries have been cut off through the building of sluices and dams. Important area losses have occurred as a result of ever more intensive polder building. In the Scheldt estuary, however, remnants of these freshwater tidal mud flats and marshes still remain. Thanks to the Sigma Plan, the area is being extended through the creation of FCA-CRTs and managed re-alignment or managed dike retreat. The Bergenmeersen FCA-CRT will develop into such a rare and ecologically valuable freshwater tidal area.

Freshwater tidal areas differ sharply from the image the general public usually has of tidal areas. They are not the low grassy vegetation or vast treeless areas of the saltwater Zwin or the brackish Drowned Land of Saeftinghe. In the freshwater part of the Scheldt, the tidal areas tend to develop into extremely structured vegetation, leading ultimately to the development of tidal forest as the determining focal element.

This chapter describes the dynamic environment in freshwater tidal areas. A number of basic processes are outlined, such as nutrient exchange and the succession of plant communities and their inhabitants. Where possible, they are compared with existing

Figure 4.1. Freshwater tidal mud flats and marshes in the Scheldt estuary

areas along the Scheldt and developments in the Lippenbroek trial project. This shows, for example, that the management of the CRT sluice can determine to a large extent the morphological and ecological development in the area (see "Lippenbroek pilot project", p. 80).

4.2 Morphology of the terrain

4.2.1 Mud flats and tidal marshes

Mud flats develop in the lowest parts of the tidal area, which are flooded by the Scheldt at each high water. Few plants can withstand the stress of this flooding, so mud flats are generally barren. The higher-situated marshes only flood during spring tides and have plant growth according to the frequency of flooding. The elevation determines this frequency of flooding and consequently the habitat that is found there. For the development of a diverse mud flat and marsh ecosystem, it is therefore vital that the differentiation in flooding frequency is comparable to that of natural mud flat and marsh areas.

In the highest parts of the mud flats, some plants nevertheless manage to put down roots, such as common algae (*Vaucheria* sp.), water speedwell (*Veronica anagallis-aquatica* ssp. *anagallis-aquatica*), marsh-pepper knotweed (*Polygonum hydropiper*) and bog yellowcress (*Rorippa palustris*). As soon as these plants establish themselves there, the mud flat has evolved into a tidal marsh. The silt to which these plants attach themselves gradually increases in height, opening the way to further colonisation.

Thanks to their higher location, the marshes are no longer subject to daily flooding. Young marshes experience the highest flooding frequency. These young marshes gain in height because they always retain

Figure 4.2. Arial photo of the pattern of streams

sediment. This lowers the flooding frequency, and eventually, they only flood during spring tides.

Marshes are interwoven with channels along which the water flows in at high tide and flows out again when the tide ebbs. These channels create a distinct relief. When the water, loaded with sediment, leaves the channels at high tide, the heaviest sediments are deposited right next to the channel: the sand. This creates sandy bank walls. The lighter sediments, the silt, are only deposited further away in the lower-lying and wetter basins (or stream ridges). This therefore not only creates variations in flooding frequency, but also in soil composition.

4.2.2 Imitating the natural tidal dynamic

To introduce a tidal mud flat and marsh ecosystem into an FCA-CRT, a specific system of sluices is required that firstly enables the daily exchange of Scheldt water, and secondly, still ensures that the area can store sufficient water. On the one hand, the sluices must therefore dramatically reduce the inflow of water to ensure the function as an FCA (tide storage). On the other hand, they must guarantee an essential daily variation in water levels (the tide), maintaining a variation in level between spring and neap tides.

The sluices of an FCA-CRT consist of a system with high inlet sluices and low outlet

Figure 4.3. CRT sluice and stream source

sluices, which can also be adjusted by stop-logs. This system can reduce the tide while maintaining the spring/neap tide variation. However, the tide curve is no longer sinusoidal, but experiences a stagnant phase (see “Lippenbroek pilot project”, p. 80).

Setting the right tidal dynamic is the decisive factor when developing tidal marshes. Hydrology is, after all, the main driving force behind physical, biological and chemical processes in tidal areas.

4.2.3 Sedimentation and erosion

Sedimentation is necessary to allow marshes to develop. The input of fresh sediment helps establish a typical marsh morphology (with among other things, stream ridges) and the typical marsh soil. These encourage the establishment of estuarine vegetation and benthic organisms. Hard polder clay does not contain the same organisms as a well-developed marsh soil. Furthermore, numerous biochemical processes occur in such marsh soil that are important to the functioning of the Scheldt ecosystem, such as the nitrogen or silicon cycle.

Overly fast sedimentation is not desirable. If alluvial deposits build up too quickly, this can create a poorly draining, semi-liquid, silt mass. In contrast to a developed mud flat teeming with benthos, liquid silt is unattractive to nature. Also because of the safety function in the FCA-CRT, excessive sedimentation must be avoided, as this leads to a loss of water-storing capacity, which in turn jeopardises protection against flooding. Because an FCA-CRT is entirely surrounded by dykes, it is less dynamic and there is more chance of sedimentation. On the other hand, the high inlet sluice only lets the top of the high-water wave in, which contains fewer suspended solids.

Besides sedimentation in and erosion of the polder area, the geomorphological development of channels is also anticipated. Despite the reduced tidal dynamic, a dense system of streams is expected to develop spontaneously (see "Lippenbroek pilot project", p. 80). As usual, an onset for the main channel was dug by the sluice construction in Bergenmeersen. This facilitates the inflow and outflow of water in the initial phase and will control, to some extent, the formation of channels away from archaeologically important sites.

In terms of sedimentation, FCA-CRTs differ fundamentally from natural marshes. In a natural marsh, a low elevation ensures a higher frequency of flooding, and thus greater silt deposits. This raises the height of the marsh, resulting in fewer alluvial deposits. This is known as negative feedback: the system will limit the alluvial deposits itself. In an FCA-CRT, the tide is not so much determined by the elevation, but by the sluices. The amount of water flowing through the sluices into the area does not change if an FCA-CRT is raised.

Monitoring of all sedimentation and erosion processes will show whether the area's tide storage changes significantly. Varying the inlet and outlet heights by adjusting stop-logs can help guide the process. This can be done depending on both the tide-storing capacity (safety) and the development of the natural dynamic in the area (natural quality).

