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Tidal wetland restoration at Ketenisse polder (Schelde Estuary, Belgium): developments in the first year

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Abstract

Ketenisse polder is a former intertidal brackish marsh (30ha) situated in the mesohaline part of the Schelde Estuary. In the 19th century its central part was embanked as a polder. In the mid 1980's the area was raised above intertidal level when it was used as a dumping site for the excavated soil from the Liefkenshoek tunnel. In 2002 the area was restored, it was levelled with a weak slope below mean high water level, creating the optimal starting conditions for the development of intertidal mudflats and marshes. Geomorphological changes, sediment characteristics and colonisation by phytobenthos, vegetation, zoobenthos, water birds and breeding birds at the restored site are monitored. The monitoring results of the first year after tidal restoration are presented. Sedimentation as well as erosion between 0 and 30cm was observed in the first year. Local changes in stream current patterns caused erosion on parts of the former mudflats; sheltered depressions filled up relatively fast. Median grain size showed large variation. Organic carbon content of the sediment varied between 0.5 and 15% and was closely related to sediment medium grain size. Chlorophyll a concentrations were negatively correlated with median grain size and tended to increase from the low water line to the shore. They were comparable to nearby intertidal areas and displayed similar seasonal variability with a maximum in spring. The large surface covered wtith *Vaucheria* was indicator of initiated succession towards tidal marsh. *Scirpus maritimus* and transitional vegetations to *Chenopodiaceae*-vegetations established with increasing altitude. The *Chenopodiaceae*-vegetations were relicts of earlier vegetations before the tidal restoration, and will probably disappear. The macrobenthos community was dominated by Oligochaetes, which were present in 73% of all samples and attained an average density of about $40*10^3$ ind. m^{-2}. Other macrobenthos species found were nematods, copepods and Corophium. On the sheltered sampling stations macrobenthic densities were high compared to those on nearby intertidal areas. In the first season, 15 breeding bird species were recorded, the most common species being the Pied Avocet (*Recurvirostra avosetta*). The most common waterbirds were Common Shelduck *(Tadorna tadorna)*, Greylag Goose (*Anser anser*), Pied Avocet (*Recurvirostra avosetta*) and Lapwing (*Vanellus vanellus*), typical species for the mesohaline part of the estuary.

The first year's results suggest that Ketenisse polder has the potential to develop towards a varied and normal functional intertidal area.

Keywords: Tidal wetland restoration; Ketenisse polder; Monitoring results; Schelde Estuary; Belgium.

Introduction

Reclamation of intertidal habitat has been a major feature of coastal management for the past 500 years. Growing awareness of the ecological and economic damage caused by this large scale habitat destruction and the general concern about possible consequences of sea level rise have led to the recognition of the need to alleviate some of this damage. The concept of habitat creation and restoration was conceived in the USA some decades ago. More recently it was also adopted in the other continents. Initially the main incentive for tidal wetland restoration was compensation for habitat loss elsewhere. However, with the growing appreciation of tidal wetland functions, new imperatives have developed with a wider range of objectives, including coastal defence, flood alleviation, water quality improvement, fisheries production, groundwater recharge and tourism and recreation. Due to the relatively recent interest in habitat creation, few evaluations have been made of the long-term outcome of schemes, particularly with regard to the ecological value of the newly created habitat.

Tidal restoration is a radical estuarine restoration measure; prior to large-scale execution its effects should be estimated within an acceptable range of accuracy. Multidisciplinary monitoring of small scale projects can help to identify key forcing factors and to infer general patterns in processes after tidal restoration. In this paper the first year monitoring results of a 30ha tidal restoration project are presented.

The study area

Ketenisse polder is a former intertidal brackish marsh (30ha) situated in the mesohaline ($3g\ Chl.l^{-1}$) part of the Schelde Estuary. Mean tidal amplitude in this part of the estuary is about 5.1m, between 0.04 and 5.14 mTAW (Belgian ordnance level). The site borders a bent in the river and has the shape of a boomerang. In the 19^{th} century its central part was embanked as a polder. In the mid 1980's the area around this central polder was raised above intertidal level when it was used as a dumping site for the excavated soil from the Liefkenshoek tunnel. The marsh was restored in 2002 as compensation for the construction of the North Sea container terminal on an intertidal mudflat near an internationally protected site (Ramsar, Birds and Habitats directive). 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. However, removed soil was to be used for dike construction works and only suitable construction material was taken and the dike was not completely smoothened. As a result the starting slope and level in the tidal frame differed along the site, leaving supratidal vegetated parts, lower bare mud and a rather steep slope along the summer dike remnants (Fig. 1; Table I). For safety reasons the most upstream part near the Liefkenshoektunnel (LHT) was left at its supratidal level.

