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The Interreg IVB North Sea Region Programme

WP5 Measures

Basic analysis reports

Measure nr° 15. Ketenisse wetland - small scale tidal wetland restoration in the brackish part of the estuary

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1 Description of measure

- Measure Category: Biology/Ecology
- Estuary: Scheldt
- Salinity zone: Mesohaline
- Pressure: Habitat loss and degradation
- Status: Implemented (in 2002-2003)
- River km: TIDE-km 92
- Country: Belgium
- Specific location: Sea Scheldt (Zeeschelde), Flanders, province Antwerp, Beveren, left bank of Scheldt between fort Liefkenshoek and Kallo sluice
- Responsible authority: Waterwegen en Zeekanaal NV
- Costs: /
- Cost category: 1,000,000 – 5,000,000 €

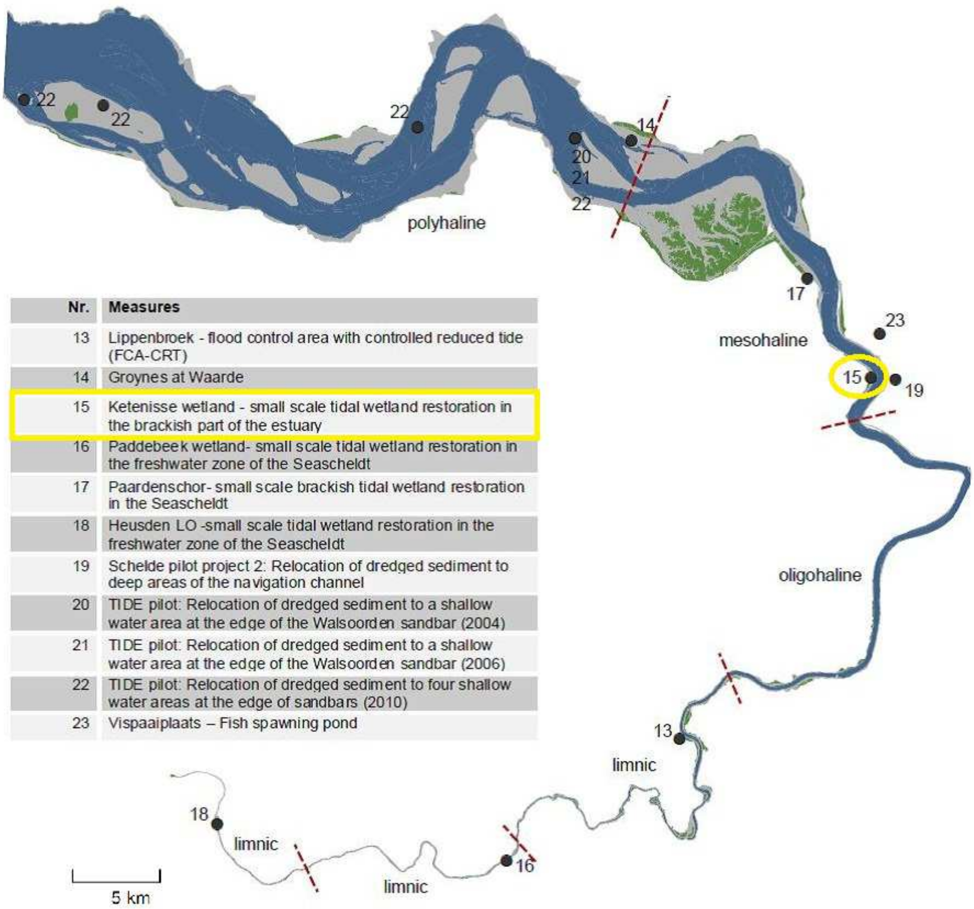


Figure 1. Location Ketenisse wetland.

Figure 2. Air view Ketenisse wetland

1.1 Measure description

The Ketenisse marsh is located in an industrial area at the left bank of the Lower Sea Scheldt (along 4km of the river), between the fortress of Liefkenshoek and the Kallo sluice (Van den Neucker et al. 2007, Speybroeck et al. 2011). The objective was to restore processes that lead to the development of a brackish tidal wetland. The restoration was a compensation for the North Sea Container Terminal on a mudflat in 1994-1995 in the Port of Antwerp. To restore the tidal wetland, the area was separated from the inland by the construction of a new dike with Sigma height (at the site of the old winter dike) and the area itself was lowered back slightly under Mean High Water level (embanked as a polder in second half 1800s and over the years elevated mainly with specie from construction works in second half 1900s). The plan was to remove the rubble of the summer dike and the dumped material and to level the area with a weak slope below mean high water level, creating the optimal starting conditions for new intertidal mudflats and marshes (60 ha, of which 35.5 ha restored). Some parts have however not been lowered as planned, resulting in large variation in height and slope leaving supratidal vegetated parts, lower bare mud and a rather steep slope along the summer dike remnants. The total area can be divided in several zones with different historical and starting situation (LHT, ABC, D, E, F, G; Table 1 & Figure 4).
This area was surrounded by two dikes: winter- and summer dike. The winter dike (from the north to the south) was elevated and broadened (Sigma height and -width). The summer dike (central zone D-E) was partly excavated.

Table 1. Description of the 7 zones of the Ketenisse marsh (Van den Neucker et al. 2007).

Zone	Description: history and starting situation for monitoring
LHT	The most downstream part of the study area was not excavated to protect the environment of the tunnel (Liefkenshoek).
ABC	Section ABC was levelled according to plan except for some hard exposed peat layers, which also created a differentiated resistance to wave action along the slope. The slope of the levelled part was relative steep (from 5 m TAW at the dike to the level of the present mudflat) because of insufficient space for a more gradual transition. At start of the monitoring, this area was not embanked and the sediment was rather sandy mud.
D	Section D is part of the former Ketenisse polder located downstream of some pipelines which are defended by surrounding dikes. Section D is in the past never elevated and now left at its original relatively low level (almost 1m below MHW). The summer dike around it was only partly removed and breached, leaving a relatively sheltered intertidal mudflat because vegetation rapidly disappeared after the breach.
Polder	This area is not under tidal influence and hence preserved the characteristics of a polder.

E	Section E is the widest part, also part of the former Ketenisse polder and located upstream of the pipelines. In this zone most construction work was done of the entire area: remains of the summer dike and elevation specie was removed and the area was levelled to almost 0.5m below MHW. Areas with specie not useful for dike construction work remained untouched and some areas were deeper excavated than others. A week slope to the river was developed for optimal start conditions for the development of intertidal area. At start of the monitoring this zone was a non-embanked mudflat and marsh area with both silt rich and more sandy mud.
F	Section F was already non-embanked before the start of the monitoring and remained mainly untouched and supratidal. However, during the construction work a temporary elevation was built near the shoreline for the excavators. In the largest part of this zone, reed rhizomes were scraped. Only at a smaller part the original reed vegetation remained unaffected.
G	Section G was excavated with a relatively steep slope because of insufficient space for a more gradual transition (similar to zone ABC). At start of the monitoring this area was a non-embanked sandy mudflat. In the more upstream part of the G section a steep cliff, with a height between 0.3 and 1.5m developed over a length of 100m (Figure 3) (Van den Bergh 2005, Van den Neucker et al. 2007).

Figure 3. Cliff at zone G (March 2003) (Van den Neucker et al. 2007).

Analysis of the evolution after restoration fits in with the decisions about the Development outline 2010 and Long Term Vision 2030 (Dutch and Flemish agreement on integrating accessibility, naturalness and flood safety) and the updated Sigmaplan (Flemish plan for flood protection combined with ecological objectives), of the Dutch and Flemish governments, that committed them to leap forward with the ecological rehabilitation of the Scheldt estuary. An important challenge is the creation of tidal wetlands by transformation of woods or agricultural land into tidal mudflats and marshes. In order to assess the feasibility and to identify possible problems any similar small scale projects already in place, such as Ketenisse, are studied in detail to improve our apprehension of the larger scale future plans.

1.2 Monitoring

The monitoring program is included in global monitoring of Scheldt estuary (Moneos) plus monitoring of variables that give information about evolution and success of restoration. The evolutions have been studied since 2002, intensively immediately after restoration and with declining effort over the years. Aspects of interest are geomorphological changes (sederoplots, profile measurements, orthophotos), sediment characteristics (granulometry, organic %, pigment, physicochemistry) and colonization by phyto- and zoobenthos (benthos, oligochaeta) are studied. Also vegetation (PQs), avifauna (water and breeding birds) and fish

were studied. These developments were compared as much as possible to the situation on nearby tidal wetlands.
Monitoring of all aspects is done near 20 sampling stations along 6 transects perpendicular to the shoreline (Figure 4), from which 11 at the restored site, 8 at the original mudflat and 1 at the remains of the original marsh. For the bird counts the area was divided in sections around these transects.