Figure 4.4. Colonisation in the Lippenbroek

4.3 Vegetation

4.3.1 Initial succession

Before the work, Bergenmeersen was an agricultural landscape consisting mainly of intensively farmed grasslands. After the construction phase, some of these grasslands remained, in addition to a large area of bare, churned-up earth in the worksite zones.

The expected development of vegetation implies a dramatic shift towards hydrophyllic species . The first summer Bergenmeersen may retain the aspect of a (flooded) grassland. Eventually the grassland species and with a slight delay, also the more stress-resistant species such as stinging nettle (*Urtica dioica*) and hairy willowherb (*Epilobium hirsutum*) will be replaced by genuine wetland species. In line with the succession observed in the Lippenbroek, colonisation is expected by purple loosestrife (*Lythrum salicaria*), broadleaf cattail (*Typha latifolia*), speedwell (*Veronica* sp.), common reed (*Phragmites australis*) and willow (*Salix* sp.). In the more frequently flooded zones, the vegetation cover will make way for mud flat zones.

*1. Schematic depiction of the vegetation on a **saltwater marsh**. Only salt-tolerant plant species are found: mud colonisers (glasswort, common cordgrass), levee species (sea wormwood, seapurslane, seablite) and tidal soil species (sea lavender, sea aster, sea plantain, seaside arrowgrass).*

*2. Schematic depiction of the vegetation on a **brackish marsh**. We recognise the same mud colonisers as on the saltwater marsh: glasswort and common cordgrass. Bulrush and reeds grow on the tidal soils, with sea couch and spearscale on the levees. Once sufficient alluvial deposition has taken place, and in the absence of grazing, an extended reed land will emerge.*

*3. Schematic depiction of the vegetation on a **freshwater marsh**. Here, we find exclusively salt-averse plant species: mud colonisers are benthic algae and rushes, after which brushwood herbs appear on the levees, with reeds and other hardy marsh plants appearing on the tidal soil. Once sufficient alluvial deposition has taken place, a willow shrub and eventually willow wood will develop.*

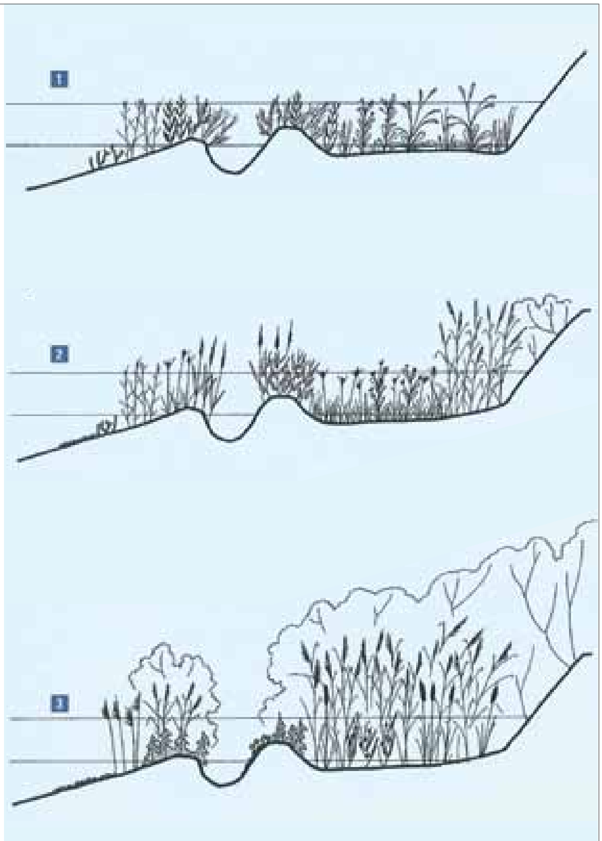

Figure 4.5. Schematic depiction of various marsh vegetations

4.3.2 Climax vegetation in a freshwater tidal marsh

The salt content in the saltwater and brackish part of the river is too high to allow trees to germinate. There, the marsh vegetation is treeless.

In the freshwater to slightly brackish part of the river, however, willows are able to germinate on the marshes, as they are highly resistant to widely varying water levels. Without management (mowing or grazing), freshwater tidal marshes therefore evolve into willow shrubs and woods. The willow tidal forest forms the climax vegetation on freshwater marshes. However, the willows on the boggy marsh soil rarely grow into tall trees: they are easily blown over in a storm, although they will continue to grow undisturbed. Freshwater marshes therefore look like mangroves: an impenetrable tangle of branches and channels.

Figure 4.6. The undergrowth of a tidal forest

The willow woods along the Scheldt naturally consist mainly of white willow (*Salix alba*) and crosses with crack willow (*Salix fragilis*). Along the Scheldt, the composition of willow wood is also subject to a heavy anthropogenic influence. The dome-shaped willow shrubs were often the product of the historical cultivation of willow twigs, used for wicker-making. These willows generally produce seeds with less germinative power than the species that form trees. On natural marshes, the dome-forming species, such as sharp-stipule willow (*Salix mollissima*) and basket willow (*Salix viminalis*), spread mainly through roots that wash up and sprout. This input is much less expected in an FCA-CRT with trash screens. Therefore it is expected that the willow shrub will tend to evolve towards a sprouting type of wood with the species specific to the area.

The undergrowth consists of marsh plants and brushwood herbs, such as rough bluegrass (*Poa trivialis*), common comfrey (*Symphytum officinale*), hedge false bindweed (*Calystegia sepium*), large bittercress (*Cardamine amara*), wild chervil (*Anthriscus sylvestris*), cleavers (*Galium aparine*), spider marsh marigold (*Caltha palustris* ssp. *araneosa*), angelica (*Angelica* sp.), touch-me-not (*Impatiens noli-tangere*), European water plantain (*Alisma plantago-aquatica*), European marshwort

(*Apium nodiflorum*), bitter dock (*Rumex obtusifolius*), cowparsnip (*Heracleum* sp.) and figwort (*Scrophularia* sp.). Specific mosses grow on the regularly flooded root base of the willows in the willow thickets and woods. These mosses prefer this dynamic, food-rich and muddy environment.