Sections a, b, c and g were levelled according to the plan except for some hard exposed peat layers, which also created a differentiated resistance to wave action along the slope. The central polder (section d) was left at its original level, almost 1m below MHW; the summer dike around it was only partly removed and breached, leaving a relatively sheltered intertidal area. Its upstream part contained some pipelines and was defended by surrounding dikes (Fig. 1; polder). Section e, the widest part, was levelled to almost 0.5m below MHW; a greater part of section f, remained untouched and supratidal.

Geomorphological changes, sediment characteristics and colonisation by phytobenthos, vegetation, zoobenthos, water birds and breeding birds at the restored site are monitored in a multidisciplinary project. Monitoring of all aspects is done near 20 sampling stations along 6 transects perpendicular to the shoreline (Fig. 1a: in a given transect sampling station numbers increase from the dike towards the river). These stations were established and referenced gradually as the works proceeded in a downstream-upstream-direction (Table I). For the bird counts the area was divided in sections around these transects (Fig. 1b). The first year's results are summarised in Table I.

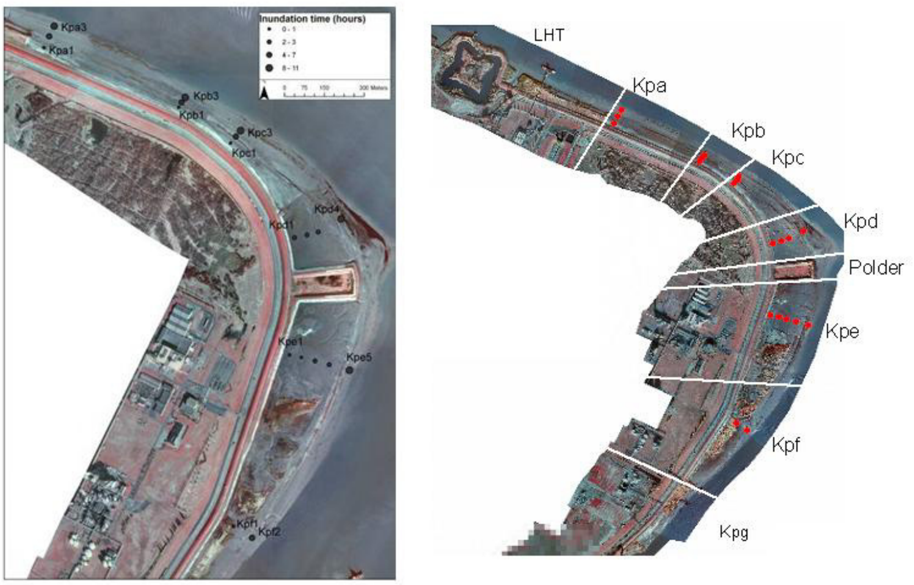

Fig. 1a. The study area in November 2003, with indication of the sampling stations along the six transects and the inundation time; b. the bird count sections.

Table I. Abiotic and biotic characterization of the sampling stations (2002-2003): date of completion, initial altitude, net sedimentation/erosion, 25 and 75% medium grain size (MGS), 25 and 75% organic matter % of sediment (OM%), chlorophyll a mean annual and maximum concentrations (g/g dry weight), Vegetation type: (1) Pioneer vegetation of *Enteromorpha* sp., (2) Pioneer vegetation of *Vaucheria* sp.-*Enteromorpha* sp., (3) Pioneer vegetation of *Vaucheria* sp., (4) *Vaucheria-Scirpus maritimus* vegetation (5), *Phragmites australis* vegetation, / no vegetation, ? unknown vegetation; total number of benthic organisms in samples and Oligochaeta densities (ind.m-²; 2002 and 2003)