Figure 4. Overview different zones and monitoring locations: sedimentation-erosionplots (red triangles) and vegetation PQ (yellow blocks). Orthophoto January 2009. (Speybroeck et al. 2011)

1.3 Monitoring results

1.3.1 Geomorphological changes

(1) Sedimentation-erosion

Sedimentation-erosion processes are very local specific since the combination of the shape index, the presence of peat layers and the very varied topography of the site along its length resulted in varied exposure and resistance to wave action (tidal, wind and from ships) across the site. Detailed graphs with elevation profiles and sedimentation/erosion results per transect can be found in attachment A.
In general, sedimentation and erosion processes strongly vary in the study area (Table 2), as well in the different zones of the area (Figure 5). Net sedimentation and erosion both varied between 0 and 30cm in the first year after restoration (Van den Bergh 2005) and between 0 and 15cm per year between November 2003 and August 2005 (Van den Bergh 2005).
Minimal changes were noticed at the supratidal stations Kpf1 and Kpe1. The more exposed intertidal stations clearly eroded (Kpa1, Kpb2, Kpc2, Kpd4 and Kpe5). The lower and sheltered stations (Kpd1-3 and Kpe2-4) showed a clear net sedimentation; at these stations some depressions filled up relatively quickly. Sedimentation and erosion generally occurred gradually, however some ‘sudden’ net erosion of more than 10cm between two consecutive measurements was observed in the very low and exposed sampling stations (Van den Bergh

2005). The top of the cliff (site G) moved land inwards as a consequence of erosion (Figure 6), already up to 2m in less than 6 months (Van den Bergh 2005).

Based on the sedimentation-erosion measurements in the different zones and some geomorphological variables, relations were studied. But a causal relation was only observed between the percentage of slope grade of the mudflat and the intensity of sedimentation/erosion (Van den Neucker et al. 2007, Speybroeck et al. 2011). Sedimentation shifts to erosion from a slope grade of 2.5% or more (Van den Neucker et al. 2007). Indeed, zone ABC and G are characterised by a steep slope by the construction work (Table 1) and globally under influence of erosion (Table 2). In zone DEF erosion is mainly restricted to the shoreline (Figure 5).

Table 2. Sedimentation and erosion per zone per year (cm/y, data November 2003 – August 2005) and the effect on the relative flood frequency (Van den Neucker et al. 2007)

Zone	Erosion - sedimentation (cm/y)	Change in relative flood frequency (%)
LHT	+5	?
ABC	-6	From 92% to 94%
D	+15	From 99% to 96%
E	+6	From 68% to 63%
F	-2	From 70% to 72%
G	-7	From 98% to 100%

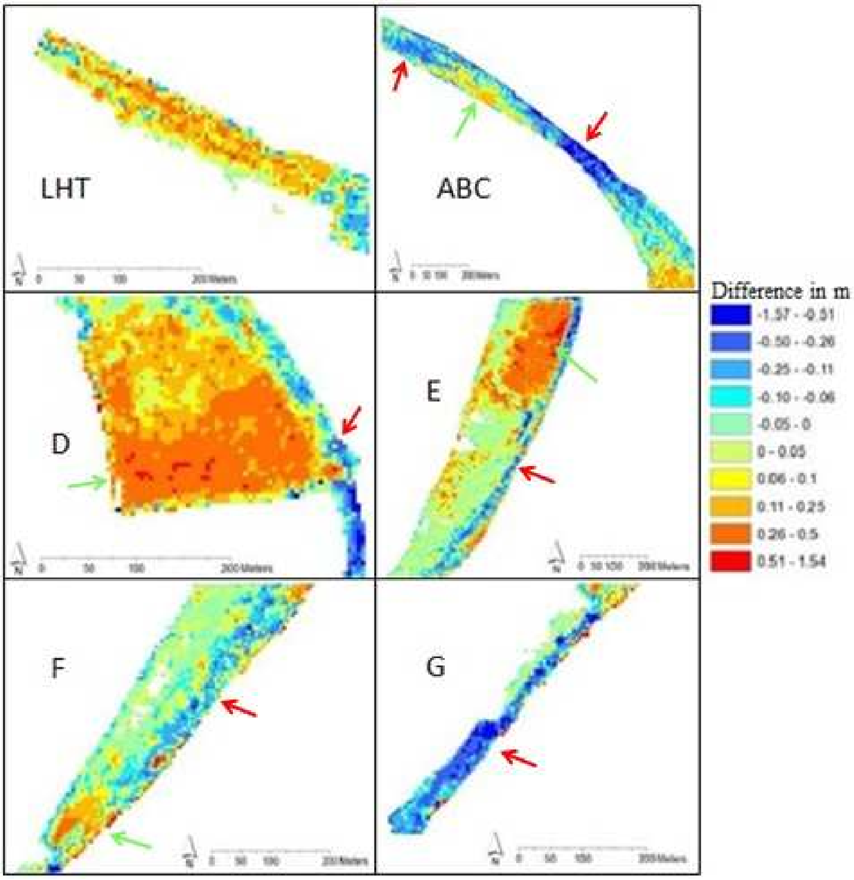


Figure 5. Difference map for all zones based on Digital Elevation Maps, November 2003 - August 2005. Green arrows indicate zones of sedimentation and red arrows erosion (Van den Neucker et al. 2007).

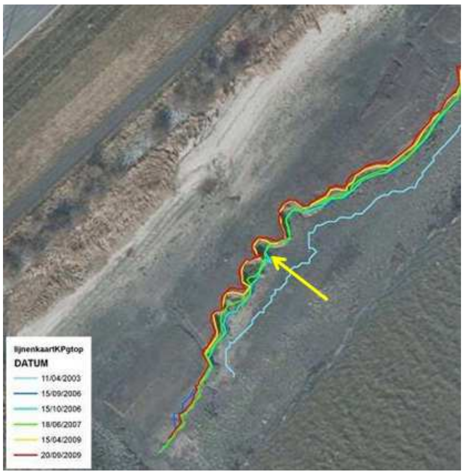


Figure 6. Evolution of the top of the cliff at zone G, 2003-2009 (Speybroeck et al. 2011).

(2) Creek network system

The creek network is important for wetland development because they arrange water supply and drainage, for the supply of seeds and also as habitat for organisms like crustaceans (*Crustacea*), fish and other (Van den Neucker et al. 2007). The onset for a creek network system established relatively quickly in the wider and sheltered D and E sections of the Ketenisse marsh where sedimentation was observed (Van den Bergh 2005, Van den Neucker et al. 2007). In zone F the creek network system established moderately and in ABC it established badly (Figure 7 & Figure 8). Once established the main channels did not alter their position very much but the sinuosity seemed to increase very gradually (Van den Bergh 2005). Between 2003 and 2005 the density (m/ha) decreased in zone DEF but not in ABC (Figure 8).

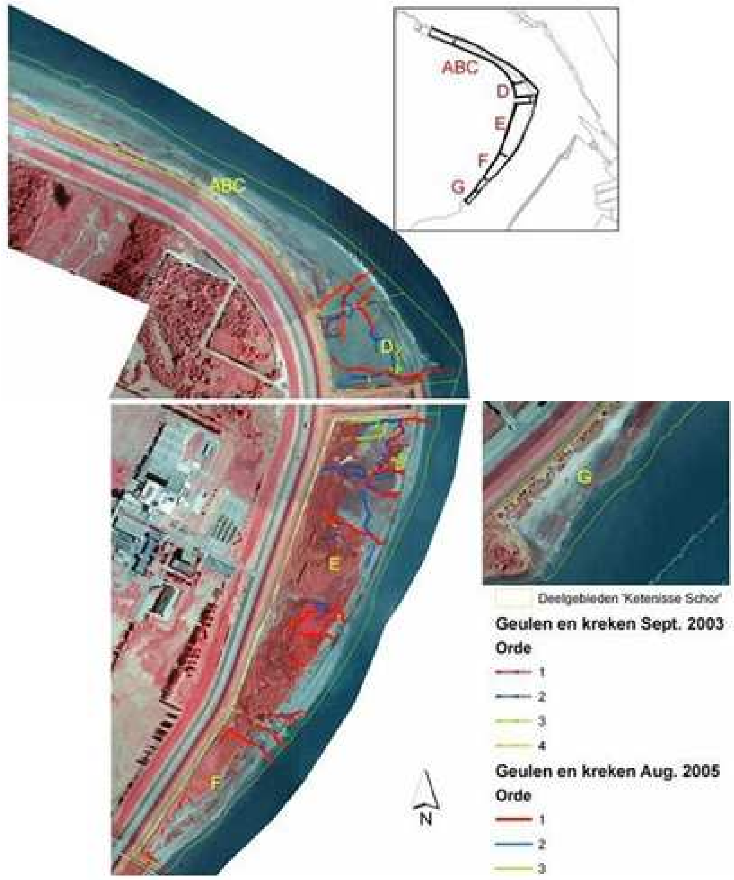


Figure 7. Overview of channels and creeks at Ketenisse marsh (Van den Neucker et al. 2007).