4.3.3 Spider marsh marigold: the tidal freshwater marsh specialist

The spider marsh marigold (*Caltha palustris* ssp. *araneosa*) is a subspecies of the "ordinary" marsh marigold. The ordinary marsh marigold (*Caltha palustris* ssp. *palustris*) is a fairly common species on well-developed wet grasslands. The spider marsh marigold, conversely, is one of our rarest species, bound to the freshwater marshes along the Scheldt and a number of other rivers.

Figure 4.7. The spider marsh marigold

What is remarkable about the spider marsh marigold is its adaptation to the action of the tides. It is, for example, much hardier than the ordinary marsh marigold. Germination is difficult due to the daily fluctuations in the tidal zone in that environment. The variety has therefore specialised on vegetative reproduction. Young leaves with their own roots develop on the buds and in the leaf axils of old leaves. The roots join together in a ball, making them look much like a spider. These "spiders" are released in the autumn, carried away by the tidal flow, and can develop into a new plant in another location. The spider marsh marigold therefore makes ingenious use of tidal movements to propagate itself.

4.3.4 Timing of operation as a determining factor

The initial situation and the time at which the sluice is opened for the first time are very important for the development of a complete vegetation succession. Experience in other areas (mainly de-poldering) shows that a long period between completion of the work and the onset of tidal flooding gives willows ample time to germinate. An extremely dense willow wood very quickly develops on the fallow ground. Once established, the willows continue to grow – even after the tide has been let in. As a result, herbaceous marsh vegetation has less chance to develop, and the complete succession pattern is shortened. The woody plants anchor the bottom with roots, thereby restricting the dynamism of the formation of streams. This is also a missed opportunity for joint use by benthos (animal life on, in or near the soil) and birds.

Work in Bergenmeersen was completed early in the spring of 2013. To allow natural succession to take place as much as possible and avoid rapid colonisation by willows, the sluice of the FCA-CRT was opened as quickly as possible, on 25 April 2013.

4.3.5 Forests in Bergenmeersen

The proportion of forest in the area is determined by controlling the inlet and outlet sluices, as these determine the ratio of mud flat to marsh. The project stipulates that the maximum flooding may be around 80% at spring tide. On the remaining 20% flooding is only expected during extreme weather conditions and can therefore be characterised as high marsh. The bare ground left after the work forms an ideal germination bed for willows. Willow woods are expected to appear quickly on this 20%. If further marshes are formed, this may extend to more than 50% of the area (in the long term even to around 75% or 30 ha of forest).

In a little afforested region as Flanders (with only around 10% forest cover), the development of several dozen hectares of forest is extremely welcome. For this same reason, the project development aims to preserve the total wooded area in the project cluster. In connection with the EIA (see Chapter 1), a forest audit was produced that monitors the wooded area for the Kalkense Meersen Cluster as a whole.

During the work, trees unavoidably had to be felled for dykes to be constructed, but also to allow nature to develop. Over the years, many (often small) plots of grassland were planted with poplars. These poplars will be felled to restore the former grassland biotopes. The deforested area will be fully restored within the project cluster. The 30 ha of willow tidal forest in Bergenmeersen represents the main positive contribution to the forest audit (alongside an alder carr in Wijmeers of approximately the same size).

Biodiversity increases with forest size. A rule of thumb is that a genuine forest environment only exists from a minimum size of 10 ha. Consolidating the many small areas of forest (on average less than 1 ha) into one larger forest of several dozen hectares therefore represents significant added value for the forest ecosystem. Moreover, the willow tidal forest thus created is also a seriously threatened type of forest and therefore highly valuable. This means that Bergenmeersen's importance also lies in the formation of forests. This may seem surprising as an image of a tidal area, but it is a normal evolution in a freshwater marsh.

4.3.6 Diatoms

Algae form the basis of the entire estuarine food chain. They capture the energy of the sun and use it to accumulate sugars through photosynthesis. The algae thus form a source of food for many small organisms

Figure 4.8. Diatom

in the water column (zooplankton) and the soil (zoobenthos), which are in turn eaten by higher trophic levels, such as crustaceans, fish or birds.

However, not all algae are equally suited as a source of food. Diatoms take precedence. These single-cell algae have a special skeleton that offers them extra protection. This skeleton is made from silicon. Dissolved silicon is therefore an essential food source for diatoms. Since diatoms are an important basis of the food pyramid, the available silicon plays an important role in the aquatic ecosystem (unlike terrestrial ecosystems).

4.4 The nutrient cycle

4.4.1 Eutrophication

One of the main problems that coastal zones and estuaries faced in recent decades is eutrophication, or over-fertilisation. Untreated waste water from agriculture, industry or households carries large amounts of the nutrients nitrogen and phosphorus into the Scheldt estuary via watercourses. However, silicon has not increased, which has led to a major change in the ratio between the nutrients silicon, nitrogen and phosphorus.

The changing ratio between the basic nutrients can lead to "silicon limitation". Diatoms grow until all the silicon has been used up. If there is then still a surplus of nitrogen and phosphorus, other unwanted algae can take it over. These so-called pest algae result in a massively negative phenomenon: among other things, foaming, anoxic water and toxic water masses. Because diatoms form the basis of the estuarine food chain, eutrophication and the associated silicon limitation can cause the collapse of the entire food chain.

4.4.2 Exchange processes in the tidal areas

The processes in an FCA-CRT and other tidal areas can have a major influence on the composition of the water. Bacteria in the mud convert nitrogen into nitrogen gas through the process of nitrification/denitrification (see "Lippenbroek pilot project", p. 80), which allows nitrogen to escape from the water. As a result, tidal areas play an important role in reducing the pollution load.

Conversely, almost no phosphate conversion takes place. Only a small fraction is absorbed by plants.

Oxygen-enrichment of the water occurs physically through the operation of the sluices, the sharp rise in the surface area of the water and the primary production of the plants in the FCA-CRT. Results from the Lippenbroek show that the amount of dissolved oxygen in the water increases enormously after it has spent time in the FCA-CRT.

A less well-known aspect is the release of dissolved silicon into the marshes, which is of great importance to the growth of diatoms (see Section 4.3.6).