	Com pletion dates	Altitude (mTAW)	Inun-dation time	Net sed/eros (cm)	MGS (µm) (25%-75%)	% OM (25%-75%)	Chla (µg.gDW^{-1}) Mean (Max)	Vegetation types Aug(2003)	Benthos Oct2002 #spec	Benthos Oct2003 #spec	Oligochaeta Oct2002 ind.m^{-2}	Oligochaeta Oct2003 ind.m^{-2}
Kpa1	June 02	5.07	1	-15.82	190 - 272	0.86 – 1.50	1.71 (4.49)	2	13	23	981	17,658
Kpa2	June 02	2.51	6	1	32 - 60	2.65 – 5.30	16.61 (98.86)	/	149	134	418,887	299,205
Kpa3	June 02	0.52	11	12.46	37 -51	4.16 – 6.66	8.08 (19.09)	/	19	11	62,784	54,936
KPb1	Aug 02	4.90	1	-0.9	166 - 281	0.99 – 1.90	3.48 (12.74)	?	1	79	6,867	981
KPb2	Aug 02	3.40	5	-31.53	63 - 206	1.02 – 3.19	5.20 (19.91)	3	2	139	6,867	11,722
KPb3	Aug 02	1.32	9	7.37	56 - 220	2.14 – 2.84	6.41 (22.16)	/	37	19	202,086	56,898
KPc1	Aug 02	5.15	0	13.28	168 - 246	1.17 – 1.86	5.91 (12.22)	1	0	58	3,924	981
KPc2	Aug 02	2.92	6	-15.73	191 - 279	0.95 – 1.50	2.47 (4.19)	3	3	8	1,962	0
KPc3	Aug 02	1.31	9	-2.85	25 - 38	7.40 – 9.50	5.76 (17.72)	/	2	12	2,943	30,411
KPd1	June 02	?	2	33.95	16 - 25	8.91 – 12.65	34.81 (93.85)	/	177	239	235,440	513,063
KPd2	June 02	4.59	3	0.35	38 - 54	4.01 – 6.17	13.72 (30.23)	3	214	306	186,390	134,397
KPd3	June 02	4.30	3	20.11	36 - 62	3.97 – 6.23	16.03 (41.48)	3	138	132	118,701	537,588
KPd4	June 02	1.72	9	-10.9	25 - 45	7..37 – 10.58	6.25 (17.94)	/	0	5	1,962	10,791
KPe1	Nov 02	5.40	0	-1.52	117 - 131	1.81 – 2.39	6.75 (15.04)	4		2		3,924
KPe2	Nov 02	4.94	1	3.19	40 - 71	2.95 – 6.00	19.64 (55.76)	3		28		44,145
KPe3	Nov 02	4.52	2	19.23	27 - 52	4.88 – 6.25	24.71 (57.91)	3		93		324,711
KPe4	Nov 02	4.60	2	11	38 - 54	3.31 – 5.80	9.25 (19.29)	/		64		239,364
KPe5	Nov 02	0.60	11	-17.65	57 - 105	2.78 – 5.15	2.95 (13.51)	/		0		0
KPf1	Jan 03	5.42	0	0	19 - 30	10.78 – 13.11	12.87 (27.50)	5		23		11,772
KPf2	Jan 03	2.22	7	-10.62	40 - 69	3.60 – 6.29	8.54 (10.07)	/		6		6,867

Geomorphological changes

When the works where finished (January 2003) a topographic levee of the situation at that moment was made by means of a total station, with a cover of 12 points per hectare. Full topographic levees by means of aerial photography and laser altimetry were taken after 8 months and 11 months. Elevation changes along transects were monitored with seasonal topographic levees every 10m. At each sampling station sedimentation-erosion was measured every fortnight in sedimentation-erosion plots. In each plot three level metal tubes are anchored in the mudflat in an equilateral triangle of 1.5m. The tubes are connected by a measuring rule and the distance between the rule and the mudflat is measured every 20cm.

Sedimentation-erosion processes

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 and consequently in very local specific sedimentation-erosion processes. Net sedimentation and erosion both varied between 0 and 30cm in the first year after restoration; both processes were also observed along each transect. 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.

Topographical changes

The onset for a creek network system established relatively quickly in the wider and sheltered d and e sections where sedimentation was observed. Once established the main channels did not alter their position very much but the sinuosity seemed to increase very gradually. This process, together with the formation of smaller channels and the transition from sedimentation to erosion channels will eventually become apparent in the coming years as they were observed by French (1996) in some UK abandoned reclamations and in several US tidal wetland restoration projects (van Oevelen *et al.*, 2000).

Due to the levelling of the site stream current patterns along the area changed. As a result Kpd4 and Kpe5, sampling stations on previously rather stable mudflats started to erode.