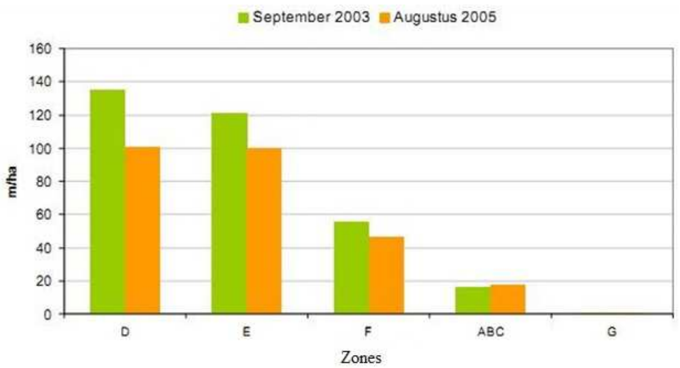


Figure 8. Evolution of channels and creek density (m/ha) within the zones of the Ketenisse marsh (Van den Neucker et al. 2007).

Two relationships were observed at the Ketenisse marsh: an exponential decreasing relation between channel- and creek density and slope; and a linear increasing relation between channel density and the average width of the area (Figure 9). So besides an opportune slope, also sufficient space is necessary for channel and creek development (Van den Neucker et al. 2007). Zone D and E are the most width zones of the study area and have also the most channel and creek development (D: 255.2m; E: 280.6m). Zone F has an average width of 153.8m, while zone ABC is a long small zone with an average width of 75.7m.

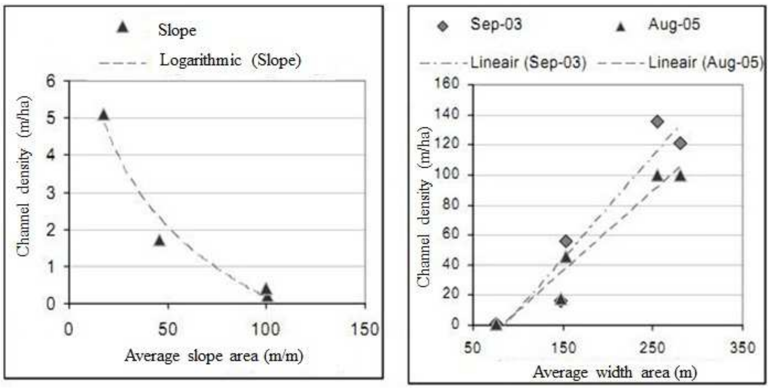


Figure 9. Relationship between de average slope (a) and width (b) of the area and the channel density in the zones of the Ketenisse marsh (Van den Neucker et al. 2007).

1.3.2 Sediment characteristics

(1) Median grain size and organic carbon content

Median grain size (MGS) showed large variation and organic carbon content of the sediment varied between 0.5 and 15% and was closely related to sediment median grain size (Van den Bergh 2005). The more sheltered stations along the D and E transects with the highest net sedimentation rates were also the muddiest, with a lower MGS (fine sediment) (Figure 10). At the F stations, which were not levelled merely because of the high mud content, MGS was also relatively low (fine sediment). The erosive sampling stations were generally sandier. Along the narrow upstream part (at section ABC) MGS increases with elevation. Sediment composition along the B transect showed large variations, changing from fine to rather sandy sediments in a few weeks' time. These changes were probably related to occasional dredging activities on the nearby 'plaat van Lillo'. A close relationship was found between MGS and organic matter content of the sediment. No relationship was found between mean %OM and net sedimentation/erosion over the first year (Van den Bergh 2005). Differences in organic matter content between the upper (0-1cm) and lower layer (0-10cm) are small, i.e. small difference between new and old sediment.

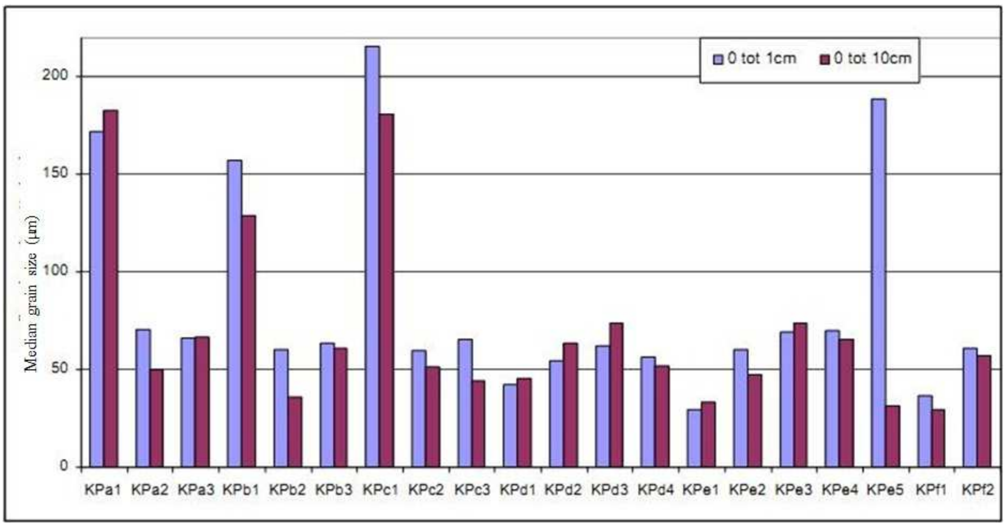


Figure 10. Sediment: median grain size per location, in µm, autumn 2009 (Speybroeck et al. 2011).

(2) Sediment quality

At Ketenisse marsh some strong and extreme contaminated sites were observed (Figure 11), mainly due to high concentrations of mercury and cadmium (Speybroeck et al. 2011). The most contaminated sites are KPd4, KPf1 and (some less frequent) KPe5, while at KPb3 only one global score was strongly contaminated. Those sites are randomly spread over the area, but except for one (KPf1) it are all low intertidal locations. In all four sites the contamination is historical. Erosion at those sites would increase the pollution concentrations.

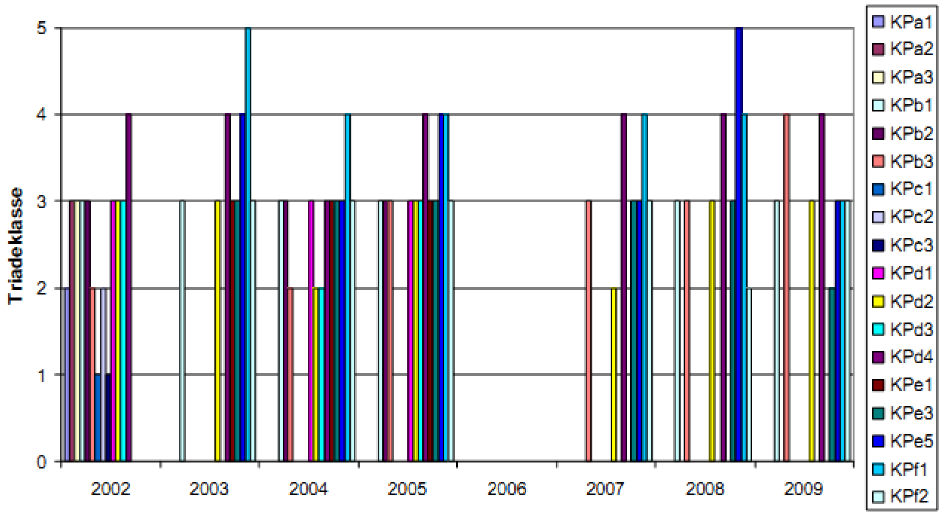


Figure 11. Global Triade score in function of the time (Speybroeck et al. 2011).