4.4.3 Silicon cycle

In particular, common reeds (*Phragmites australis*) absorb dissolved silicon (DSi) (H4 SiO4) through the roots. Once the silicon has been absorbed by the plant, it is fixed in highly silicon-rich structures:

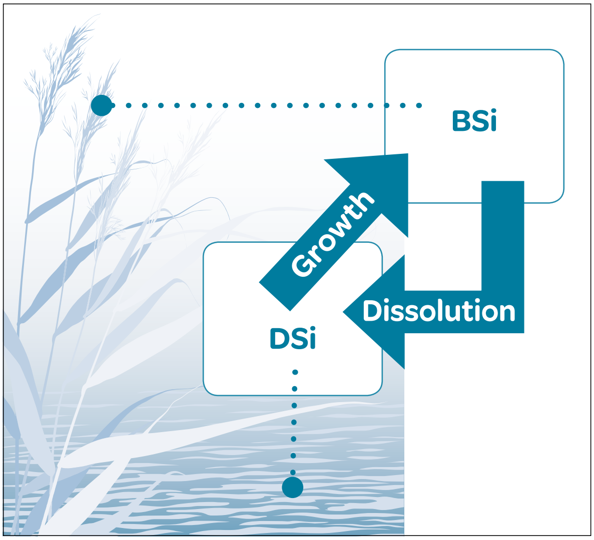

Figure 4.9. The silicon cycle

phytoliths (biogenic silica or BSi). The fixing of silicon can give a plant various competitive advantages compared with other species: greater resistance to plant diseases, damage from herbivores and metal toxicity, and greater strength. Reeds stack up silicon during their growth: higher concentrations of silicon are found in the longest-living plants, at the end of the growing season. Once a dead reed stem has fallen over (e.g. knocked over by wind or water), the silicon can dissolve into DSi and become a source of silicon.

Besides dead reed stems, there are other potential sources of BSi for marsh sediments. At high tide, a great deal of floating material such as sediment, dead and live phytoplankton and other plant material is carried in by the water. Some of this material settles onto the surface of the marsh. The BSi from the decaying organic material is also stored in the sediment.

The BSi in the sediment gradually dissolves into DSi in the interstitial water. This means the concentrations of dissolved Si in freshwater marsh interstitial water are much higher than the concentrations in flood water. During the frequent floods, the BSi that has dissolved into DSi can easily be exchanged with flood water. BSi also dissolves relatively quickly when it comes into contact with water with low dissolved silicon concentrations. Therefore, the Scheldt water that flows out of the CRT is enriched with silicon compared with the incoming water. Marshes form rich reservoirs of silicon within the estuarine ecosystem, which is important for the growth of diatoms and the support of the food pyramid.

In short, the Bergenmeersen FCA-CRT will play a role in the enrichment of dissolved silicon and oxygen, and in the reduction of the nitrogen load. It is expected that there will be at least a local positive impact on the ecosystem of the Scheldt.

4.5 Higher trophic levels

4.5.1 Fish

Importance of the Scheldt estuary to fish

Estuaries serve as nursery grounds for many young marine and freshwater fish and are a transit and spawning zone for migratory fish. In the Sea Scheldt, on the one hand, marine fish species flourish to upstream of Antwerp; some species even swim further to past Dendermonde. On the other hand, freshwater fish are sometimes seen downstream of Zandvliet. A great many of the species of fish known in Flanders can thus occur in the Sea Scheldt. In 2012, sampling revealed 41 species of fish in the Sea Scheldt. These figures are considerably high than in the past. The return of migratory fish in particular illustrates the benefit of the efforts made to reduce the pollution load in the river and increase oxygen levels.

The FCA-CRT as fish habitat

Within the estuary, the mud flat and marsh areas play an important role as an incubating and foraging area. Research into the fish communities in the Lippenbroek show that fish can also make use of an FCA-CRT. The area is less dynamic than the estuary and the diversity of habitats ensures that different species come into their own at different stages of life. Over the years, the number of species and individuals has increased in every type of habitat studied. A total of 20 species were observed.

The fish community in the Lippenbroek initially consisted mainly of pioneer species and introduced species such as the three spined stickleback (*Gasterosteus aculeatus*), the Prussian carp (*Carassius gibelio*) and the stone moroko (*Pseudorasbora parva*). Over the years the fish community evolved differently according to the habitat, with mainly European smelt (*Osmerus eperlanus*) in the stream, common roach (*Rutilus rutilus*) in the reservoir and three-spined stickleback in the permanent pools.

Species such as the Prussian carp, the stone moroko and the common roach complete their entire life cycle in the Lippenbroek. Migrating species such as the European flounder (*Platichthys flesus*), the European smelt and even the European seabass (*Dicentrarchus labrax*) use the Lippenbroek as a nursery area (see "Lippenbroek pilot project", p. 80). Predatory fish such as the European pikeperch (*Stizostedion lucioperca*) mainly forage in the reservoir.

It is expected that the creation of the Bergenmeersen FCA-CRT can contribute significantly to the fish community of the river ecosystem. This could be directly, through the creation of habitat in the flood area, and indirectly, by improving conditions in the river (see Section 4.4). Initial fish monitoring has produced highly encouraging results (see Chapter 8).

Eel in the FCA-CRT

The importance of the Lippenbroek as a foraging area for the European eel (*An-*

Figure 4.10. Common roach

Figure 4.11. Eel

guilla anguilla) was recently investigated. The question was whether the FCA-CRT is important as a foraging area for eel and if so, how the eel's diet in the FCA-CRT differs from that in the Scheldt.

Comparison of the stomach contents of eels from the Lippenbroek and the Scheldt revealed that the diversity of prey in the Lippenbroek is around four times greater than in the Scheldt. In the Lippenbroek, eels feed more on terrestrial prey such as earthworms, caterpillars and other insects, in addition to fish, fish eggs and other benthic organisms. The energy value of the prey taken in both cases was calculated using information from the literature. This showed that the value in the Lippenbroek was around twice as high as in the Scheldt.

Although a health index reveals approximately equal values, it was demonstrated statistically that eels caught in the Lippenbroek are significantly heavier for a given body length than the examples caught in the Scheldt. It has therefore been shown that FCA-CRTs are an important habitat for the eel and contribute towards the recovery of the eel population.