In the more upstream g section a steep cliff, with a height between 0.3 and 1.5m developed over a length of 100m. In less than 6 months it eroded up to 2m landwards.

Sediment characteristics

Sediment cores (diameter 2cm) were taken monthly at each station. Three replicate samples were taken from the top cm and one from the top ten centimetres. Sediment composition was analysed with laser diffraction in a Malvern Mastersizer.
The more sheltered stations along the d and e transects with the highest net sedimentation rates were also the muddiest, with a lower median grain size (MGS). At the f stations, which were not levelled merely because of the high mud content, MGS was also relatively low. The erosive sampling stations were generally sandier. Along the more narrow upstream part (sections a-c) 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 ($\%OM = 108.89MGS^{-0.8081}$; $R^2 = 0.8398$). No relationship was found between mean %OM and net sedimentation/erosion over the first year.

Microphytobenthos

Microphytobenthos on the Ketenisse mudflat was monitored monthly in 2003 by quantifying chlorophyll a concentrations in the upper cm of the sediment. Sediment samples were freeze-dried and pigments were extracted by sonnication in 90% acetone. Chlorophyll a was measured fluorometrically according to Welschmeyer (1994). Chlorophyll a concentrations varied between 0.3 and 118µg.g sediment dry weight^{-1} with the highest values found on sections d and e. They were comparable concentrations found on Groot Buitenschoor, a mudflat situated nearby (M. Lionard, unpublished data). Chlorophyll a concentration generally peaked in the period March to July. This is in agreement with previous studies in the Schelde Estuary (De Jong and De Jonge, 1995). The timing of the chlorophyll maximum varied between sampling stations.
As often observed in estuarine mudflats (*e.g.* Lucas and Holligan, 1999), chlorophyll a concentration increased with decreasing sediment MGS. Chlorophyll a concentration also increased with intertidal elevation. In turbid conditions sediments higher in the tidal frame have a shorter submersion period and therefore have higher temperatures, are subjected to a lesser degree to hydrodynamic disturbance and receive on average more light (Fig. 2). 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.

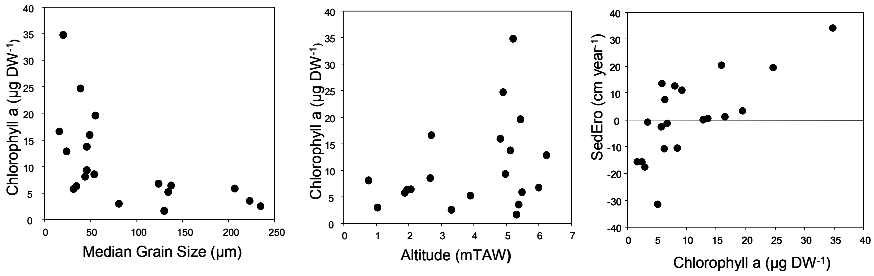

Fig. 2. Relation between annual average chlorophyll a concentration and sediment median grain size, position above mean low water level and net sedimentation-erosion rates in 2003.

Microphytobenthos is known to play an important role in the stabilisation of intertidal sediments (review in Stal, 2003). A close relationship was found between chlorophyll a concentrations and sedimentation-erosion rates (Fig. 2). Chlorophyll a concentration might therefore be a potential indicator for sedimentation and erosion in newly created marshes.

Vegetation

Successional changes in vegetations are best observed by the combined use of permanent plots and vegetation maps (Smits *et al.*, 2002). Four transects were added between the six originals; along the 10 transects 38 permanent plots were established. In September 2003 vegetation relevés of these permanent plots were made according to the decimal scale of Londo (1976). In addition a detailed vegetation map was made of an 8.6ha section near transect e. This section was selected because its width (230m), elevation and gentle slope allowed geomorphological and ecological processes to take place over a large gradient. The boundaries and elevation (mTAW) of the different vegetation types were measured using a theodolite Wild Leitz TC 1600. A digital elevation model of the study area was computed by converting point altitude measurements into a continuous grid (4x4m) by Kriging interpolation. For each grid cell of the elevation model the occurring vegetation type was identified.