1.3.3 Benthos

(1) Microphytobenthos

Microphytobenthos is known to play an important role in the stabilisation of intertidal sediments (Stal 2003, Van den Bergh 2005) and gives an indication for benthic primary production (Van den Neucker et al. 2007). At the Ketenisse marsh it was only measured in the first year after the restoration of the area. Chlorophyll a concentrations varied between 0.3 and 118µg.g sediment dry weight-1 with the highest values found on sections D and E (Van den Bergh 2005). They were comparable concentrations found on Groot Buitenschoor, a mudflat situated nearby (Van den Bergh 2005). The highest concentration chlorophyll a was observed during spring and summer (Van den Bergh 2005, Van den Neucker et al. 2007), but the moment of maximum chlorophyll production was not similar for every location (Figure 12). This is in agreement with previous studies in the Scheldt Estuary (De Jong and De Jonge 1995, Van den Bergh 2005).

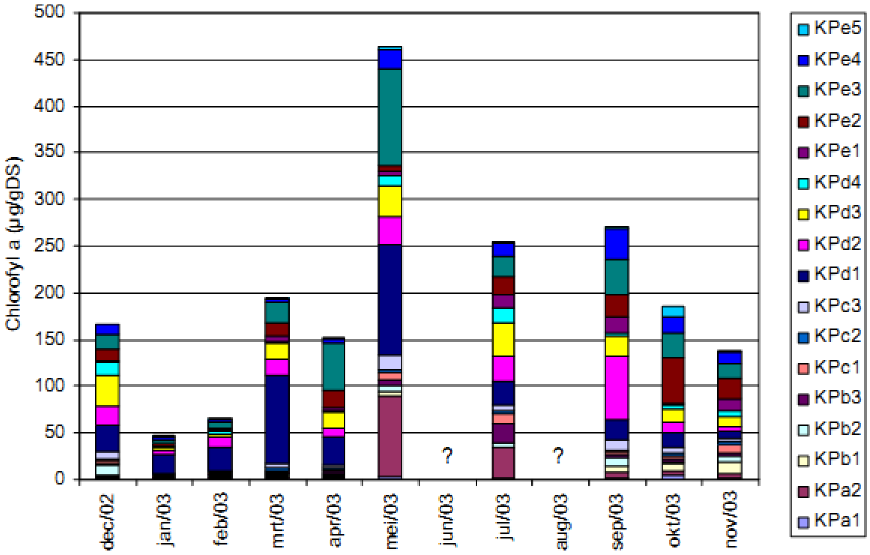


Figure 12. Chlorophyll a concentrations in the upper soil layer (0-1cm) per location at the Ketenisse marsh in the first year after the restoration work (?: no measurement) (Van den Neucker et al. 2007).

The highest concentration chlorophyll a was observed in finer sediments (Van den Bergh 2005, Van den Neucker et al. 2007) (Figure 13). Moreover, higher concentrations were also observed in sediment at high elevated areas (Van den Bergh 2005, Van den Neucker et al. 2007) (Figure 13). Although transects E and F were only levelled between November 2002 and January 2003, chlorophyll a concentrations were not significantly lower than in the other transects. This indicates that microphytobenthos populations can rapidly colonize newly constructed mudflats (Van den Bergh 2005). Finally, a close relationship was found between the chlorophyll a concentration in the upper soil layer (0-1cm) and sedimentation-erosion rates (Van den Bergh 2005) (Figure 13). Chlorophyll a concentration might therefore be a potential indicator for sedimentation and erosion in newly created marshes (Van den Bergh 2005).

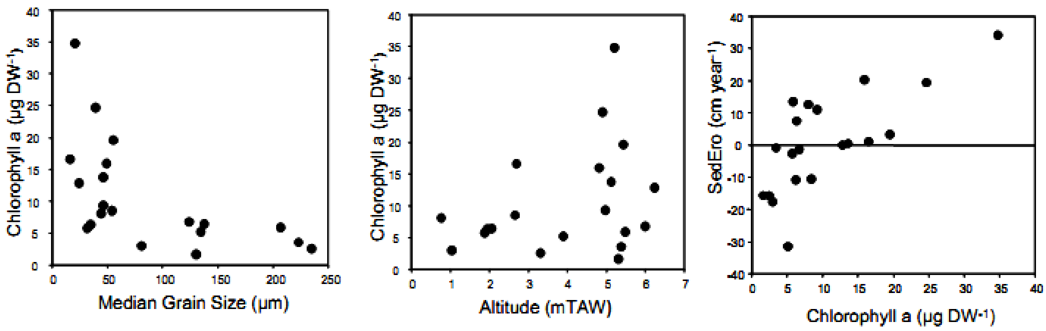


Figure 13. Relation between annual average chlorophyll a concentration and sediment median grain size, position above mean low water level and net sedimentation-erosion rates in 2003 (Van den Bergh 2005).

(2) Macrobenthos

During the entire monitoring period (2002-2009) benthos fauna was dominated by mud shrimp (44%, *Corophium volutator*) and earthworms (44%, *Oligochaeta*), followed by Common ragworm (9%, *Nereis diversicolor*) and *Dun Sentinel* (2%, *Assiminea grayana*) (Figure 14) (Speybroeck et al. 2011). Other species represented only 1% of the benthic fauna.

However, in biomass Oligochaeta are less important. Biomass is dominated by Common ragworm and to a lesser extent by mud shrimp and the more marsh related *Dun Sentinel* (Figure 14) (Speybroeck et al. 2011).

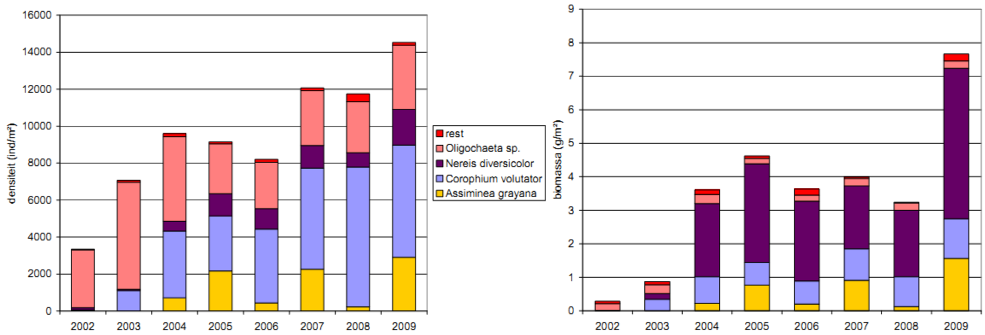
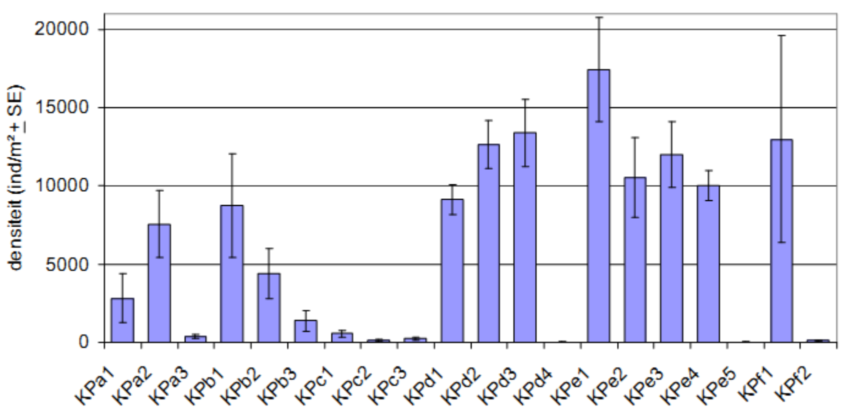


Figure 14. Average density (left) and average biomass (right) per specie and per year (Speybroeck et al. 2011).

The different transects and sample locations differ clearly in density and biomass (Figure 15) (Speybroeck et al. 2011). The benthos density in the higher elevated locations of KPa and b are lower than at KPd and e, but the difference is clearer for biomass. Transect C is poor for all benthos aspects (diversity, density, biomass). Whereas the steeper KPf transect has low benthos density and –biomass, the flatter parts of KPd and KPe are rich in benthos and offer more fouraging potential for birds. At every transect the lower values are observed at the low locations (KPa3, KPb3, KPc3, KPd4, KPe5, KPf2). This corresponds with the general pattern of the Sea Scheldt where high(er) values were observed at the high and mean high intertidal locations, while the low values in the lower parts of the intertidal are comparable with the values in the subtidal part (Speybroeck et al., unpublished data, in (Speybroeck et al. 2011)). Another explanation is that the low intertidal locations were more contaminated and are hence possibly toxic for macroinvertebrates (Speybroeck et al. 2011).
The average density and average biomass of macrobenthos was on the original mudflat much lower compared to the restored part (Van den Neucker et al. 2007). From these results it seems that erosion sensitive locations are characterised by poor benthos communities (Speybroeck et al. 2011). Also a higher slope, larger grain size and larger dynamisms seems to be characteristic for zones with poor benthos both in number of species as in individuals. These are also explanations (steep, erosion and large grain size) for the relatively low development of benthic fauna at the zone ABC (Figure 15), hence this zone was not successful to create an optimal starting situation for marsh development.



