Building with Nature

EcoShape

Monitoring of effects on the shore vegetation of a sand engine in Lake IJssel, offshore Workum

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Results of the terrestrial vegetation monitoring 2011-2012

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Preface

This report was made in the framework of an integrated monitoring project, where also other ecological and morphological variables were recorded in order to evaluate the effects of the pilot sand engine in front of Workummerwaard, Lake IJssel, Fryslan. In principle, coastal vegetation may have three functions: (1) as a part of the coastal defence system, both by dissipating wave energy and by preventing erosion, (2) as a habitat for birds, and (3) as a carrier of local biodiversity. All these aspects have been considered in the present project.

Here we present: (i) the monitoring set-up,(ii) the results of fist monitoring round (T0 situation, in 2011), and (iii) results of analysis of differences in the vegetation before and after establishing the sand engine (2011-2012), where the results of first and second year of monitoring were integrated. We evaluate the results of the terrestrial vegetation study, including species composition, structure, aboveground biomass and elevation measured within the vegetation. We also assessed roots density, which is an indicator of vegetation potential to prevent soil erosion. Additionally, the soil erosion prevention potential was assessed by evaluating the belowground (root) biomass. The assessment of the belowground biomass was realized within a student project and supported by the local terrain manager It Fryske Gea.

It should be realised that the period of two years covered by this study is extremely short for vegetation monitoring, especially as the effect of the sand engine on geomorphology was extremely small over this period. Normally, vegetation changes should be detectable over periods of c. 3 / 5 years. Therefore it is highly recommended to continue the present monitoring over a longer period, e.g. 5 - 10 years.

Samenvatting

In dit project wordt de vegetatie van de Workummerwaard gemonitord om effecten vast te kunnen stellen van zandsuppletie op de vooroever. Er zijn 32 permanente plots (PQs) van 4 m^2 vastgelegd waarin soortensamenstelling, structuur, en bovengrondse biomassa van de vegetatie is vastgesteld. Tegelijk is de hoogteligging bepaald. Deze metingen hebben plaatsgevonden in juni 2011 en juni 2012. Bovendien heeft additioneel in mei 2012 een bemonstering van de ondergrondse biomassa op drie diepten plaatsgevonden, en een heeft en beperkte bodemchemische analyse plaatsgevonden.

De resultaten laten zien dat de vegetatie tussen 2011 en 2012 significant veranderd is, maar de veranderingen zijn moeilijk te duiden. De veranderingen in de vegetatie zelf (soortensamenstelling en hoeveelheid per soort) wijzen op vernatting, maar dit wordt niet ondersteund door de hoogtemetingen die juist een stijging van het bodemoppervlak laten zien. Maar ook veranderingen in hoogteligging zijn op dit moment niet eenduidig vast te stellen omdat er grote discrepanties zijn tussen Lidar en DGPS waarnemingen. In elk geval kan met zekerheid gesteld worden dat er in 2012 (nog) geen effecten van de suppletie op de vegetatie zijn vast te stellen. Het gebied wordt intensief begraasd en dit heeft zeker grote effecten op de vegetatie, maar het is niet vast te stellen in hoeverre de begrazing ook (deels) verantwoordelijk is voor de waargenomen veranderingen in de vegetatie. In het algemeen wordt de interpretatie van de resultaten van deze monitoring bemoeilijkt door (a) het betrekkelijk geringe aantal plots in een uiterst heterogene vegetatie, (b) de korte periode tussen de eerste en de tweede waarneming, en (c) het ontbreken van kwantitatieve gegevens over begrazingsintensiteit.

De waarnemingen aan boven- en ondergrondse biomassa laten zien dat de vegetatie in zekere mate bijdraagt aan de erosiebestendigheid van de Workummerwaard; dit blijkt onder andere uit een vergelijking met normen die door Rijkswaterstaat voor dijken zijn vastgesteld. Echter, de huidige vegetatie is waarschijnlijk onvoldoende om erosie bij zware stormen te voorkomen.

Aanbevolen wordt om de monitoring op dezelfde wijze nog een aantal jaren voort te zetten, waarbij de waarnemingsfrequentie wel verlaagd kan worden van jaarlijks naar eenmaal per 2 - 3 jaar.

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1. Background

The Workummer Buitenwaarden is a marsh area outside the levees along the Frisian IJsselmeer coast. From the coastal safety perspective, the foreland in front of the levee improves safety for the inland area by acting as a buffer, dissipating wave energy. Besides from the protection of the area from flooding, this coastal area fulfils a range of other functions. Large forelands are nature reserves and include limited agricultural activities (cattle and horse grazing), and many locations along the coast are used for recreation. This report focuses on an important nature area (Workummerwaard), under the management of the nature management organisation 'It Fryske Gea'. The area is one of the crucial bird protection areas in Fryslan, where a large population of meadow birds, geese, waders, shore birds, gals and sterns find suitable breeding sites as well as feeding and resting habitats. Regionally it is also important for migratory birds.

Due to projected climate change and associated sea-level rise, it is proposed to rise the lake level to increase the fresh water retention capacity, and facilitate the discharge of water into the sea. A maximum rise of the lake level of 1.5 meter was suggested by the Delta Committee in 2008. Such a rise will have large consequences for the Frisian IJsselmeer coast. The forelands will be drowned and possibly completely disappear. The intended lake level rise creates a demand for innovative solutions to sustain a safe situation along the levees while maintaining its function as a nature reserve and recreation area. With the anticipated lake level rise, an improvement of coastal defence is necessary. The sand engine (“zandmotor”) concept is an efficient strategy to transport sediment to the coast using sedimentary dynamics. However the concept has not yet been proven in a low wave and tide energy setting.

In the Building with Nature program, a pilot design for Workummer Buitenwaarden was proposed to test whether by using the dynamics of a natural system, a foreland in front of the levees of the Frisian coast can be maintained during lake level rise. This pilot project will give insight into the behaviour of the sedimentary system and the development of ecological systems affected by an increase in sediment supply. This knowledge will determine the feasibility and the applicability of the Building with Nature solutions on a larger scale along the coast of the Frisian IJsselmeer.

The Workummer Buitenwaarden pilot project consists of sand nourishment and the monitoring of its effects. This pilot is the first one to be executed in this type of the low-dynamics (fresh water) system. The sand nourishment will be placed in front of a nature reserve, therefore its ecological effects are the focus for the monitoring campaign. Apart from the monitoring of sediment transport, morphological changes and change of the coastal line using novel technologies (by Deltares), the ecological effects on the nature reserve are also being monitored, and the results of the ecological and morphological monitoring will be integrated.

The pilot project sand engine Workummer Buitenwaarden started in February 2011 and focuses on nature development. A nourishment of 25.000 m^3 sand was placed in autumn 2011, c. 500 m outside the shoreline over a length of c. 500 meter (see Fig. 1). Additionally an 'eco-dynamic dam' (consisting of wooden poles to slow down the water movement northwards) was built (Fig. 1) in order to facilitate the deposition of sediment. A reference (T0) situation for ecological and physical conditions is essential for a successful monitoring campaign. The project started by recording the T0 situation in 2011 and monitoring continued until the end of 2012.

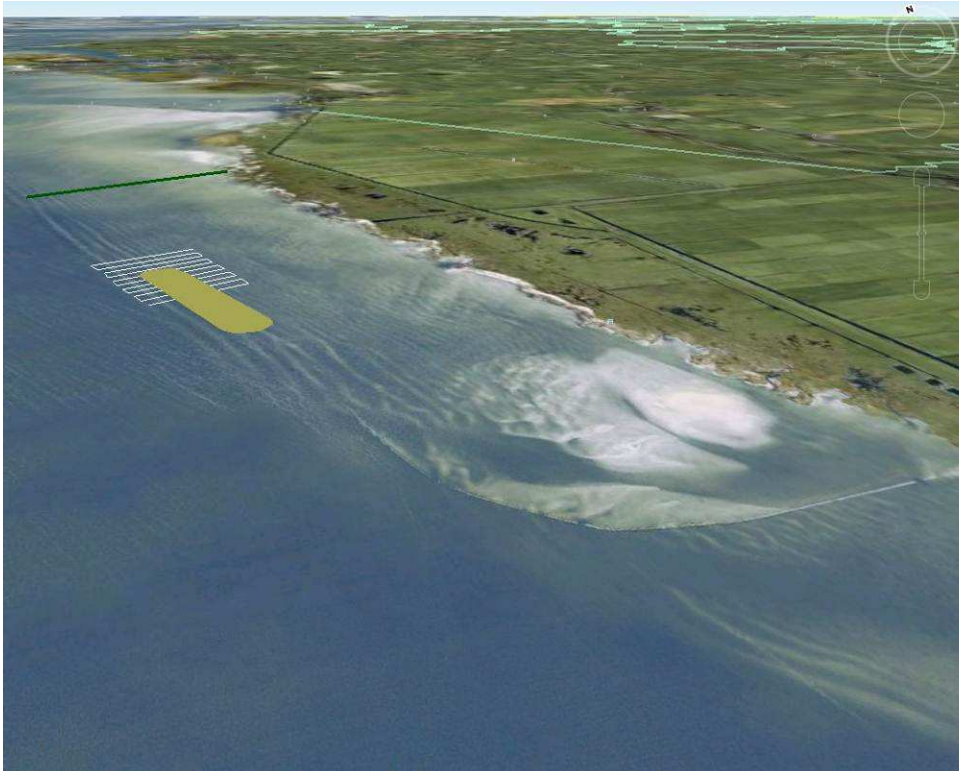


Figure 1: Overview of the pilot project sand engine Workummerwaard (design). The green line at the top of the picture represents the eco-dynamical dam, the light brown polygon represents the approximate location of the sand nourishment. The white grid represents the fiber optical grid used for monitoring of the sediment movement.