The sector contained seven vegetation types (Fig. 3), corresponding to the results of a Twinspan (Two-way Indicator Species Analysis) on the 38 vegetation relevés of the permanent plots (Hill, 1979). Spatial distribution of the different vegetation types was closely related to intertidal elevation, which sets the tidal inundation regime in a given place (Fig. 4). Tidal inundation regime is indeed one of the major determining parameters for the distribution of tidal marsh vegetation (Adam, 1990, Olff *et al.*, 1997, Sánchez *et al.*, 1996). Vegetation types of vascular plants grew between 4.73 and 6.15mTAW. *Vaucheria* vegetations, terrestric algae which are considered as the initial stage in tidal marsh colonisation, already established as low as 3.86mTAW. The high proportion of tidal mudflat and *Vaucheria* area was indicator of the very early stages of the brackish tidal marsh succession. Next stages consisted of *Scirpus maritimus* vegetation and subsequently *Chenopodium* sp. and tall herb vegetation, with transitional types in between. The *Chenopodium* sp. vegetation types on the study site were more typical for non-tidal situations, they were remnants of the existing vegetations before tidal restoration and will probably disappear under tidal influence. Further monitoring results will confirm or disprove this hypothesis.

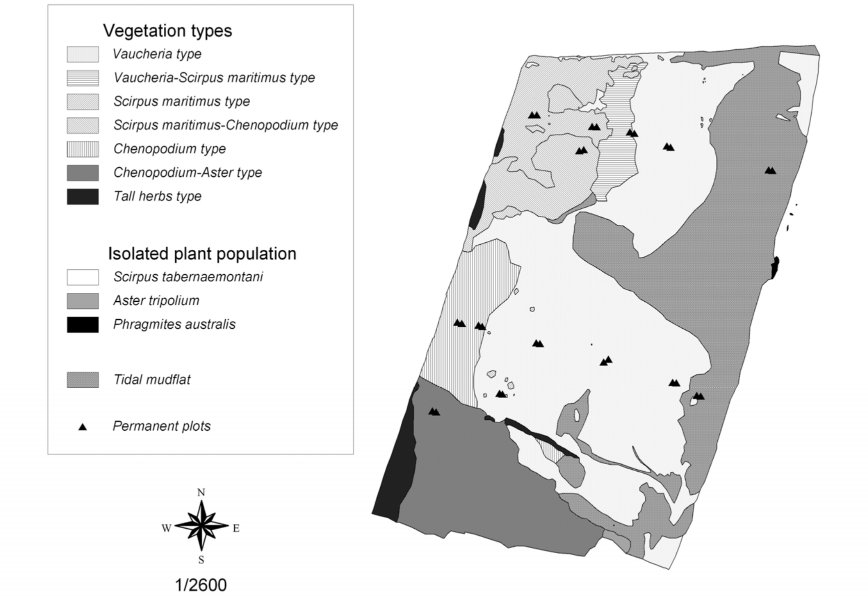

Fig. 3. Detailed vegetation map (anno 2003) of a part of section Kpe.

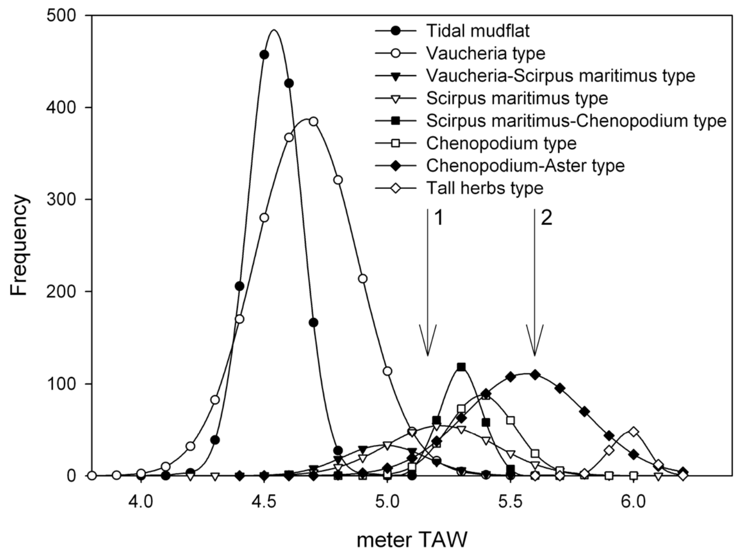

Fig. 4. Distribution (fitted curves) of the seven appearing vegetation types and the tidal mudflats along the elevation gradient at the study site (1: mean high tide; 2: mean spring high tide).