Figure 4.12. Twaite shad

The return of the twaite shad

Until the end of the nineteenth century, the Scheldt was an important spawning area for various species of migratory fish such as the twaite shad (*Alosa fallax*) and European smelt (*Osmerus eperlanus*). The populations of these species were large enough to allow commercial fishing. The Scheldt became so polluted during the twentieth century that an anoxic zone was created and parts of the river were de facto biologically dead. Considerable efforts have been made to improve the ecological quality of the Scheldt since the end of the twentieth century. In the first place, efforts to treat domestic waste water play an important role. The Sigma Plan is continuing to improve the ecological quality (habitat, nutrient cycle) and by increasing the area of estuarine habitat through the removal of polders or the creation of FCA-CRTs.

As a result of these efforts, fish stocks are recovering. One species that has made a remarkable comeback in the Scheldt is the twaite shad (*Alosa fallax*). The twaite shad is a member of the herring family and can grow to a length of 60 cm. Because of the spots on its sides, it is also known as the spotted giant herring. Another local name is the May fish, because it is caught in the tidal zone of major rivers in the spring (May). The twaite shad is an anadromous fish: it lives in the sea, but spawns in the mouths of rivers. If the temperature rises above 11°C, the fish swim upstream. Where the tides are more pronounced, they lay their eggs in more low-dynamic zones with gravel and/or sand.

Until a few years ago, twaite shads were no longer found in the Scheldt. Now both adults and juveniles are being found, which points to successful reproduction. The lower limit of dissolved oxygen for twaite shads is 3 mg/l. The presence of twaite shads is therefore an indication of good water quality. If the water quality continues to improve, the twaite shad could herald the return of other species.

4.5.2 Birds

General

Freshwater tidal areas maintain particularly large and diverse bird populations. The Scheldt is of international importance for 21 species of waterfowl. Approximately 100 species of bird use the estuary to breed or when passing through. This is why almost all of the tidal area of the Sea Scheldt was designated as a Habitats and Birds Directive area.

The Scheldt between Ghent and Dendermonde is characterised by a narrow navigable channel and very little mud flat and marsh areas. The waves created by ships make it impossible for birds to look for food along the water line in peace. Waterfowl numbers are therefore also much lower. Where there are still mud flats and marshes of reasonable size, such as in the tidal arm by Ghent, the population of reed birds and waterfowl is more diverse and more extensive.

Figure 4.13. Bluethroat

The relationship of several bird groups to the developing environment is outlined below. Not all species and groups are covered. The focus is on bird groups that are likely to be encountered in Bergenmeersen.

Songbirds

Depending on the proportion of willow shrub, two groups of songbirds can be distinguished on the freshwater marshes. The first only breeds in relatively broad and fresh reed vegetation without thickets. Typical species are the sedge warbler (*Acrocephalus schoenobaenus*) and the common reed bunting (*Emberiza schoeniclus*).

A second group consisting of the Eurasian reed-warbler (*Acrocephalus scirpaceus*), the marsh warbler (*Acrocephalus palustris*) and the bluethroat (*Luscinia svecica*) not only breed in pure reeds, but in coarse reeds, brushwood and thickets. They also breed easily in relatively narrow, linear strips of reed vegetation.

Bergenmeersen will remain unmanaged, and over time a large part of the FCA-CRT will evolve into willow tidal forest. The settings of the sluice of the FCA-CRT will determine the evolution of the proportion of mud flat and marsh and thus also the breeding area of the second group of reed birds in particular.

Herons

The nature objectives of the updated Sigma Plan include a limited number of breeding pairs for colony-forming thicket- and tree-breeders, such as black-crowned night-herons (*Nycticorax nycticorax*), Eurasian spoonbills (*Platalea leucorodia*) and purple herons (*Ardea purpurea*). Creating opportunities for these species consists of providing

Figure 4.14. Purple heron

suitable breeding locations close to good foraging areas.

The purple heron is currently not a breeding bird in Flanders. It is relatively flexible in its choice of nesting location. Key preconditions are tranquil environment and a nesting place that is difficult for predators to reach. They nest in reeds or dense scrub (willow and alder thickets) as well as high in the trees. The foraging habitat of the purple heron consists mainly of marshy areas and ditches in grassland areas. The birds forage exclusively by day, actively walking along the banks. Their food consists of fish, mammals, amphibians and large water insects.

There is considerable potential for the purple heron in the Kalkense Meersen Cluster, thanks to the combination of suitable foraging habitats: wet grasslands, marshes, reed land, combined with the development of willow tidal forests of which Bergenmeersen can become the primary example. This combination makes the cluster one of the most promising zones for the purple heron along the Scheldt.

Bergenmeersen could become important as a breeding location for a number of other species of heron. A condition is that good spatial complementarity is established at cluster level between Bergenmeersen as a breeding area (breeding colony) and the rest of the Kalkense Meersen Cluster as a foraging area. At the same time, Bergenmeersen could become attractive as a foraging area to species such as the Eurasian spoonbill and genuine "marsh herons" such as the night heron.

Waterfowl

Large groups of ducks are mainly found in the freshwater part of the Sea Scheldt. For the common teal (*Anas crecca*), the area in the zone upstream from Dendermonde is very important. During the winter, up to 1,000 overwintering common teals are

Figure 4.15. Common teals

counted. With up to 300 individuals, the Northern shoveler (*Anas clypeata*) is approaching the Ramsar norm here (1% of the population of north-western Europe). The larger mud flat and marsh areas, such as the tidal arm by Ghent, are home to up to 70 mute swans (*Cygnus olor*). The importance of the mud flats and marshes becomes even greater in times of frost, when other freshwater areas in the vicinity freeze over. The tidal areas along the Scheldt then form an area for rest and foraging that helps maintain populations in adjacent areas.

The different species of duck depend on mud flats and open water for their food. Common teals (*Anas crecca*), gadwalls (*Anas strepera*), common shelducks (*Tadorna tadorna*) and mallards (*Anas platyrhynchos*) filter mud, looking for seeds, earthworms (*Oligochaeta*) and other benthic organisms. Common shelducks are known to eat small crustaceans, snails and diatoms. Common pochards (*Aythya ferina*) and tufted ducks (*Aythya fuligula*) dive in the water for their food. The ducks look for food and shelter in the relatively open marshes when water levels are higher.