2. Project objective

For a successful application of 'Building with Nature' measures in a low wave-energy setting and for the up-scaling of the pilot solutions, a clear understanding of the ecological responses of the system is crucial. Nature conservation is an important function of the area. Because of that a careful monitoring of the state of habitats and the vegetation development is essential.

The objective of this project is to evaluate the effects of the pilot measures by a monitoring scheme (both ecological and morphological). For this purpose the monitoring of the following ecological characteristics was carried out: (1) vegetation development, (2) habitat (vegetation) structure, (3) root density, in various vegetation types.

3. Monitoring set up

Here we present the set-up of the ecological part of the monitoring system to study the effects of sand nourishment at the Workummer Buitenwaarden along the Frisian IJsselmeer coast.

3.1. Monitoring of the vegetation development

Vegetation development is monitored on permanent plots ('PQs'), which are squares of 4 m^2 where the species composition and other characteristics of the vegetation are recorded. In this project the vegetation was recorded before the sand nourishment in 2011 (T0 data) and 1 year after the experimental modification in 2012 (T1 data).

The effects of sediment deposition on vegetation will be likely be spatially heterogeneous along the coast and decrease with the distance from the shoreline. Therefore, the permanent plots are located along the coast, in the zone where sediment deposition is expected, along transects perpendicular to the shoreline. The monitoring is concentrated in the shore zone because the largest changes are expected to take place there.

In order to evaluate the effect of the sand nourishment on the habitat state, we need to compare the vegetation development and the dynamics of the processes (e.g. sediment capture by the standing vegetation) with a situation where sediment input is not expected. Therefore, control transects were located further away from nourishment area to test if the developments in the vegetation are due to the applied measures, or are simply the result of the internal processes in the area such as vegetation succession. The changes of the vegetation on morphological structures such as islands or sand banks was also monitored.

The first vegetation monitoring on the PQs was carried out end of June 2011, in the vegetative season optimal for species identification. The time and practical realisation of the monitoring was consulted with the local terrain manger of It Fryske Gea, and conducted in a way to minimize disturbance for the breeding birds.

Details are as follows:

- PQs were placed along 5 transects located on the land, approx. perpendicular to the shoreline (see Fig. 2).
- Transects on the land were c. 100 m long and consist of 5-6 PQs, located near the shoreline (the starting plot c. 1-2 m from the open water, and other plots at c. 12.5 m, 25m, 50m and 100m from the starting plot). In this way the changes close to the water line (which are more likely to occur), will be easiest to detect.
- Coordinates recorded by DGPS (with an accuracy of a few mm) will be used to repeat PQs in exactly the same location in the next monitoring rounds.
- In total 32 PQs were established, of which were 26 in the transects. Six additional PQs were located close to transect t1, i.e., close to the bio-dynamic dam (see Fig. 2).
- All established PQs will be monitored twice (in 2011 and 2012).
- PQs on land are of a standard size of 4m^2 (a circle with r=1.13 m or diameter=2.26 m). PQs were recorded according to plant-sociological standards,

using the (modified) Braun-Blanquet scale of species abundance, and stored in 'Turboveg´ format. All vascular plants species were identified. Also dominant moss species were identified.

- The grazing pressure in the Workummerwaard location is rather high (cows, horses, geese). Cattle grazing intensity is relatively stable over the years, but it varies within the year (less intensive in the spring, more intensive in summer and autumn). Cows and horses are gazing the area from June till late autumn. Geese also contribute to grazing pressure (year round but most intensively in winter). Grazing also varies in space. Grazing strongly influences vegetation structure and indirectly also vegetation composition. As we are not interested in effects of grazing on the vegetation and grazing is considered to be part of the system in this site, the PQs sites were not fenced.

This set up allows to determine the effects of sand transport and deposition on the vegetation development, taking account of the autonomous processes in the area, and will show in which zone (both in water and on land) the impact of the applied measure is strongest.

Monitoring transects

No.	# PQs	effect/control
t4	6	control
t1	5	effect, aquatic transect eco-dynamic dam, + 6 points in the vacinity of the dam
t2	5	effect, aquatic transect
t5	5	effect
t3	5	control, aquatic transect

Figure 2: Location of transects in the study area with short characteristics of each transect.

3.2. Vegetation structure and land morphology within the vegetation

Our aim is to monitor the vegetation in interaction with the sediment deposition. The land morphology will be monitored from the air (LIDAR, coordinated by Deltares), but this gives little information on the elevation under dense vegetation, and the extent of sediment deposition inside the vegetation, which may be different for pioneer vegetation, grassland or reed. The extent to which vegetation captures sediment or slows down wave action depends on vegetation structure and roughness. The capacity of the vegetation to prevent erosion depends on the plant root density. These factors are thus important for erosion prevention and for future morphology, but they also have a direct influence on safety issues. Therefore, a number of additional measurements were carried out parallel to the vegetation monitoring, to provide a better understanding of how the area functions in terms of bio-engineering processes (interactions between 'bio-engineers' and the environment) and resilience of the natural system:

1. We measured the elevation of the permanent plots in order to estimate sediment deposition in the vegetation over time using DGPS technology (RTK DGPS: Magellan Z-max RTK). This measurement was carried out on all PQs. As both

"local" (e.g. eroded and re-deposited) as well as supplemented sand can contribute to the increase of elevation, we also monitor the elevation change of the control plots. Due to the low dynamics of the system (i.e., absence of tidal movement), the dynamics of sediment deposition is expected to be rather low. Therefore, DGPS measurements were performed before the nourishment was applied, and were repeated in 2012, at the end of the monitoring period. In each plot 5 measurements were taken to account for micro-relief.

2. The vegetation roughness was estimated from vegetation structure i.e. height (average height of tall herb layer), maximum height (height of the tallest herbs) and cover (cover of herbs). Also digital photographs were made in each plot of the vertical structure of the vegetation by taking a horizontal shot against a white screen as a background. These can be used for a more exact evaluation of roughness or biomass estimates. The vegetation structure can be also be monitored using LIDAR-based height estimates, which was however not attempted in this study. This information can be used to verify, calibrate and extrapolate the ground-level monitoring to a larger spatial scale.

Vegetation roughness and root density were evaluated only once, in 2011. It is recommended that these characteristics will be evaluated again in later years.

3.3. Habitat structure and distribution

Vegetation changes can also be evaluated on the basis of sequential maps.

A recent vegetation map for this area does not exist (pers. comm. H. de Vries, It Fryske Gea), but a map of the habitat types based on fieldwork in 2010 is. This map can be used as a T0 in the monitoring. After the next habitat mapping (to be carried out after 5 - 12 years, which can be considered as a T1) the maps can be compared and possible changes can be evaluated. However, such maps often have an insufficient accuracy to detect changes on a short timescale.

3.4. Root density evaluation

The root density was measured by sampling topsoil cores (0-10 cm) and visually evaluating the number of roots. This was carried out on all permanent plots. We used a simple method modified after the one used to evaluate erosion resistance of vegetation on levees (Hazebroek & Frissel 2004). The method is based on the density of roots and rooting depth. It uses a simple classification (Table 1). The evaluation of the results is based on criteria proposed in earlier studies (Hazebroek & Frissel 2004), adapted to the present situation (Fig. 3).