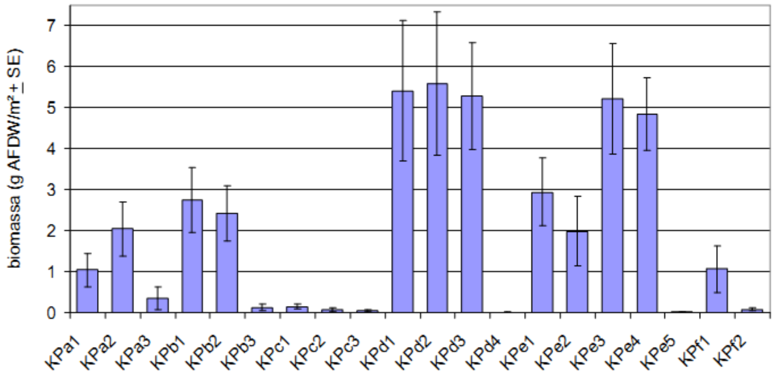


Figure 15. Density (up) and biomass (down) per location – overage over time 2002-2009 (vertical lines indicate the standard deviation) (Speybroeck et al. 2011).

(3) Oligochaeta

Total Oligochaeta fauna exist mainly of 6 taxa: *Paranais litoralis* (21%), *Enchytraeidae* (17%), *Lumbricillus lineatus* (17%), *Tubificoides heterochaetus* (17%), *Heterochaeta costata* (14%) and *Amphichaeta sannio* (12%) (Speybroeck et al. 2011). At the restored area, the number of taxa increased during the monitoring period (2002-2005) (Van den Neucker et al. 2007). The number of taxa at the original mudflat strongly fluctuated and at location KPf1, between remains of the original marsh, the number of taxa remained rather stable. At the original mudflat the density of oligochaeta was in general much smaller compared to the restored area (Van den Neucker et al. 2007). At the restored area *P. litoralis* was the most dominant taxa, while at the original mudflat *T. heterochaetus* was more abundant (Van den Neucker et al. 2007).

The presence of various Oligochaeta taxa can be linked with different habitat types (Speybroeck et al. 2011). *Enchytraeidae* is mainly observed in the higher zones with marsh development (eg. along transects E and F). *Tubificiodes heterochaetus* is almost not observed in marshes but mainly at lower muddy locations. *Heterochaeta costata* is also not observed in marshes but also not at lower sandy locations. This taxa is mainly observed in good developed mudflat without vegetation. Also *Amphichaeta sannio* seems to have similar habitat requirements.

1.3.4 Vegetation

Just like for benthos are the present morphologic processes responsible for the vegetation succession and colonisation: locations with sedimentation are characterised by progressive succession and locations with erosion by regressive succession (Speybroeck et al. 2011). In addition, the relative flood frequency determines possibilities for vegetation and fauna development. For Ketenisse this means that pioneerecotopes are located between 5m and 5.4mTAW and all zones above 5.4mTAW that are vegetated are marsh ecotopes.

Two vegetation maps of Ketenisse are presented (Figure 16). The most downstream zone (at transects ABC) is characterised by a steep slope (>2.8%) with consequently erosion and regressive succession (almost no marsh vegetation) (Speybroeck et al. 2011). Only at the higher parts, close to the dike, elevation occurs by Aeolian deposition (by the wind). As a consequence some vegetation is present close to the dike: Sea Aster (*Aster tripolium*), Sea clubrush (*Scirpus maritimus*), Sea Couch (*Elymus athericus*) or Common reed (*Phragmites australis*). Supratidal a plant community developed with Buck's-horn plantain (*Plantago coronopus*), Creeping bentgrass (*Agrostis stolonifera*), Celery (*Apium graveolens*), Sea-milkwort (*Glaux maritime*) and Sea aster as aspect determining species between which also

Sea hard-grass (*Parpholis strigosa*) can be found. Most part is however bare soil (wet sand, wet muddy sand, dry sand and water-saturated sediment) or covered with Vaucheria (*Vaucheria sp.*) or Microphytobenthos (MFB) (Figure 16).
In the zone upstream of the embanked polder (at transects DE and E) the slope is flat enough for sedimentation (<2.8%) and consequently progressive succession (marsh development) (Speybroeck et al. 2011). From East to West there is a gradient from low to high. At the lowest part the bare mudflat is colonised by Vaucheria (*Vaucheria sp.*), followed by Sea Aster (*Aster tripolium*) and Sea clubrush (*scirpus maritimus*) and in the end Common Reed (*Phragmites australis*) (Speybroeck et al. 2011).
The most upstream part (EF) is similar as zone ABC.

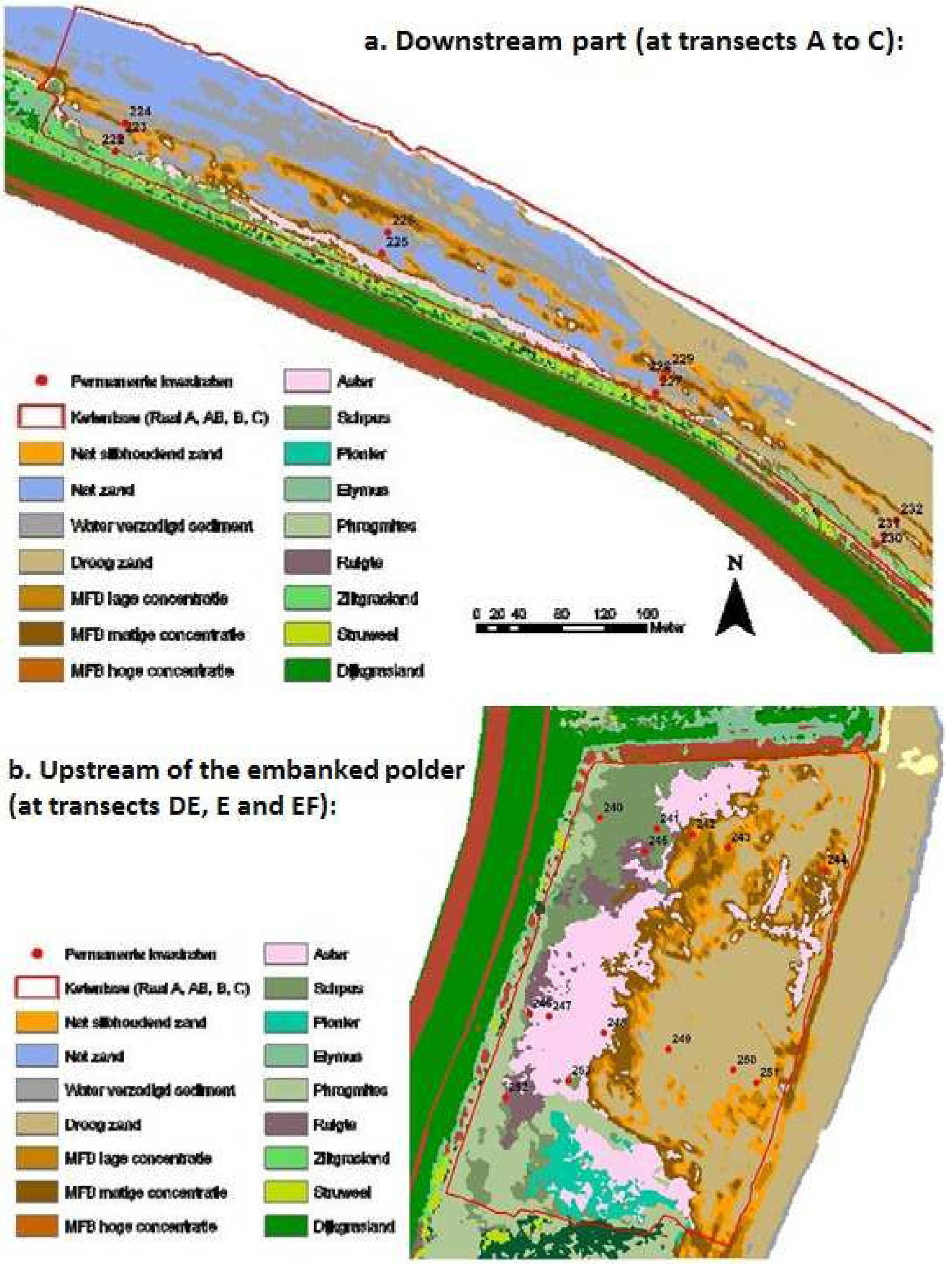


Figure 16. Vegetation map of the (a) downstream and (b) upstream part of Ketenisse, for 2007 (MFB: microphytobenthos) (Speybroeck et al. 2011).