Macrobenthos

Five replicate samples were taken at each station with a small core (3.5cm) to a depth of 10cm. In the laboratory the samples were preserved with a 4% formaldehyde solution after sieving over a 1mm and a 250µm mesh-size sieve. Both fractions were sorted under a dissecting microscope and the animals were counted.

In 2002, Oligochaeta were found at all stations, with generally more organisms found in the smaller fraction. Maximum abundance was found at the first restored station Kpa2 (418,887 ind.m^{-2}), minimum at station Kpa1 (981 ind.m^{-2}). Also high densities were found on the sheltered Kpd and Kpe stations and were relatively high compared to nearby brackish mudflats; the low densities and the species composition corresponded to what was found on the existing intertidal mudflats at Ketenisse in 1999 (Van den Bergh *et al.*, 2003). *Tubificoides heterochaetus* and *Paranais litoralis* were by far the most common species. On the muddy Kpd-transect, relative abundance of *Paranais litoralis* decreased with intertidal elevation in favour of *T. heterochaetus*. In 2003 densities were lower in most of the exposed stations; at the d-transect an increase was noticed (Fig. 5).

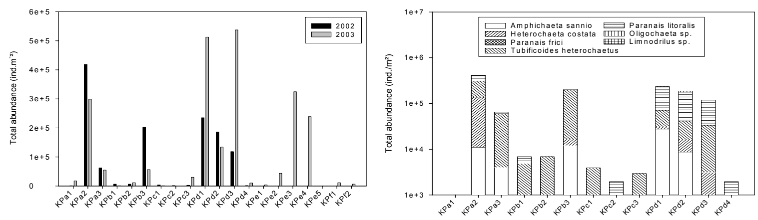

Fig. 5. Total abundance (2002 and 2003) and species composition of Oligochaeta (2002).

Other macrobenthic species present in the Oligochaeta samples were also examined. In 2002, most macrobenthic organisms were found at stations Kpa2 (149), Kpd1(177), Kpd2 (214) and Kpd3 (138). Nematoda and Copepoda were the two most common taxa. Acari, Corophium and Nereis were rarer. In 2003 the total number of macrobenthic species on the Kpd-transect increased and Corophium became relatively more important. The importance of Nematoda decreased in favour of Corophium. Kpa2 showed a slight decrease in total number of macrobenthic organisms (134), all other stations (except Kpd4) showed an increase. The macrobenthic species composition on the e-transect, which was levelled later, was most comparable to the d-transect. Stations with relatively higher densities were mostly stations with a low median grain size, high organic matter content and high chlorophyll concentrations. All probably related to inundation regime. The presence of vegetation negatively affects benthic densities. A relationship was found between macrobenthos abundance and chlorophyll a concentrations (Fig. 6). Higher chlorophyll concentrations possibly indicate higher food availability. Macrobenthos abundance and sediment composition where not statistically related in a similar way.

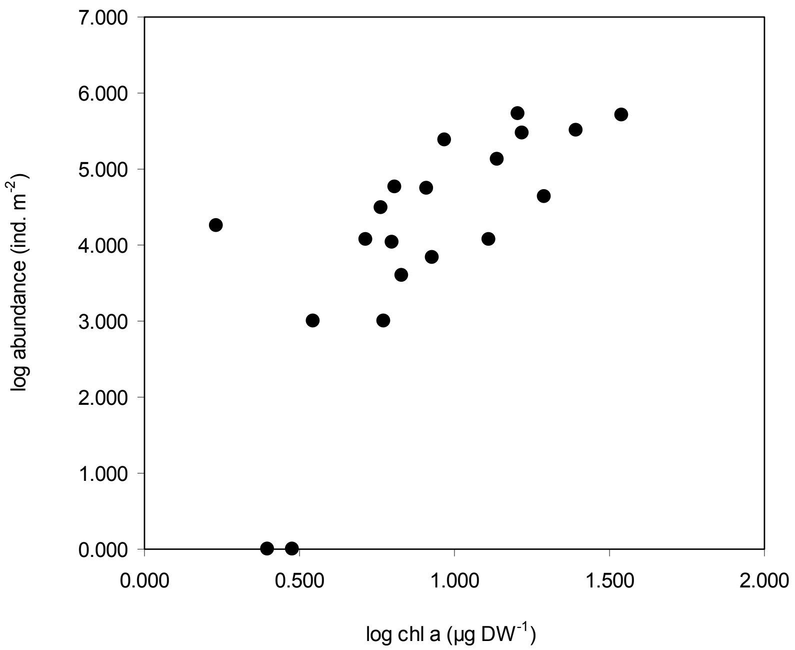

Fig. 6. Logarithm of the abundance of Oligochaeta versus the logarithm of chlorophyll a concentration.