Table 1: Classes of roots density according to VTV (Voorschrift Toetsen op Veiligheid Primaire Waterkeringen).

class	No of roots
0	No roots
1	1-5
2	6-10
3	11-20
4	20-40
5	>40 / matt of roots

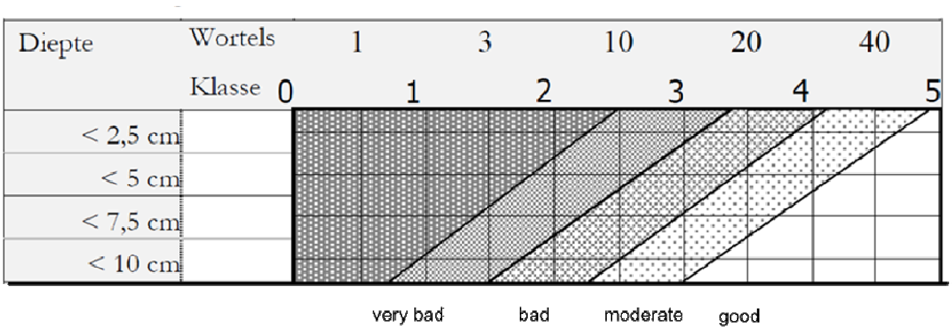


Figure 3: Evaluation score as a function of rooting density and rooting depth (evaluation criteria VTV). Based on these two parameters the safety classes are defined, as indicated below the scheme.

4. Methods of data analysis

The development of the vegetation was monitored in transects where effects are expected and in control plots, and analysed for similarities or differences.

Data analysis and evaluation of the sand addition effects on the vegetation:

- PQs data were stored using Turboveg database software (standard for vegetation monitoring)
- Data on vegetation composition were analysed using multivariate statistics. In such analysis the differences in vegetation composition (and species abundance) in space, as well as the changes over time can be identified and related to differences or changes in environmental conditions.
- The differences in elevation between T0 and T1 for each plot were calculated using DGPS data. The results (difference in altitude, measured within the vegetation) were related to vegetation type, distance from the shore line (zone) and vegetation roughness.
- Data on vegetation structure and roughness (based on the vegetation relevés) will be integrated with the data on elevation. Simple statistical analysis of these data was performed to identify the strength and significance of the relationship between vegetation roughness and other variables.
- The change in the vegetation between 2011 and 2012 (from T0 to T1) was analysed using multivariate statistics, and the statistical significance of the change was determined.
- Data on the root density data were related to the vegetation type and distance from shoreline, using multiple regression. Our results were compared with the standards of root density on dikes (safety measurements).

5. Results of T0

Here we present the results of the first vegetation monitoring round, including a description of the area in terms of the vegetation.

5.1. Vegetation and geomorphology of the transects

The landscape of Workummerwaard still has patterns of tidal marshes with still visible creeks, lower sections and higher banks. In the past (i.e., before the construction of the Enclosure Dike in 1938) processes of sedimentation and sediment deposition were strongly affecting this area. On the old maps the wide sand banks and a zone of tidal marshes are visible in front of the levee (Fig. 4). Also the pattern of drainage ditches (major canals and smaller ditches) is visible. This, together with the effect of grazing, contributes to a high structural diversity, which is beneficial for birds (for breeding and feeding habitats).

Some elements of the vegetation are remnants of saline or brackish conditions: a number of species that indicate salt or brackish conditions were found in the area (see appendix). In and along the creeks the vegetation consist mainly of *Schoenoplectus tabernaemontani* and *Bolboschoenus maritimus (=Scirpus maritimus*), typical for coastal vegetation and dune valleys. The soil probably still contains salt (at least in the organic layer covering the fine white sand). The old creeks (lower sections of the grasslands) are filled with sediment and overgrown by lawns of *Agrostis stolonifera, Potentilla anserina* and *Carex nigra*. Patches of reed (*Phragmites australis*) cover the lower bank of the lake or overgrow sections of wet meadows.

Grazing definitely has a large impact on the vegetation of the area. The faeces of cattle and geese were often found in the study area. Cattle is entering and grazing the reed patches but also ranging over the entire gradient. Horses often avoid wetter sides and graze mainly the drier meadows. Geese graze the lawns of *Agrostis stolonifera* and *Juncus gerardii* to a very short length. Some locations are heavily trampled by cattle. In such places the grazing pressure is most likely determining erosion and vegetation development.

The location of plots on each transects (together with its id) is indicated on the aerial photos (Figs. 5 – 9). Also the elevation profile of each transect is included. Near the shoreline, wetland vegetation can be found (transect 1 and 4) or a zone with high sand and shell banks (transects 2, 3 and 5). Further away (5 to 50 m from the shoreline) the elevation is less and summer water levels are c. 10 cm or less below soil surface in most plots. Still farther from the shoreline the elevation slowly increases again, up to the dike.

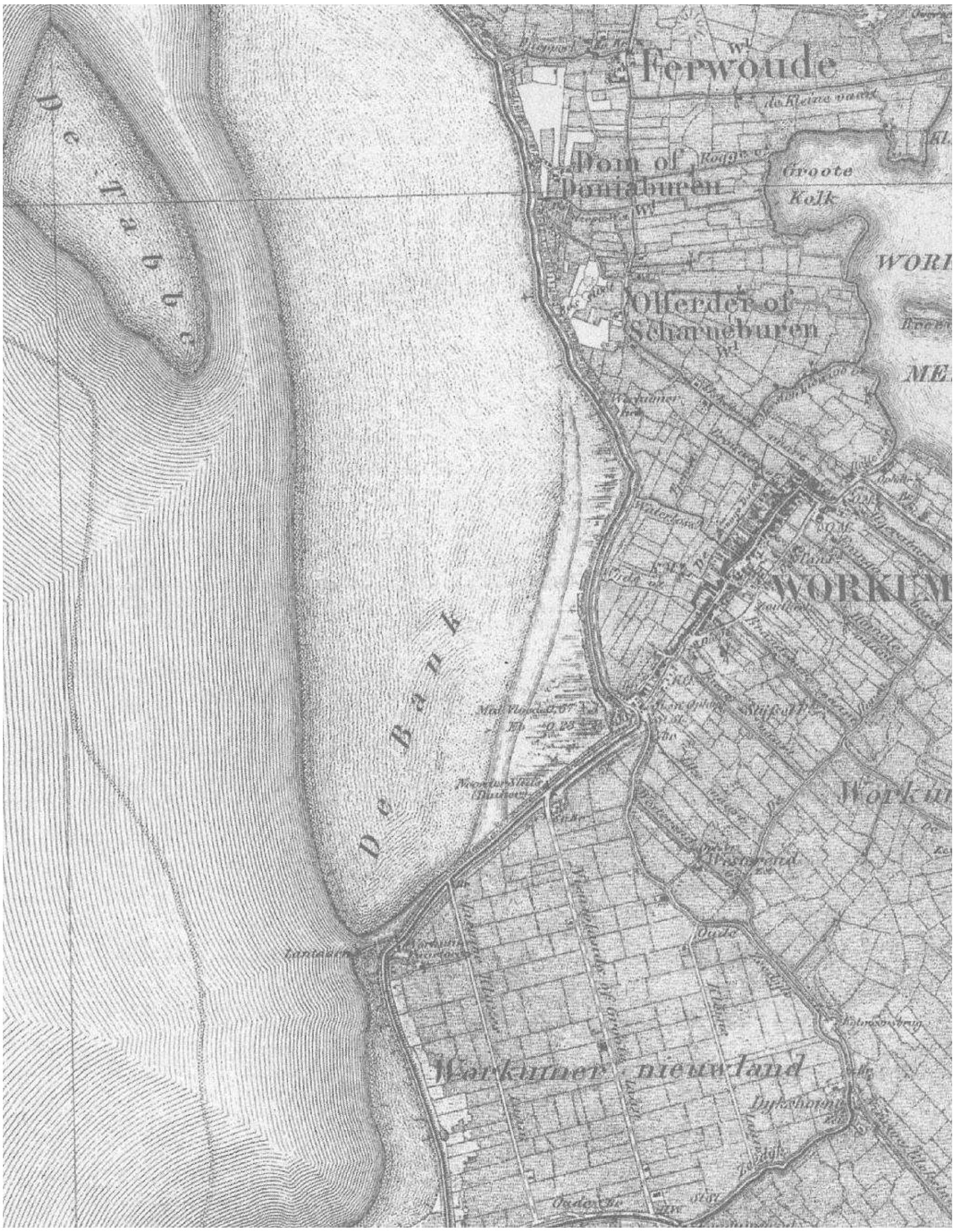


Figure 4: Historical image of the Workummerwaard: Topographic atlas 1864.