1.3.5 Avifauna: water birds and breeding birds

(1) Water birds

In total 46 water bird species were observed on Ketenisse during the monitoring period November 2002 and December 2006 (Van den Neucker et al. 2007). Number of bird days was used as unit for the bird monitoring. The number of bird days varied between 2500 and 12750 per month (2002-2006) (

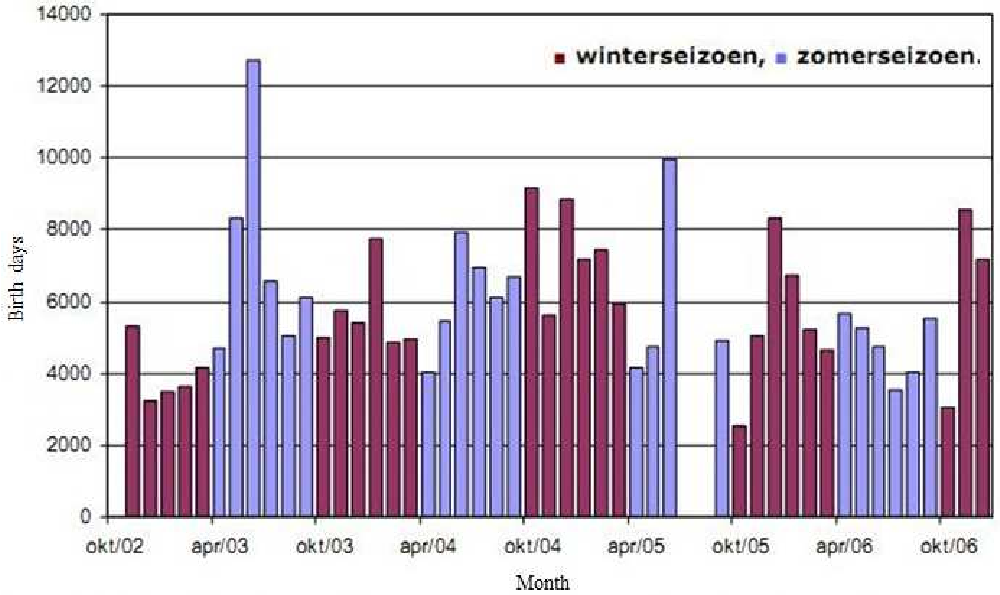


Figure 17) (Van den Neucker et al. 2007). The maximum of bird days was counted in June 2003 and June 2005, respectively due to the very high abundance of Common Shelduck and Lapwing (Van den Neucker et al. 2007). A positive trend was observed for the total number of bird days per season during the first three winter seasons (

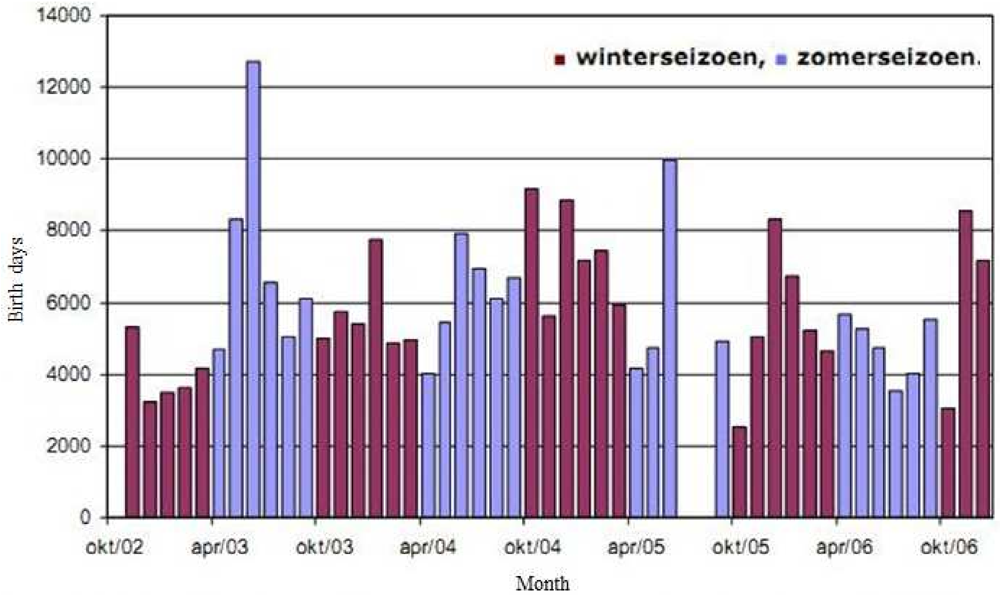


Figure 17).

The most numerous species were Common Shelduck (*Tadorna tadorna*), Greylag Goose (*Anser anser*), Pied Avocet (*Recurvirostra avosetta*) responsible for 31%, 18% and 9% of the total number of bird days and all of them are typical species for the mesohaline part of the estuary (Figure 18) (Van den Bergh 2005, Van den Neucker et al. 2007). On average, the largest number of birds was observed on the restored parts of zones D and E (KPd and KPe)

(Figure 19) (Van den Neucker et al. 2007). Common Shelduck and Pied Avocet (*Recurvirostra avosetta*) feed on the more sheltered, low dynamic mudflats in KPd and KPe and breed on their highest parts. Greylag Goose feed on the Scirpus maritimus vegetation in these sections and rest on the mudflats. Lapwing (*Vanellus vanellus*), Gadwall (*Anas strepera*) and the migrating waders are more common on the sandier sections (kpa, kpb, kpc, kpf en kpg). Curlew (*Numenius arquata*) was found in all sections (Van den Bergh 2005). Overall, geese are typical winter guests, Common Shelduck and Pied Avocet are especially abundant in summer.

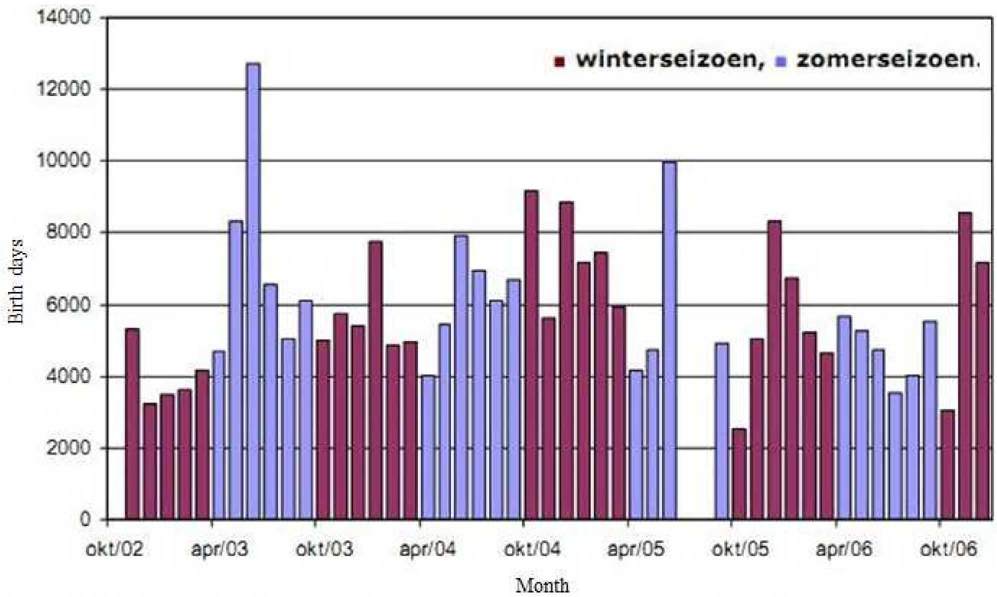


Figure 17. Total number of bird days per month on Ketenisse (November 2002 – December 2006), red bars: winter season, blue bars: summer season (Van den Neucker et al. 2007).

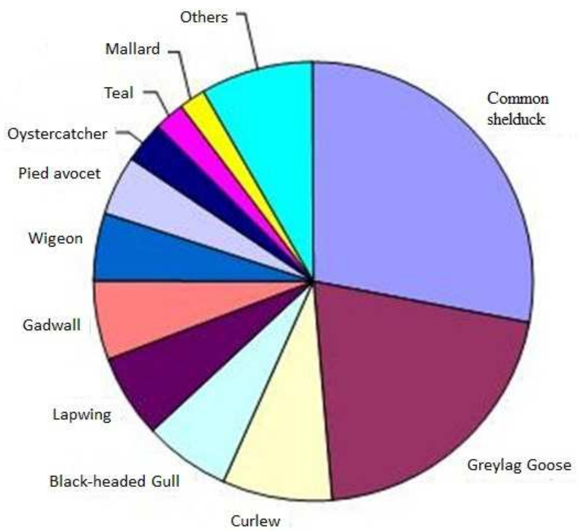


Figure 18. Relative abundance of species during the monitoring period (November 2002 – December 2006), based on number of bird days (Van den Neucker et al. 2007).