Water birds and breeding birds

In total 43 water bird species were observed. Season maximum was in summer with 12,600 bird days in June (Fig. 7). Common Shellduck (*Tadorna tadorna*), Greylag Goose (*Anser anser*) and Pied Avocet (*Recurvirostra avosetta*) were the most numerous species, responsible for 31%, 18% and 9% of the total number of bird days. Geese are typical winter guests, Common Shellduck and Pied Avocet are especially abundant in summer. Common Shellduck 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* vegetations 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 (Fig. 8). In total 15 species of breeding birds were observed; Pied Avocet was by far the most common breeding bird.

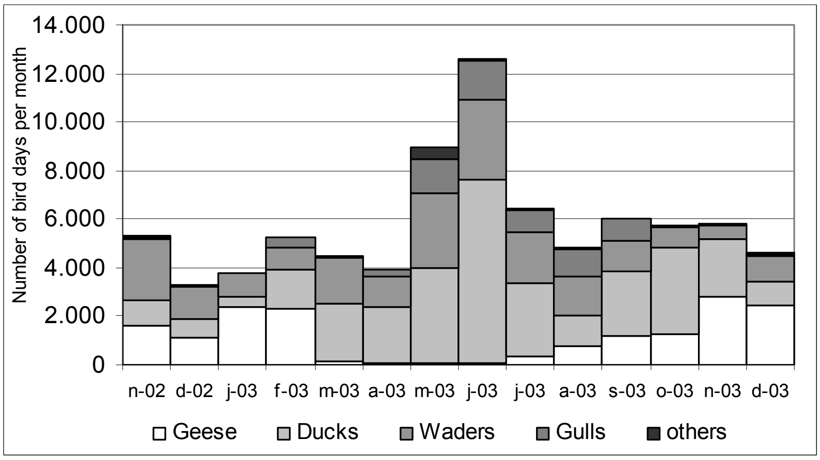

Fig. 7. Seasonal variation for the different species groups of water birds (bird days/month).

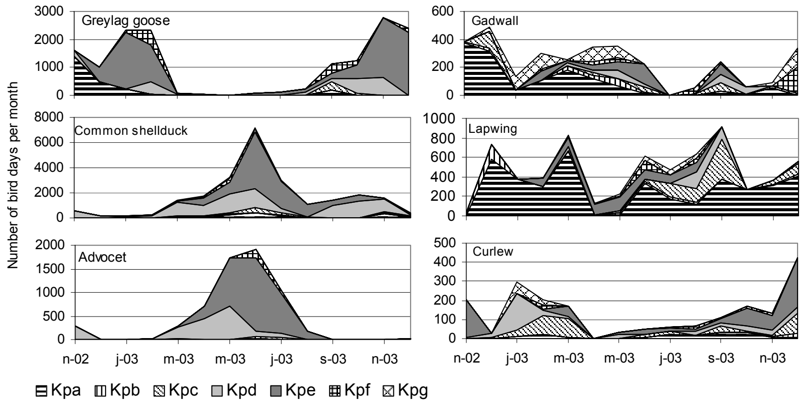

Fig. 8. Seasonal distribution of the most common waterbird species on the muddier (plain) and sandier (striped and chequered) sections of Ketenisse polder (bird days per month).

Conclusions

One year after tidal restoration Ketenisse polder was developing into a varied and functional intertidal area. Colonisation by microphytobenthos, macrobenthos, vegetation and birds started soon after levelling. The onset for a creek network system was seen in the wider and sheltered d and e sections. Once established, the pattern of this network doesn’t seem to change. Unexpected was the remarkable development and erosion of a steep cliff in the most upstream part of the study area, caused by the changed stream current patterns.

The differences in the starting conditions were reflected in the differences in evolution across the site. 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. These areas also contain relative high macrobenthos densities and are selected by typical species such as Common Shellduck 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 macrobenthic densities. They attract other bird species. Succession stages of tidal marsh vegetation were observed and most apparent on the sections with a weak slope.

The applied monitoring scheme seems to be adequate to monitor the developments on the new site, even though it is rather labour-intensive. 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.

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