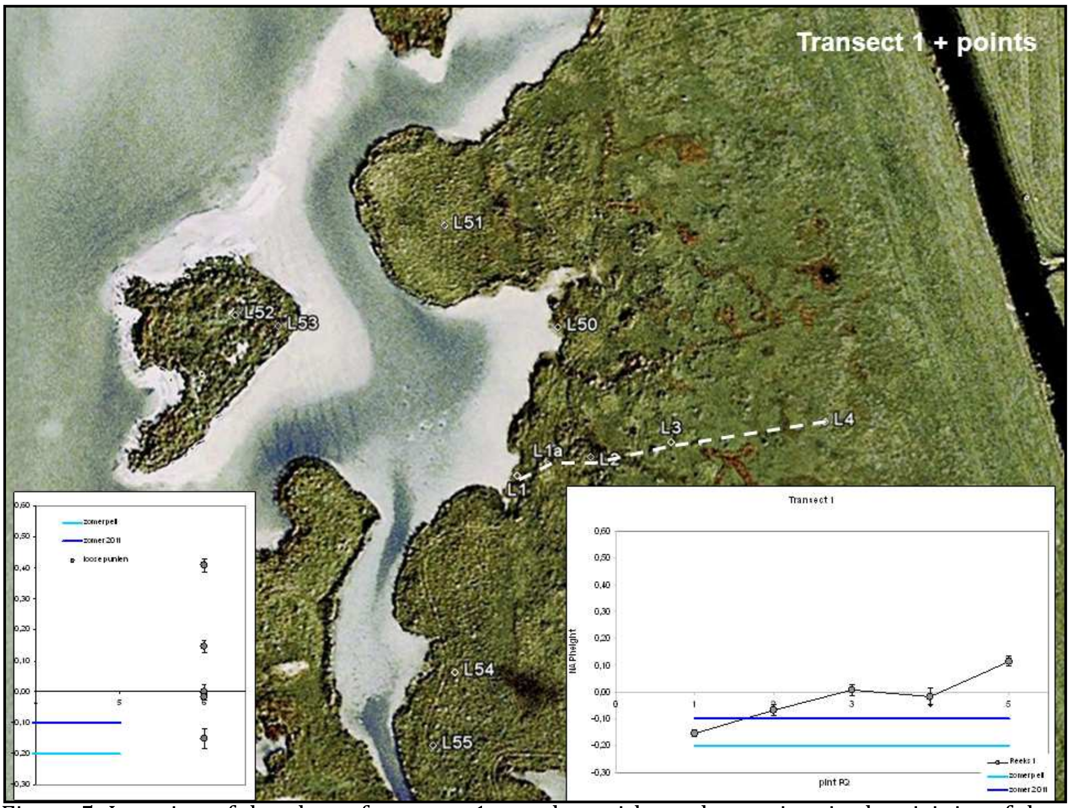


Figure 5: Location of the plots of transect 1 together with random points in the vicinity of the eco-dynamic dam. (Source aerial photo: Google Earth 2011). The NAP altitude profile is included together with the average water levels in winter and summer in Lake IJssel. The profile shows the plot's elevations (average of 5 points in each plot) starting with the plot closest to the water (from left to right).

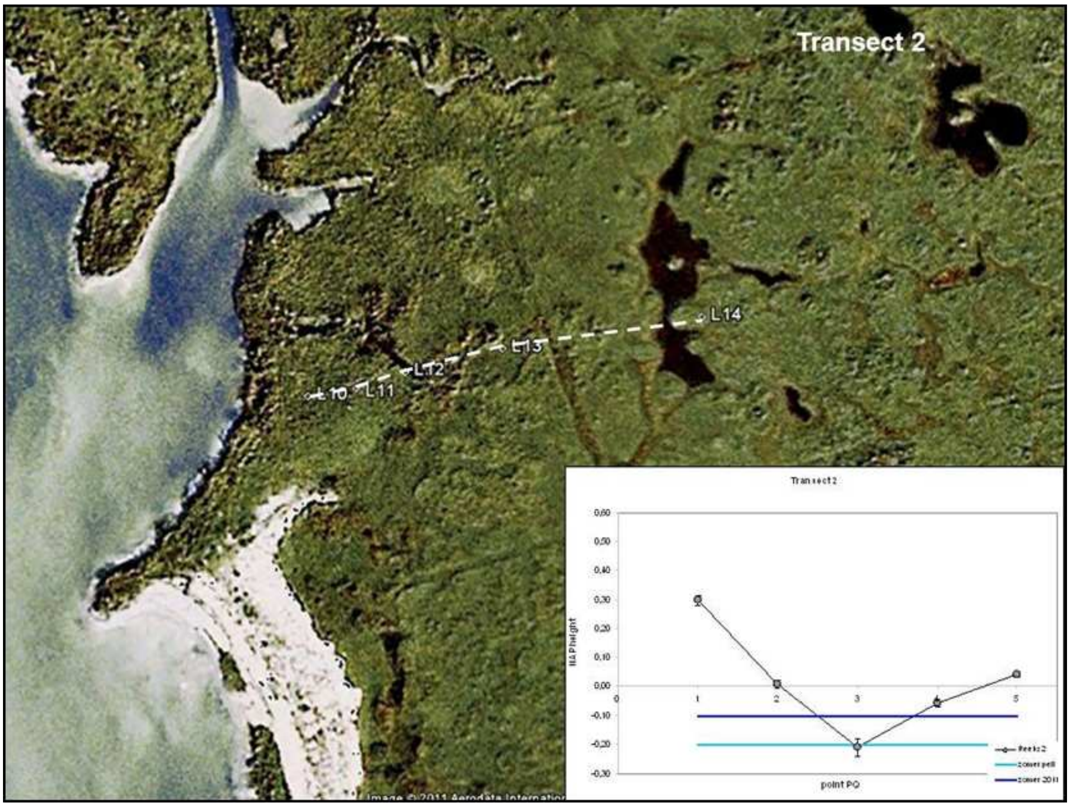


Figure 6: Location of the plots of transect 2 (Source aerial photo: Google Earth 2011).

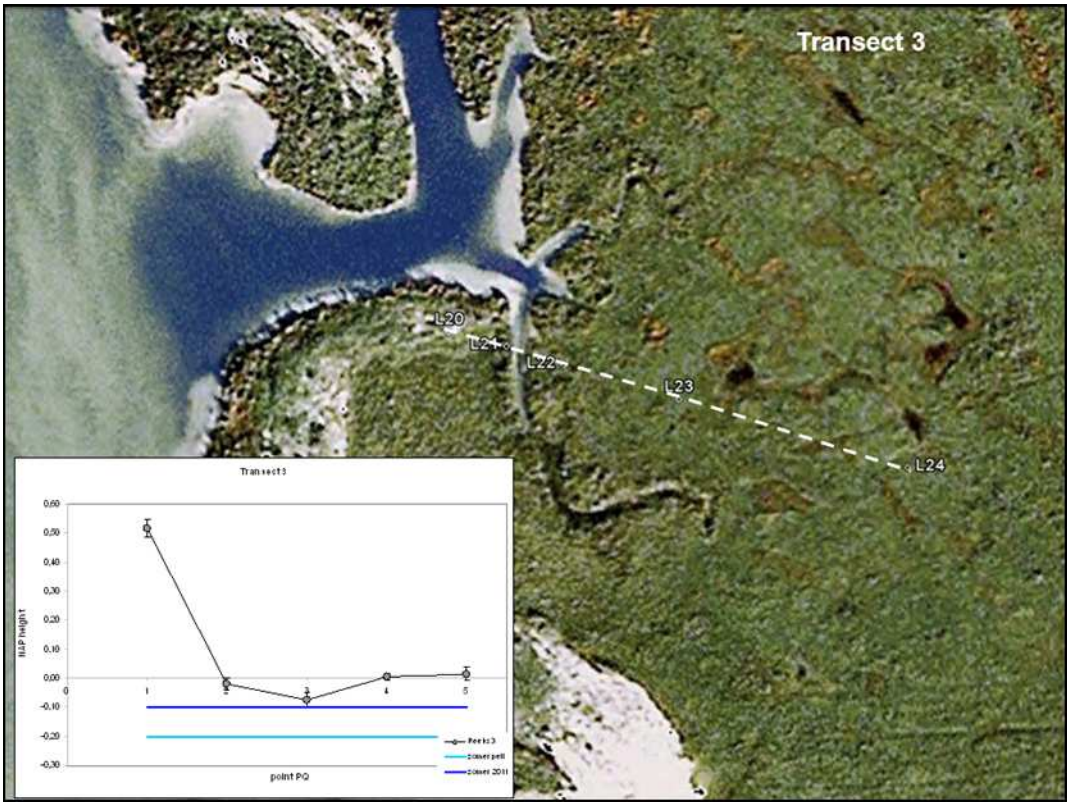


Figure 7: Location of the plots of transect 3 (Source aerial photo: Google Earth 2011).