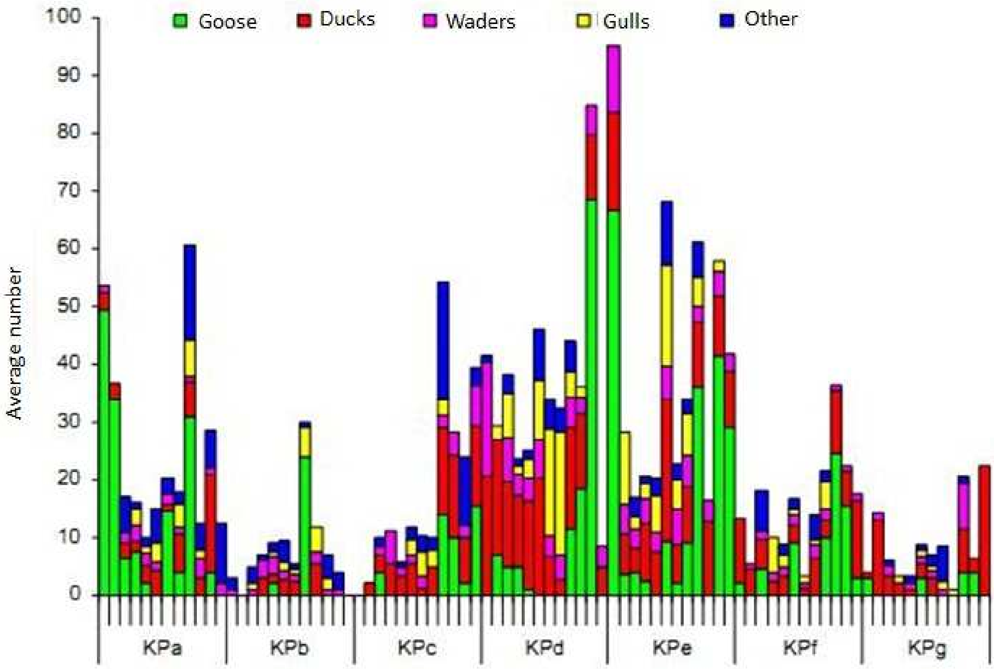


Figure 19. Average number per month for the different species groups on the restored part of Ketenisse, per zone (2003-2006) (Van den Neucker et al. 2007).

(2) Breeding birds

The most abundant breeding birds on Ketenisse are some typical species for marsh habitat, like Common Redshank (*Tringa tetanus*) and Common Shelduck (*Tadorna tadorna*) (Van den Neucker et al. 2007). The Reed vegetation seemed a good breeding habitat for Eurasian Reed Warbler (*Acrocephalus scirpaceus*), Reed Bunting (*Emberiza schoeniclus*) and Bluethroat (*Luscinia svecica*). The Sigmadike is also used for breeding by Meadow Pipit (*Anthus pratensis*), Eurasian Skylark (*Alauda arvensis*) and Little Ringed Plover (*Charadrius dubius*).

The expansion of reed vegetation in the southern part of Ketenisse had led to the immediate colonisation by species such as Reed Bunting, Bluethroat, Eurasian Reed Warbler and Marsh Warbler (*Acrocephalus palustris*). This fast colonisation was probably also catalysed by the habitat loss at the inner side of the Sigmadike along the Ketenisroad.

During the period 2004 to 2006 remarkably less numbers of waders were observed to breed on Ketenisse. For Pied Avocet (*Recurvirostra avosetta*) and Little Ringed Plover (*Charadrius dubius*) this was possibly due to the advanced succession stadium of marsh vegetation. Only on the grass strip (not embanked zone LHT in the north of Ketenisse) and in the little polder between zone D and E, the number of waders remained stable. The number of waders decreased as a consequence of the development of large Reedbeds, in particular in the southern part.

1.3.6 Fish

Fish was found both on the restored area and mudflat of Ketenisse (at transects KPe and KPd). During spring (March) it appeared that mainly European seabass (*Dicentrarchus labrax*) uses the habit situated higher in the tidal frame like marsh creeks and the excavated zones of the restored areas (Van den Neucker et al. 2007). The preliminary results indicate that the elevation of habitat is a determining factor for the relevance of the habitat for fish.

2 Execution of main effectiveness criteria

2.1 Effectiveness according to development targets of measure

Step 1: Definition of development target

The main target was to restore processes that lead to the development of a tidal wetland. Therefore the Ketenisse area was levelled in 2002 with a weak slope below mean high water level, creating the optimal starting conditions for the development of intertidal mudflats and marshes. After restoration (since the end of 2002) the area is again an intertidal flat habitat in the brackish part of the Scheldt that is flooded twice a day. And monitoring results of the first year suggest that Ketenisse polder has the potential to develop towards a varied and normal functional intertidal area (Van den Bergh 2005).

Step 2: Degree of target achievement

However, based on wider monitoring results (Gyselings et al. 2004, Van den Bergh 2005, Gyselings et al. 2006, Van den Neucker et al. 2007, Speybroeck et al. 2011) we conclude that the degree of target achievement is **rather medium**. The slopes at the extreme ends of the site are too steep and net erosion takes place. In the central part two aspects of the final design differed significantly from the original plan. Some areas, where the topsoil was not useful as construction material for dikes, were not excavated below mean high water level and remained almost supratidal. The old dike was not removed according to plan and as a result almost flat plateaus, with a steep slope towards the river were constructed instead of a gentle overall slope from the dike to the river. This had consequences for the habitat functions of the site. At T0 higher vegetation was already in place, supratidal as well as tidal marsh vegetation. Some of it died off; in other places it remained and served as source for typical fauna and flora. The plateaus now provide low dynamic habitat. They silted up and a relatively rich macro-benthic invertebrate community was built up, providing extra foraging and roosting time and space for birds.

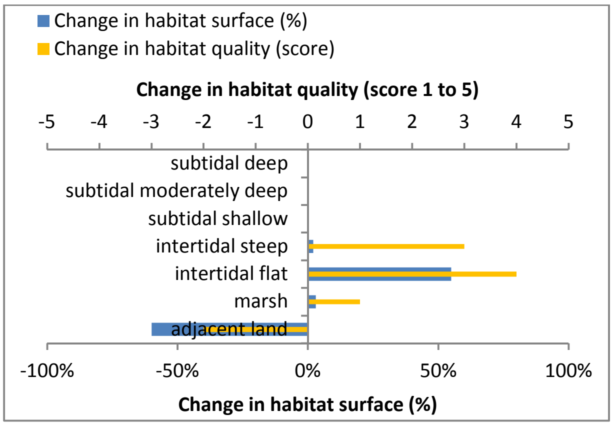
The differences in the starting conditions were reflected in the differences in evolution across the site (Van den Bergh 2005). On the sheltered and wider Kpd and Kpe sections in general net sedimentation was observed with sediments of low MGS, high OM content and chlorophyll a concentrations (Van den Bergh 2005). These areas also contain relative high macrobenthos densities and are selected by typical species such as Common Shelduck and Pied Avocet for foraging. The other, more dynamic sections also show erosion in some parts, generally have higher MGS, lower OM content, Chlorophyll a concentrations and macrobenthos densities (Van den Bergh 2005). They attract other bird species. Succession stages of tidal marsh vegetation were observed and most apparent on the sections with a weak slope.

2.2 Impact on ecosystem services

<u>Step 1</u>: Involved habitats

The measure Ketenisse wetland in the oligohaline zone of the Scheldt estuary was about the creation of intertidal habitat by transforming adjacent land into mainly intertidal flat habitat with a high change in the habitat quality.

Ketenisse is a former intertidal brackish marsh located in an industrial area. After restoration an open brackish tidal area of 60ha (of which 35.5 ha restored) was created along 4km of the river. In the more upstream part of the G section a steep cliff, with a height between 0.3 and 1.5m developed over a length of 100m (Figure 3) (Van den Bergh 2005, Van den Neucker et al. 2007). The cliff is under strong pressure of erosion and moves land inwards.