The action of the tide in Bergenmeersen is creating a dynamic system that will reach a state of equilibrium in a number of years or decades (see "Lippenbroek pilot project", p. 80). The initial situation will include a large proportion of mud flats and open water, which means mainly ducks and waders are expected at the onset. As the marshes evolve and become covered with reeds and willows, reed birds and thicket-breeders can colonise the area.

4.5.3 Mammals

General
The number of mammal species expected in Bergenmeersen is quite a bit smaller than the number of bird species. For several species adapted to the water, however, the area could provide a habitat in time.

Water shrew
The water shrew (*Neomys fodiens*) is found in water-rich biotopes with rich bank vegetation and structurally rich banks. In addition to the banks of streams and lakes that are not too steep, the flood zones of rivers, marshy areas and reedy borders also form the biotope of this species in Flanders. Wooded areas are also possible (temporary) habitats. The water shrew is a good swimmer and looks for its food – all manner of invertebrates and small fish – in the water. The shrew is a mobile species that is found in the Scheldt basin and could possibly colonise the flood area.

Figure 4.16. Water shrew

Beaver
The common otter (*Lutra lutra*) and Eurasian beaver (*Castor fiber*) are on the rise in Flanders, and are therefore significantly interesting. Bergenmeersen is not expected to become a suitable area for otters, but things may well be different for the beaver.

Figure 4.17. Beaver

The ecological amplitude of the beaver is considerable: the species can be found in flowing highland streams, lowland marshes, but also in tidal areas. In principle, the beaver needs adequate open water to build a lodge, channels to move about without leaving the water and sufficient food. Beavers are uniquely able to adapt circumstances to their advantage. They do this, for example, by building dams or digging small channels to extend their range. This is why they are also known as "ecosystem engineers". Beavers are strict vegetarians: thanks to special bacteria in their caecum, they can digest woody plants without any problem. They prefer soft varieties of wood, such as poplar, willow and birch, of which they eat the bark, twigs and leaves. They also eat a variety of water and marsh plants, including the roots.

Studies in Canada indicate that the density of beaver lodges is nowhere greater than in untouched estuaries or tidal forests. The area required by a family of beavers is thus relatively small in a freshwater tidal area. Therefore Bergenmeersen could be big enough to house a beaver family.

Beavers became extinct in Flanders in the nineteenth century, but are now gradually colonising Flanders again after being reintroduced in Wallonia. It is therefore not impossible that the beaver will soon also appear in Bergenmeersen.

4.6 Sluice settings as guiding factor

The setting of the sluices in an FCA-CRT is decisive for the development of the area. This is because the sluices determine the tide, and the tide is the determining factor in estuarine areas. In Bergenmeersen, the aim is to develop such an estuarine area and to give the natural succession as many opportunities as possible. Adaptive sluice management was chosen in order to anticipate on the developments in the area. This is described in Chapter 8, where the relationship with other requirements (such as safety) is also discussed.

The basic requirements for sluice management in favour of nature development can be summarised as follows:

1. Allow tidal flooding as soon as possible after the completion of the construction works. This prevents the land from becoming quickly and permanently wooded.
2. In an initial period (the **transformation phase**), a fairly high tidal dynamic should be created to begin the formation of channels and deposit a first layer of sediment. The former agricultural area is converted into an estuarine area as quickly as possible, with as large a proportion as possible of mud flats.
3. In the subsequent, possibly rather long period (the **succession phase**), the sluice management should be carefully controlled to allow mud flats to gradually evolve into marshes and the succession

to reed vegetation and willow tidal forest can take place.

4. Once the desired mud flat/marsh ratio has been achieved, the sluices can be given their permanent settings (**stable phase**). The global picture of the area is then more or less established; it now consists of up to 75% willow tidal forest. In the long term, however, the relief can be altered by sedimentation and erosion such that the flooding frequencies differ from the desired final picture. At that point, minor adjustments to the sluices may be required.

4.7 Conclusion

The concept of an FCA-CRT is a recent one. Bergenmeersen is the first full-scale FCA of this type in the world, after the Lippenbroek pilot area. Compared with de-poldering, the situation is highly controlled. After all, the sluice of the flood area and the sluice settings will determine the dynamics and succession of mud flats and marshes.

Current knowledge of the tidal areas in the freshwater part of the Scheldt, including the Lippenbroek, give us an idea of the future development of the Bergenmeersen area. The final picture is a willow tidal forest of approximately 30 ha and a mud flat area of approximately 10 ha, cut through by tidal channels. The whole guarantees exceptionally diverse fauna and flora, the expected elements of which are more or less known. However, surprises cannot be ruled out, given the size of the area and recent developments in the Scheldt basin. The influence of the new arrangement on the local river ecosystem will be subject to close monitoring.

Figure 4.18. Tidal forest

4.8 References

- ***Natuurherstelplan Zeeschelde: drie mogelijke inrichtingsvarianten.*** *(Nature restoration plan for the Sea Scheldt: three possible design variations.) E. Van den Bergh et al. (1999), Institute for Environmental Management report, Brussels: IN 99/18. ISBN 90-403-0108-5. IV / www.inbo.be/files/bibliotheek/37/173437.pdf*
- ***Tidal Freshwater Marshes.*** *In: Wetlands 3rd edition. Mitsch & Gosselink (2000) / ISBN: 0-471-29232-x*
- ***Studierapport natuurontwikkelingsmaatregelen ten behoeve van de Ontwikkelingsschets 2010 voor het Schelde-estuarium.*** *(Study report for nature development measures for the 2010 Development Outline for the Scheldt Estuary.) E. Van den Bergh (2003), RIKZ working document, 2003.825x / www.inbo.be/docupload/1345.pdf*
- ***Zoogdieren in Vlaanderen. Ecologie en verspreiding van 1987 tot 2002.*** *(Mammals in Flanders. Ecology and dis-*