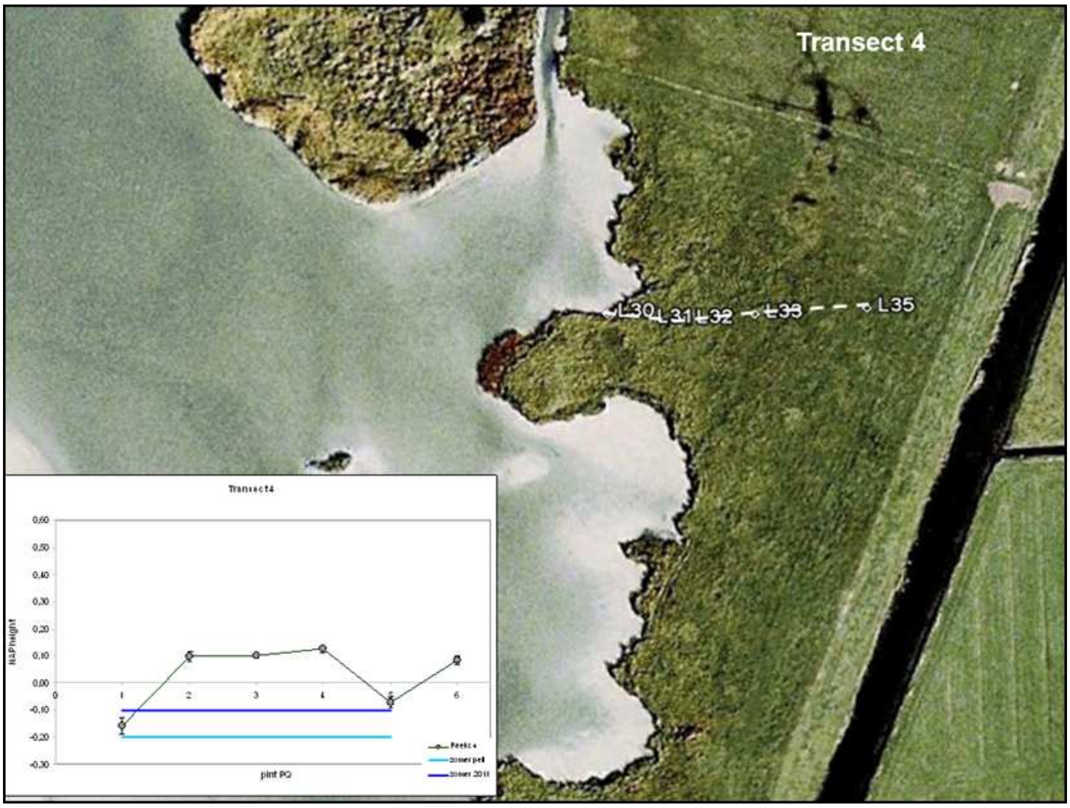


Figure 8: Location of the plots of transect 4 (Source aerial photo: Google Earth 2011).

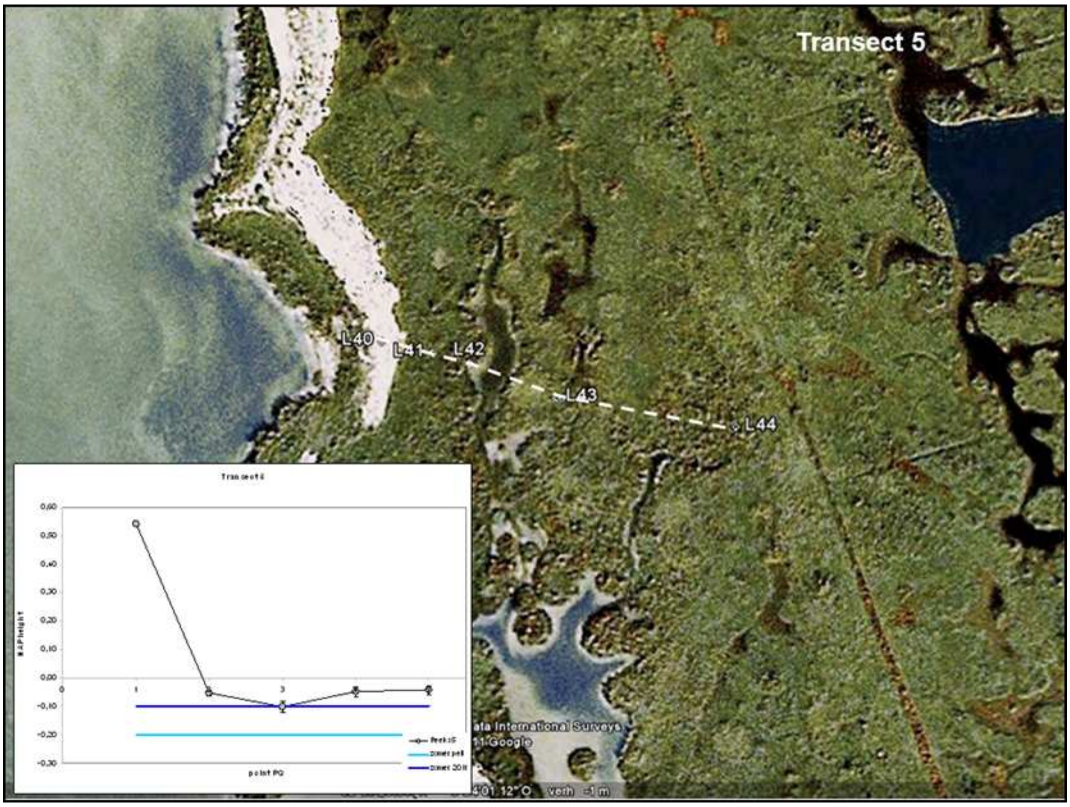


Figure 9: Location of the plots of transect 5 (Source aerial photo: Google Earth 2011).

5.2. Vegetation zonation

In total 32 relevés were recorded, with 93 species.
The vegetation records were classified using Twinspan for Windows software (by Mark O. Hill & Petr Smilauer, version 2.3). The division was performed up to 5 levels (eigenvalues: 0.323; 0.322; 0.389; 0.278; 0.220) and resulted in 6 vegetation types described below.

The vegetation of Workummerwaard consists of a range of grassland and wetland species from fresh-, brackish- and salt conditions, and is in a transition state due to decreasing salinity, erosion processes and locally intensive grazing. Therefore the vegetation is difficult to classify in the existing syntaxonomy, and we use a local vegetation typology.

Each vegetation type was found in a specific elevation. The sparse vegetation of sandy banks (type 1) was found in the higher sections (NAP +0.44m), the meadow types (type 4 and type 5) were found in the intermediate sections (mostly between NAP + 0.0 and +0.1), a little bit lower laying sections were occupied by type 6 (transition between meadow and wetland vegetation, between NAP 0.0 and -0.05) and in the lowest sites (NAP between -0.05 and -0.2) the vegetation type 2 and 3 were found (vegetation dominated by reed near the shoreline and in the ditches). Vegetation types 2 and 3 and vegetation types 4 and 5 were both found at similar elevations (Fig. 10). There were no clear differences between these vegetation types in terms of depth of the fine sand under the organic soil layer (Fig. 11). An exception was the vegetation of sandy banks, where an organic layer was lacking.