Score habitat quality
1 = very low quality
2 = low quality
3 = medium quality
4 = high quality
5 = very high quality

Figure 20. Ecosystem services analysis for Ketenisse wetland: Indication of habitat surface and quality change, i.e. situation before versus after measure implementation. The change in habitat quality, i.e. situation after the measure is implemented corrected for the situation before the measure, is '1' in case of a very low quality shift, and '5' in case of a very high quality shift.

<u>Step 2</u>: Expected impact on ecosystem services, compared with targeted ecosystem services, and expected impact on beneficiaries

More information about the methodology and the correct interpretation of the results could be found in the overall measures report (Saathoff et al. 2013).

(1) Overall expected impact on ES: From the ES assessment it is concluded that this measure generates overall a positive expected impact for many ES, mainly for "biodiversity", cultural service (Inspiration for culture, art and design), and regulating service (Erosion and sedimentation regulation (by water bodies)).

(2) Expected impact on targeted ES: The expected impact for the development target "biodiversity" is positive.

(3) Expected impact on beneficiaries: The expected impact for the different beneficiary groups is overall slightly positive, with a positive expected impact for future use.

Table 3. Ecosystem services analysis for Ketenisse wetland: (1) expected impact on ES supply in the measure site and (2) expected impact on different beneficiaries as a consequence of the measure

Ketenisse wetland - small scale tidal wetland restoration in the brackish part of the estuary

Cat.	Ecosystem Service	Score
S	"Biodiversity"	2
R1	Erosion and sedimentation regulation by water bodies	2
R2	Water quality regulation: reduction of excess loads coming from the catchment	1
R3	Water quality regulation: transport of polutants and excess nutriënts	0
R4	Water quantity regulation: drainage of river water	0
R5	Erosion and sedimentation regulation by biological mediation	1
R6	Water quantity regulation: transportation	0
R7	Water quantity regulation: landscape maintenance	1
R8	Climate regulation: Carbon sequestration and burial	1
R9	Water quantity regulation: dissipation of tidal and river energy	1
R10	Regulation extreme events or disturbance: Wave reduction	1
R11	Regulation extreme events or disturbance: Water current reduction	1
R12	Regulation extreme events or disturbance: Flood water storage	1
P1	Water for industrial use	0
P2	Water for navigation	0
P3	Food: Animals	0
C1	Aesthetic information	1
C2	Inspiration for culture, art and design	2
C3	Information for cognitive development	1
C4	Opportunities for recreation & tourism	1

Beneficiaries:	
Direct users	0
Indirect users	1
Future users	2
Local users	1
Regional users	1
Global users	1

X Targeted ES

Legend: expected impact*	
3	very positive
2	positive
1	slightly positive
0	neutral
-1	slightly negative
-2	negative
-3	very negative

*: Indicative screening based on ES-supply surveys and estimated impact of measures on habitat quality and quantity. Quantitative socio-economic conclusions require local supply and demand data to complement this assessment.

2.3 Degree of synergistic effects and conflicts according to uses

Ketenisse is a nice example to combine nature development and the creation of recreation possibilities. The governmental department for nature in Flanders considers the creation of stairs over the dike for watching birds behind a transparent wall, combined with information panels. Ketenisse is also favorable for cyclers with a nice cycle pad along the flowery Scheldt dike. On the north side (in the direction of Liefkenshoek, along sections LHT and ABC) this cycle pad is however not finished. At the downstream part (Fort Liefkenshoek) there is a tower with a nice view and a pub. This cycle route is also planned to be integrated in the Ecological InfraStructure cycle route (EIS-cycle rout) in the harbor area. The initiative to open the local service road is linked to the project ‘the Antwerp harbor more environmental friendly’. However, some actors are not in favor to open this road for cyclers because that would disturb the resting and foraging birds on the small mudflat area.

The polder can be visited during educative excursions (eg. bird watching day) by the environmental association (Natuurpunt-WAL).

3 Additional evaluation criteria in view of EU environmental law

3.1 Degree of synergistic effects and conflicts according to WFD aims

The restoration of an intertidal wetland can attribute to 4 main pressures in the mesohaline zone of the Scheldt. However, Ketenisse is only a small scale pilot project (60 ha). The real effect of Ketenisse to the Scheldt estuary is hence minimal. The real objective of Ketenisse was also the research aspect. Small scale projects were studied to learn more about the creation of an optimal starting condition for the development of valuable intertidal wetlands.

Indicator Group	Code	Main pressures **mesohaline** zone Scheldt	Effect?					Description
			- -	-	0	+	++	
S.I.	1.1	Habitat loss and degradation during the last about 100 years: Intertidal					x	A former intertidal brackish marsh located in an industrial area is expanded by management realignment.
S.I.	1.5	Gross change of the hydrographic regime during the last about 100 years					X	At larger scale, a intertidal wetland can contribute to the hydrographic regime of the estuary (eg. water storage capacity and safety function)
S.I.	3.1/3.2	Decrease of water and sediment chemical quality			X			The sediment at Ketenisse was already highly contaminated and hence improving the quality is difficult.
D.I.	1.3	Land claim during the last about 100 years					X	A former intertidal brackish marsh located in an industrial area is expanded by management realignment.
D.I.	1.7	Relative Sea Level Rise					X	Adjacent land is given back to the estuary. A larger estuary is more dynamic to manage extreme events and disturbances.
D.I.	2.12	Port developments			X			

S.I. = state indicator; D.I. = driver indicator

3.2 Degree of synergistic effects and conflicts according to Natura 2000 aims

Intertidal wetlands are important under the habitat directive for estuaries. More specifically, brackish marshes are rare and in Europe only in the mouth of the Elbe and Western Scheldt. The creation of a brackish intertidal wetland in the Sea Scheldt is hence of high value related to habitat diversity.

Management realignment offers a possibility to enlarge the estuary and create valuable intertidal wetlands.

Ketenisse is muddy and very attractive for bird species. Nine common water birds on Ketenisse are on bird directive's list for protected bird species.

Conservation objectives (Sea scheldt)	Specification	Effect?					Short explanation
		- -	-	0	+	++	
Protected habitats: Coast and brackish habitats	Atlantic marshes (HD, code 1330)				X		Newly created intertidal wetland in the protected area BE2300006, and quality improvement for this type of habitat.
Protected birds	Acrocephalus paludicola			X			Not observed
	Anas acuta			X			Not observed
	Anas clypeata			X			Not observed
	Anas crecca (Eurasian Teal)					X	Common water bird on Ketenisse
	Anas Penelope (Eurasian Wigeon)					X	Common water bird on Ketenisse
	Anas strepera (Gadwall)					X	Common water bird on Ketenisse
	Anser albifrons			X			Not observed
	Anser anser (Greylag Goose)					X	Common water bird on Ketenisse
	Anser brachyrhynchus			X			Not observed
	Anser fabalis			X			Not observed
	Arenaria interpres			X			Not observed
	Recurvirostra avosetta (Pied Avocet)					X	Common water bird on Ketenisse
	Aythya ferina			X			Not observed
	Aythya fuligula			X			Not observed
	circus cyaneus			X			Not observed
	Circus bewickii			X			Not observed
	Egretta alba			X			Not observed
	Larus argentatus (European Herring Gull)					X	Common water bird on Ketenisse
	Larus canus			X			Not observed
	Larus ridibundus (Black-headed Gull)					X	Common water bird on Ketenisse
	Numenius arquata (Curlew)					X	Common water bird on Ketenisse
	Numenius phaeopus			X			Not observed
	Philomachus pugnax			X			Not observed
	Platalaea leucorodia			X			Not observed
	Pluvialis apricaria			X			Not observed
	Tadorna tadorna (Common Shelduck)					X	Common water bird on Ketenisse

4 Crux of the matter

The creation of new ecological valuable intertidal wetlands can contribute to estuarine restoration as it enables habitat development and biodiversity. Success factors are related to the improvement of estuarine processes (such as sedimentation-erosion, creek formation and soil development).

Ketenisse was however not a complete success. The steeper parts of the site showed net erosion and seemed less functional as habitat. If the central slope would have been excavated according to plan sedimentation/erosion and habitat development would have been quite different (Van den Neucker et al. 2007). There would have been relatively less mudflat with a long exposure time. On the other hand, habitat diversity and gradual transitions might have been more elaborate.

The applied monitoring scheme seems to be adequate to monitor the developments on the new site, even though it is rather labour-intensive (Van den Bergh 2005). Developments on levelled sites start shortly after the end of the works, therefore it is important to monitor intensively in the early stages. The monitoring frequency is evaluated yearly and, if necessary, adjusted to the developments on the site (Van den Bergh 2005).

Knowledge gaps are related to the contribution of the different variables that contribute to the changes in elevation, and taking into account the impact of local estuarine characteristics such as sediment balance and wave impact.

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