tribution from 1987 to 2002.) S. Verkem et al. (2003), ISBN: 90-77507-01-9

- ***Zoetwaterschorren als siliciumbuffers in het Schelde-estuarium.*** *(Freshwater marshes as silicon buffers in the Scheldt estuary.) E. Struyf et al. (2006), Water July-August 2006 / www.tijdschriftwater.be/artikel24-1HI.pdf*
- ***Ecosysteemvisie Cluster Kalkense Meersen (zone 1). Studie t.b.v. aanleg overstromingsgebieden en natuurgebieden i.h.k.v. het Sigmaplan.*** *(Ecosystem vision for the Kalkense Meersen Cluster (zone 1). Study for the development of flood areas and nature areas as part of the Sigma Plan.) G. Van Ryckegem et al. (2008), INBO.R.2010.3 / www.inbo.be/files/bibliotheek/83/246583.pdf*
- ***Natuurontwikkeling in het Lippenbroek. Herstel van estuariene natuur via een gecontroleerd gereduceerd getij.*** *(Nature development in the Lippenbroek. Restoration of estuarine nature through a controlled reduced tide.) T. Maris et al. (2008), Natuur.Focus 7(1):21-27 / www.rlrl.be/rivierkenner/images/lippenbroek_2008.pdf*
- ***Scheldetraject Gentbrugge-Melle; ecologische potenties in het bovenstrooms Zeescheldetraject.*** *(Path of the Scheldt from Gentbrugge-Melle; ecological potential upstream in the Sea Scheldt.) F. Piesschaert et al. (2009), INBO.R.2009.47 / www.inbo.be/files/bibliotheek/09/186109.pdf*
- ***Onderzoek naar de trekvissoorten in het stroomgebied van de Schelde.*** *(Study of the migratory fish species in the Scheldt basin.) M. Stevens et al. (2009), INBO.R.2009.9 / www.inbo.be/files/bibliotheek/97/184297.pdf*
- ***Onderzoek naar de gevolgen van het Sigmaplan, baggeractiviteiten en havenuitbreiding in de Zeeschelde op het milieu. Geïntegreerd eindverslag van het onderzoek verricht in 2009-2010.*** *(Study of the effects of the Sigma Plan, dredging activities and extension of the port in the Sea Scheldt on the environment. Integrated final report of the study carried out in 2009-2010.) T. Maris & P. Meire (Red.) (2011), University of Antwerp / www.vliz.be/imisdocs/publications/235935.pdf*
- ***Evaluatie van natuurontwikkelingsprojecten in het Schelde-estuarium.*** *(Evaluation of nature development projects in the Scheldt estuary.) J. Speybroeck et al. (2011), INBO.R.2011.21 / www.inbo.be/files/bibliotheek/75/224675.pdf*
- ***The role of a freshwater tidal area with controlled reduced tide as feeding habitat for European eel (Anguilla anguilla, L.).*** *C. Van Liefferinge et al. (2012), Journal of Applied Ichthyology 28(4):572-581 / DOI: 10.1111/j.1439-0426.2012.01963.x*
- ***Visbestandopnames in het Lippenbroek, een gecontroleerd overstromingsgebied met gereduceerd getij in het Zeeschelde-estuarium. Viscampagnes 2006-2012.*** *(Levels of fish stocks in the Lippenbroek, a flood control area with reduced tide in the Sea Scheldt estuary.) J. Breine et al. (2012), INBO.R.2012.67 / www.inbo.be/files/bibliotheek/97/242097.pdf*
- ***The vegetation silica pool in a developing tidal freshwater marsh.*** *S. Jacobs (2013), Silicon 5(1): 91-100 / DOI: 10.1007/s12633-012-9136-9*

PILOT PROJECT
THE LIPPENBROEK

The concept of the flood control area with controlled reduced tide (FCA-CRT) is being applied for the first time on a large scale in Bergenmeersen. But it was previously tested extensively in the Lippenbroek pilot project (Hamme). There, various universities and institutes, such as the University of Ghent, the Free University of Brussels, the Research Institute for Nature and Forest, Flanders Hydraulics Research and the Royal Netherlands Institute for Sea Research, headed by the University of Antwerp, are investigating the operation of the concept. The key question for the Lippenbroek: can sustainable ecological structures and functions develop in FCA-CRTs that are qualitatively and quantitatively similar to those of undyked mud flats and marshes?

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The Lippenbroek is a former polder area of 10 ha along the left bank of the Scheldt in Hamme. It was a typical Scheldt polder used for agriculture, with maize and potatoes as the principal crops and a small poplar plantation.

The Lippenbroek lies in the freshwater tidal area of the Scheldt, some 10 km upstream of Rupelmonde. In times of flood, this meant that the area received part of the pollution load of the city of Brussels and experienced high nutrient concentrations and a low oxygen saturation when the water flowed in. Because the intention was to measure the area's contribution to the recovery of the quality of the estuary's water, this was not seen as a problem. Water treatment in Brussels (and throughout Flanders) has since advanced considerably, and the quality of the Scheldt water has improved significantly.

In 2004, work began to convert the area into an FCA-CRT. This involved building the new ring dyke, lowering an overflow dyke on the side of the Scheldt and constructing a new inlet sluice to create the reduced tide. Drainage is through a separate sluice construction with a non-return valve.

A low elevation, +2.5 to 3 m TAW, is typical of such an area. By way of comparison: the undyked marshes before the Lipenbroek lie at +5.5 to 6 m TAW. The ingress of water into the flood area must ensure that the tide in the lower-lying polder approaches that of the river

Figure 4.19. Arial photo of the Lippenbroek

as closely as possible. The inlet sluices were therefore fitted with stop-logs. Experiments with "trial water ingress" helped find the most suitable sluice configuration.

The sluices were opened permanently in March 2006. An extensive monitoring programme was begun to see how the organisation of such a flood area leads to the development of mud flats and marshes.

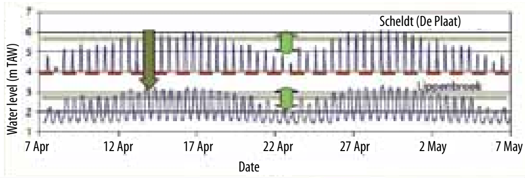
Tidal cycle

Modelling showed that, thanks to the system of high inlets and low outlets, it is possible to vary the frequency of flooding considerably. However, the inlet construction must be sufficiently high (+4.7 m TAW in the Lippenbroek). Only then is there sufficient difference in water ingress duration and volume to create the desired significant variation in water levels in the polder.