Vegetation typology:
Type 1: sparse vegetation on bare sand or shell banks with *Sedum acre* and *Tripleurospermum maritimum* (4 relevés: 13,18,24,33*)
Type 2: vegetation in ditches, or vegetation dominated by *Hippurus vulgaris* and *Eleocharis palustris*, (3 relevés: 7, 15,16*)
Type 3: tall vegetation dominated by reed *Phragmites australis* or *Schoenoplectus tabernaemontani* , *Scirpus maritimus*, with wetland species such as *Mentha aquatica, Rorippa nasturtium-aquaticum* (7 relevés: 3,9,20,23,26,30,35*)
Type 4: vegetation dominated by *Agrostis stolonifera* with co-dominance of *Carex nigra*, *Juncus gerardii, Potentilla anserina* (6 relevés: 8,11,12,17,27,28*)
Type 5: meadow (a drier type) vegetation with grasses: *Festuca rubra, Holcus lanatus, Agrostis stolonifera,* and herbs *Dactylorhiza majalis, Pulicaria dysenterica*, and *Plantago lanceolata* (5 relevés: 4,5,6,10,31*)
Type 6: mixed (mosaic) vegetation with dominance of *Agrostis stolonifera*, with low density of taller plants: *Schoenoplectus tabernaemontani* , *Scirpus maritimus*, and some other indicators of brackish conditions (7 relevés: 14,19,21,25,29,32,34*)
* original Turboveg coding

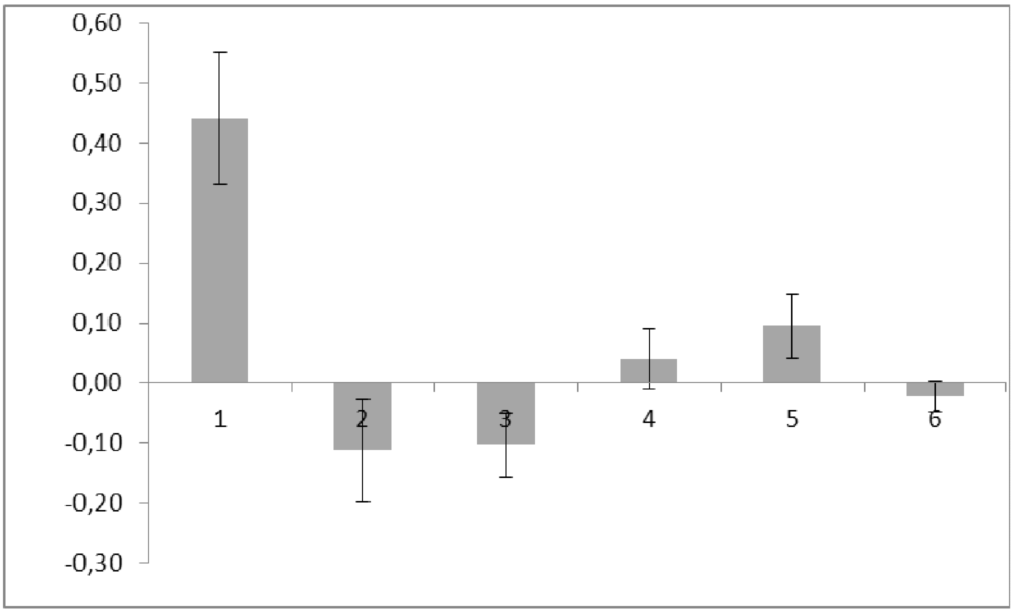


Figure 10: Elevation (NAP) of the six vegetation types (average of 5 measurements, error bars indicate ±SD).

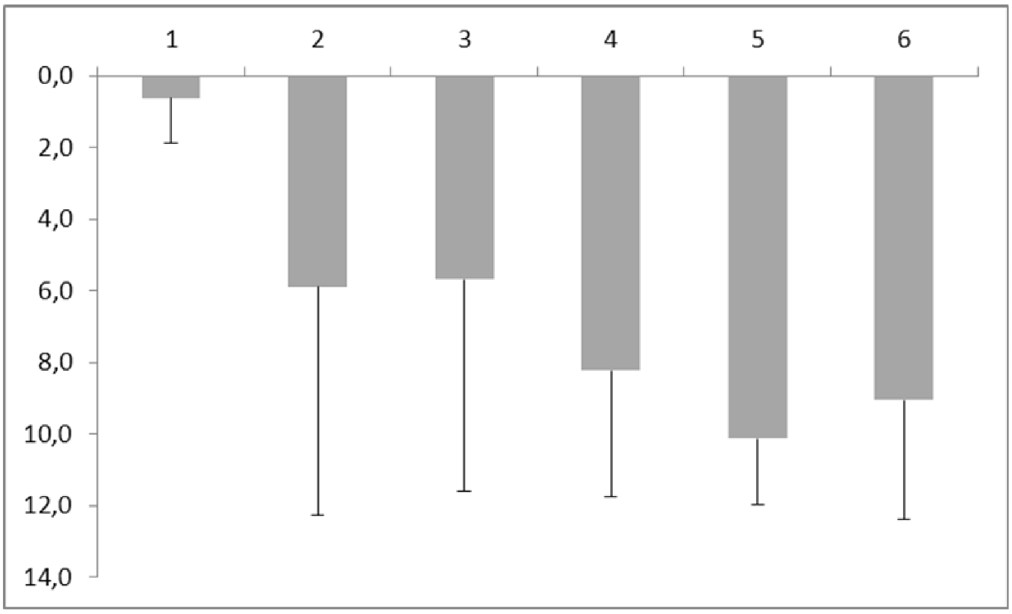


Figure 11: Depth of the fine sand under the organic soil layer in the six vegetation types.

5.3. Vegetation structure

Although the vegetation structure is rather variable, the differences are not clearly reflected in the average and maximum vegetation height (Fig. 12). This is due to the layered structure of the vegetation: e.g. in meadow vegetation the main layer is relatively low, but reed or other tall plants are also present in the vegetation, however with a low abundance. Vegetation roughness determined on the bases of average and maximum vegetation height was the highest in the vegetation type 3 and slightly lower in type 2, intermediate in vegetation types 5 and 6 and lowest in types 1 and 4.

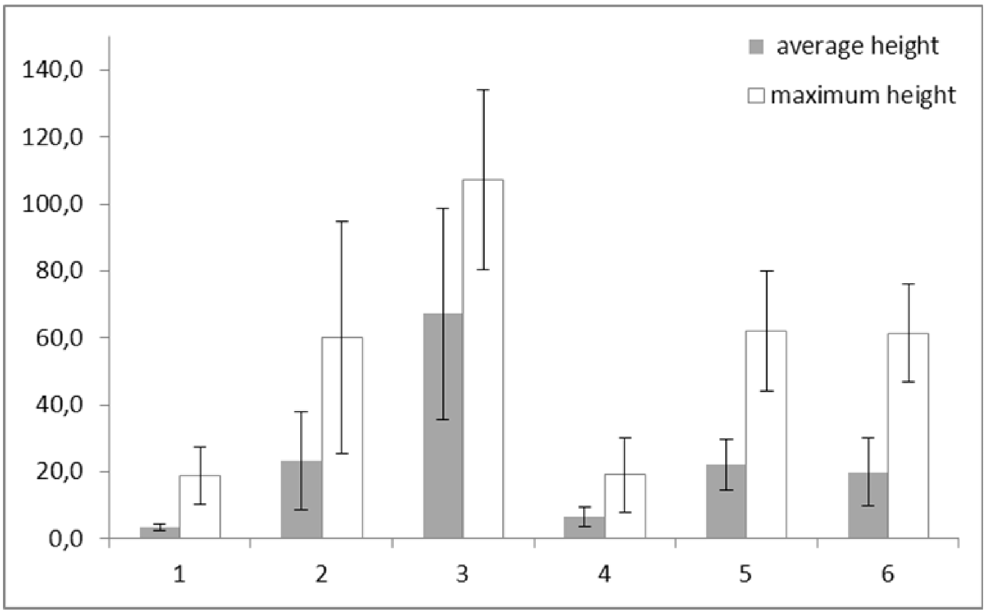


Figure 12: Vegetation structure expressed as average and maximum vegetation height in the six vegetation types (average of several measurements, equal to the number of the records of each vegetation type, error bars indicate ±SD).

5.4. Vegetation composition in relation to the environmental factors

Vegetation composition was analysed using multivariate analysis with Canoco 4.5 for Windows software (Leps and Smilauer 2003). We used the species abundance data and the available environmental variables data (e.g. NAP elevation, depth of the sandy sediment, etc.). For this analysis the abundance data were reclassified into 9 numerical classes (see Table 2) which were entered into the analysis untransformed. All relevés (i.e., the ones made in 2011 and 2012) were analysed together so the data matrix consisted of 64 samples and 116 species. No weighting of species or samples was used.

Table 2: Reclassification of the abundance data for multivariate analysis.

Abundance species	New class
r	1
+	2
1	3
2a	4
2b	5
2m	6
3	7
4	8
5	9

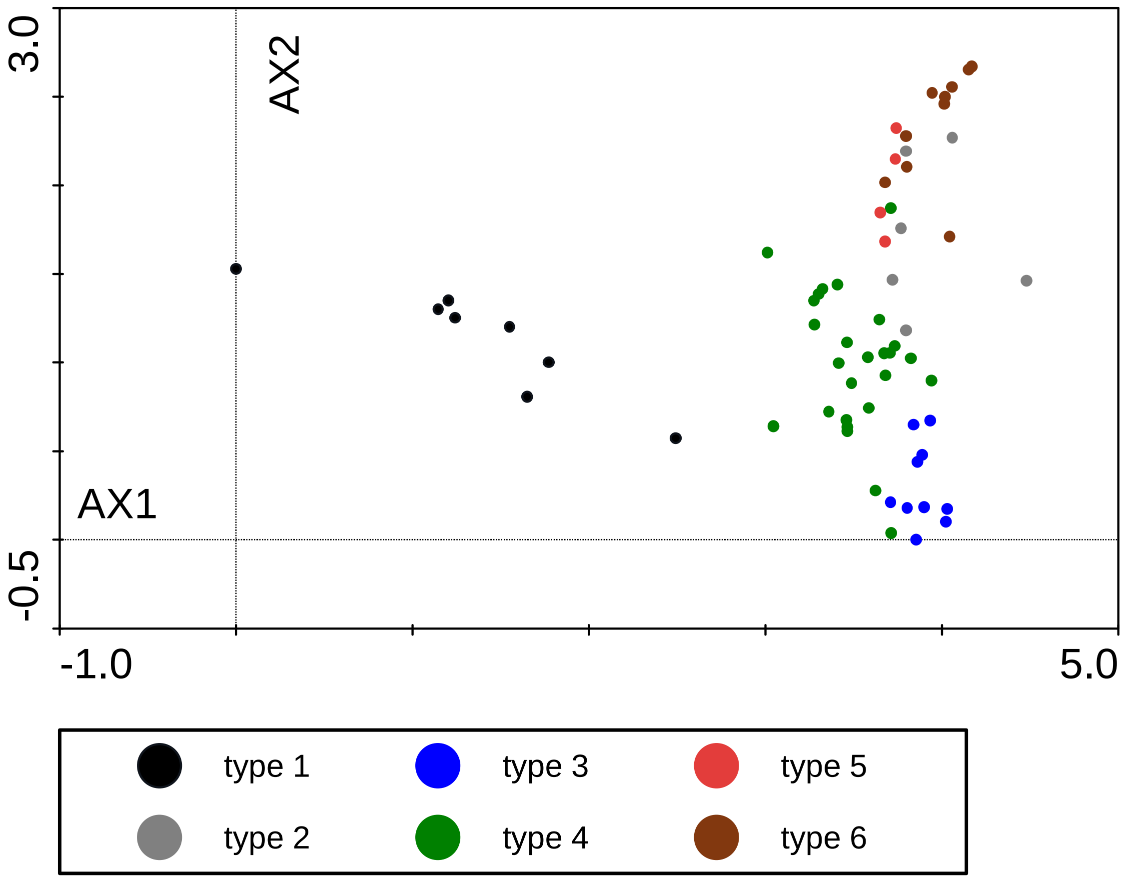


Figure 13: DCA ordination of the vegetation (32 samples). Ordination explained 18.6% of variance in the species data on first two axes (eigenvalues on first and second ordination axes were 0.512 and 0.265, respectively). Symbols colour indicates the vegetation types.

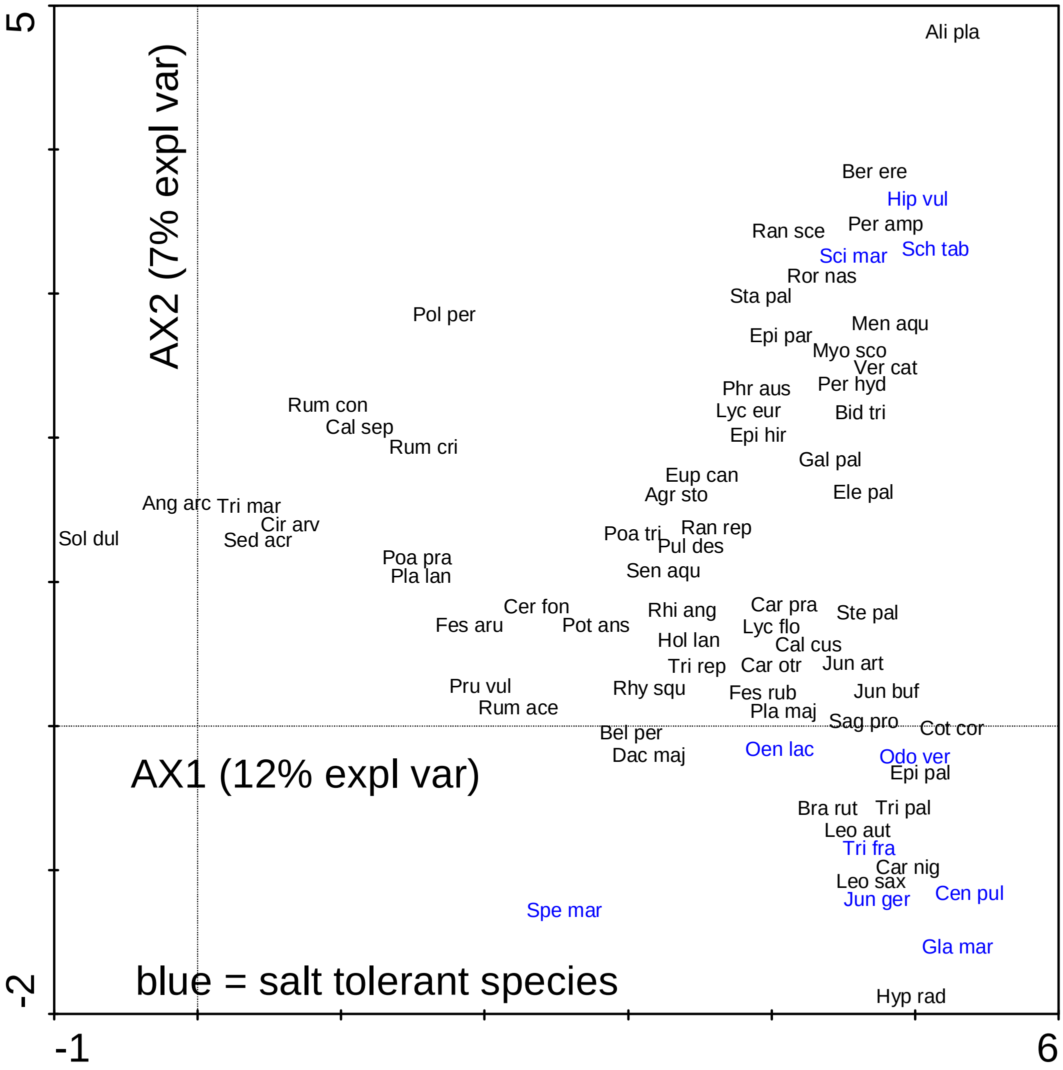


Figure 14: Species plot of the DCA ordination. This plot can overlay Fig. 13 in equal scaling and in that case has a distance interpretation (the closer a species name is to a sample point, the higher the probability to find it in that sample). Species names are the first 3 letters of the genus name and the first three letters of the species name.

In a detrended correspondence analysis (DCA) the first two ordination axes together explained 18.6% of variance in the species data. The gradient lengths for the first two axes were 4.5 and 2.7 SD units, respectively, which allow the use of unimodal methods i.e. canonical correspondence analysis (CCA), the result of which is shown in Fig. 13 (samples) and Fig. 14 (species). The ordination shows that the vegetation on the sand banks (type 1) is clearly different from the vegetation in the rest of the area. This is apparent both from the position of the samples belonging to type 1 in the plot in Fig. 13, and from the strong decrease in eigenvalue between the first and second axis (0.48 and 0.29, respectively). Apparently the first (horizontal) axis mainly represents the contrast between the sand bank vegetation and all other vegetation. The second axis mainly represents the gradient from dry (lower end) to wet (upper end), which is apparent from the position of the types in Fig. 13, the position of the species in Fig. 14, and the environmental gradients shown in Fig. 15.