Measurements of the water level in the Lippenbroek and De Plaat reference marsh show that the sluice construction reduces the high water level by around 3 m, without affecting the variation between neap tide and spring tide. The slack tide is reduced to the level of the polder. As a result the Lippenbroek is not flooded daily, but experiences a wide range of flooding frequencies. These are mainly determined by the sluice configuration and no longer by elevation in relation to the level of the Scheldt. This provides opportunities for marshes to develop in low-lying areas.

Figure 4.20. Situation of the Lippenbroek

Figure 4.21. Tidal variation



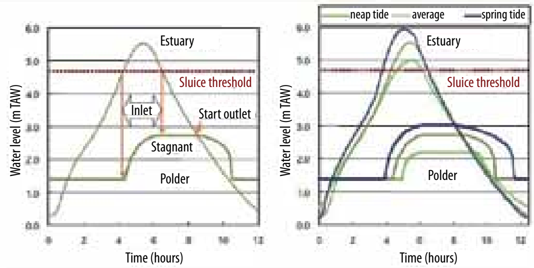


Figure 4.22. Tidal modelling

Detailed measurements of individual tidal cycles show, as already indicated by the modelling, that the shape of the tide is altered. The tidal curve is no longer sinusoidal. The tidal cycle in the FCA-CRT now has three phases: flood, stagnant and ebb. As soon as the level of the Scheldt exceeds the high ingress level, a powerful flood occurs. Following ingress, the stagnant phase begins. The ebb phase can only begin when the level of the Scheldt drops below the water level in the Lippenbroek. The stagnant phase, which lasts an average of 2 to 2 and a half hours, is a key artefact of an FCA-CRT. For a similar flooding frequency, such flood areas therefore experience an extended period of flooding. The possible ecological implications of this are being investigated in the Lippenbroek.

Sedimentation and erosion

Sedimentation is monitored closely due to its considerable importance for the ecosystem and safety. The results are clear: the Lippenbroek exhibits sedimentation speeds that are comparable with those of natural marshes. At the lowest points these are high, up to 10 cm a year. The higher parts hardly silt up at all, with just a few millimetres a year. As a result, the lower parts increase in height more quickly and the area levels off: we get a marsh plateau, cut through by large and small channels. Somewhat unexpectedly, these channels form quickly and easily in the Lippenbroek. The hard polder clay and the sluice constructions do not prevent the tide from cutting out numerous new channels. Obviously this process takes time,

Figure 4.23. Network of streams in the Lippenbroek

but after just six years, a clearly branched network of streams has begun to emerge. The existing polder ditch was also affected by the tide. This ditch became wider and deeper towards the mouth; it is silting up into a narrow channel at the back of the area.

Water quality

Water that leaves the Lippenbroek is clearly of better quality than water that flows into it. Passing through the sluices and spending time in the area ensure significant oxygen enrichment.

One important characteristic of natural tidal areas is that they remove nitrogen. The inflow and outflow of nitrogen in the Lippenbroek was therefore closely monitored during various tidal campaigns. With each tidal movement, the Lippenbroek removed approximately 10 kg of nitrogen from the Scheldt water. That is a lot, but the area of FCA-CRTs will never be large enough to reduce the current nitrogen load in the Scheldt to an acceptable level. Measures at the source are therefore required, such as water treatment plants and restrictions on the use of fertiliser. Tidal areas have the job of removing the remaining diffuse influx that evades the water treatment plants.

Phosphorus was not initially removed from the Lippenbroek, on the contrary. There was an outflow of phosphorus during the first few years, probably a legacy of years of fertilisation in the former arable land. In recent years, however, the trend has reversed and the Lippenbroek is now also absorbing phosphorus.

The export of silicon is a more subtle story. When there are no shortages in the estuary, the Lippenbroek absorbs dissolved silicon. If there are shortages, it is expected that dissolved silicon will be released: this is how natural marshes work. And initially, this was indeed what happened in the Lippenbroek: large amounts of dissolved silicon were released from the mud flats and marshes. But a large part of that silicon will probably be consumed in the Lippenbroek itself. The channels and tidal pools that are permanently under water are hot spots of biological activity. The released silicon strengthens the function of the Lippenbroek as a rich food area, but the export of dissolved silicon to the Scheldt has decreased.

Fauna and flora

For a habitat to recover successfully, complete fauna and flora development is needed to form a stable food chain. Vegetation, zoobenthos and fish have been monitored systematically since March 2006; the bird population has been monitored since autumn 2006. These observations are dealt with in Chapter 4.

What is remarkable for the Lippenbroek is the influence of the separate inflow and outflow of water on fish migration. Targeted basket weir catches show that the fish are not entering the polder in large numbers via the water inlet. Rather, a fairly limited passive migration was noted via this route. Nevertheless, the fish do find their way in and out of the flood area, via the outlet sluice. Perhaps the fish are attracted by the oxygen-rich lure flow that leaves the polder as the water flows out. This means the fish are migrating against the outflowing water, from the Scheldt to the polder. It is expected that outlet sluices will also be mainly responsible for fish migration in other areas.

Conclusion

The Lippenbroek shows that estuarine recovery in low-lying polders can be made to proceed very quickly by developing FCA-CRTs. Thanks to the creation of suitable tidal conditions, spontaneous rapid evolution follows towards a functional mud flat and marsh ecosystem. Oxygen enrichment and nutrient cycling were demonstrated in the Lippenbroek. The prolonged flooding period of an FCA-CRT does not seem to present an obstacle to colonisation by fauna and flora.

The effects of the Lippenbroek on the water quality of the Scheldt itself cannot be measured. This is because the pilot project is too small to have an influence. However, model calculations show that large FCA-CRTs such as Bergenmeersen nevertheless make a significant contribution to the Scheldt ecosystem. The updated Sigma Plan provides for the creation of hundreds of hectares of that type of flood area, thereby giving the Scheldt estuary a welcome boost.

Figure 4.24. The yellow iris grows profusely in the Lippenbroek.