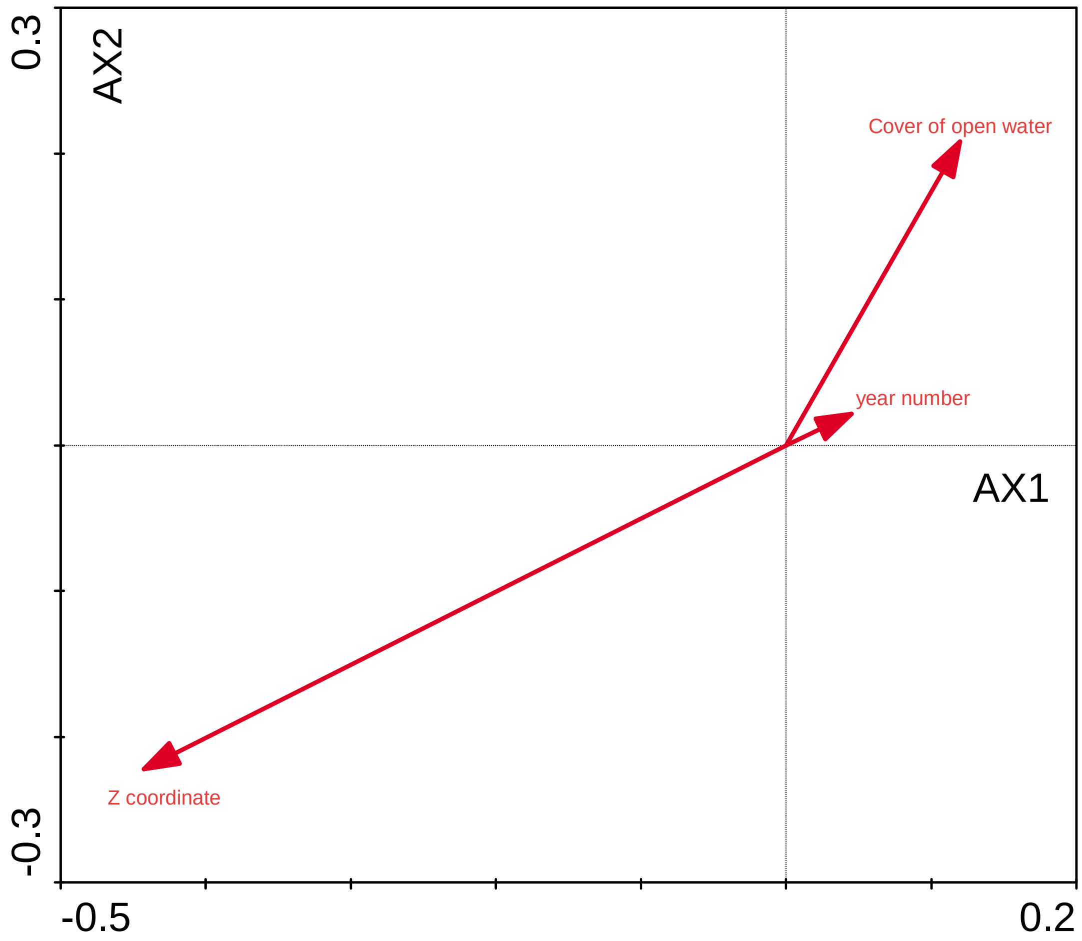


Figure 15: environmental gradients in the ordination diagram of Fig. 13. All given variables increase in the direction of its corresponding arrow.

Photo 1: Vegetation zonation in the Workummerwaard: Scarce vegetation on the sand and shell banks (upper left); tall vegetation with reed (upper right); short vegetation of wet meadows with *Agrostis stolonifera* (lower left); drier meadows, closer to the dike (lower right) (Photos: A. Klimkowska).

6. Differences before and after establishing the sand nourishments

6.1. Elevation height within the vegetation

The elevation within the vegetation were measured in 2012:
- at the same time as the vegetation monitoring and in the same time of the year as in 2011,
- with DGPS technique by the same company as before, with use of the same equipment and by the same person as a year earlier (accuracy of ±2cm in the vertical direction),
- according to the same field procedure: measurements at the PQ plots, at least at 5 points to account for local relief, final elevation height is the mean of the sub-measurements.

The change in elevation was calculated for each plot. The resulting differences in altitude were tested for all plots and in relation to vegetation type. Data were analysed by repeated measures ANOVA (RM ANOVA) with and without between-subject factor (vegetation type), without co-variables. The statistical analysis were performed with the software package SPSS 19.0.

First we tested an effect of time on entire data set (RM anova; no between-subject factor). We found a small but **significant increase** of the elevation (Effect of time $F = 27.02$, $p < 0.0001$, see Fig. 16). The same was concluded from a simple t-test (for paired samples). The average increase was from 0.04 m above NAP to 0.078 m above NAP, thus c. 4 cm).

Secondly we tested an effect of time on the change in evaluation height in various vegetation types (RM anova; between-subject factor: vegetation). We found again a significant effect of time ($F = 19.32$, $p < 0.0001$), but no effect of interaction between time and vegetation type ($F = 0.418$, n.s. $p=0.832$). This means that the increase of the elevation was significant in all vegetation types, irrespective of their position (sand banks or wet meadows or marsh vegetation) (Fig. 16). In some vegetation types the variability of elevation was higher than in others, which may be related to (macro)relief. We also found that in some vegetation types the average increase in elevation was larger than in others (Fig. 16). In the drier meadow variant with *Festuca rubra* (type 5) and in the tall vegetation with reed (type 3) the increase in elevation tended to be most pronounced. However, this can be seen only as a trend, as the differences from point to point were large and the effect of vegetation type in elevation increase was not significant.

We also found a consistent increase of the elevation over all transects in time (RM anova; between-subject factor: transect, we used five transects and the loose points as a 6th transect. Here too the effect of time was significant ($F = 30.32$, $p < 0.0001$), but effect of an interaction between time and transect was not ($F = 1.62$, n.s. $p=0.191$). That would suggest that the elevation in the control transects increased as much as in the effect transects (where effects of nourishment were expected). Nevertheless, the average increase in elevation was smaller in the control transects (t3, t4: 1.4-1.9 cm), compared to the effects transects (mainly t2, t5: 6.1-6.6 cm). Again this can only be seen as a trend as the effect of transect was not significant.

For the interpretation of these results we should bear in mind that the average accuracy of the DGPS measurements (RTK GPS: Magellan Z-max RTK) in the vertical direction is ±2cm. furthermore the micro-relief within the vegetation is responsible for local differences between 1.5 cm to 2.9 cm (micro-relief differences are indicated as standard deviation of the height measurement on the PQs, and we did not find substantial differences between vegetation types in this matter). We are thus limited by the technical possibilities and by natural variability in micro-relief. For an accurate determination of small changes that take account of micro-relief, a different measurements technique should be used, e.g. using a pin-frame for the determination of small elevation changes in short fixed transects, or metal or concrete loggers anchored in the subsoil, where the relative height of the soil surface can be measured with accuracy of millimetres.

In the light of the above remarks, in combination with the short monitoring period it is impossible to formulate strong conclusions. Anyway there seems to be a trend for elevation to increase, but this cannot be clearly ascribed to sand nourishment or sediment transport. In that case we would expect more pronounced differences between vegetation types or transects. The elevation increase might also be an artefact due to e.g. temporal differences in grazing intensity, soil wetness, or litter accumulation. None of these differences were very evident, however.

We also compered the elevation measured by DGPS and measured by remote sensing, using digital elevation model data from 2011 and 2012 based on the Lidar data (provided by Deltares). The height values from remote sensing were generated for the precise locations of the PQs (central points). We could only generate 25 elevation height values based on the digital elevation models, due to no data pixels. We found that the difference between values measured on the ground (averaged for a plot, so the effect of micro-relief was removed) and the values from digital model (averaged per 0.5 x 0.5 pixel) was 3.2 ± 3.3 cm (mean ± SD) in 2011 and 4.6 ± 2.3 cm (mean ± SD) in 2012. The minimal and maximal difference between both measurements methods was respectively 0.2 cm and 12.7 cm in 2011, and 0.7cm and 10.3 cm in 2012. Lidar elevation measurements are most reliable in scarce vegetation or on bare sand and shell banks. However, the mean differences for only these sites (in total 6 points) were still relatively large: average 2.7 ± 1.3 cm (mean ± SD), minimal and maximal differences 1 cm and 4.5 cm in 2011 and average 6.8 ± 2.1 cm (mean ± SD), minimal and maximal differences 4.3 cm and 10.3 cm in 2012. We conclude that average differences between the both data sources overlap with the accuracy of the elevation measurements techniques (± 5 cm for Lidar and ± 2 cm for DGPS).

Next, we made a simple comparison of the relative change of elevation per point between 2011 and 2012, for each of the two data sources. In the case of 11 points the two sources of data indicated a change in opposite directions and in 12 points both data sources were consistent about the direction of change. Furthermore, in the case of 18 points the DGPS measurements indicated a larger change (sometimes up to 9 times larger), while only in the case of 5 sites Lidar measurements indicated a larger change. In the case of 2 points DGPS indicated a change in elevation, while Lidar did not.

Surprisingly, in about 50% of points the analysis of elevation change based on the two data sources gave different results. On average the Lidar results were more conservative, i.e. indicating little changes and mainly a decrease in elevation, while the DGPS results indicated larger changes and mainly an increase. However it should be born in mind that Lidar is more prone to errors, especially in the dense or tall vegetation. The Lidar data predominantly suggested erosion of the sand banks.

Overall it can be concluded that both types of measuring techniques are complementary. In case of the direct comparison of the results we tend to trust more the direct DGPAS data (ground truth data), as they are more accurate and are independent of the vegetation height and biomass.

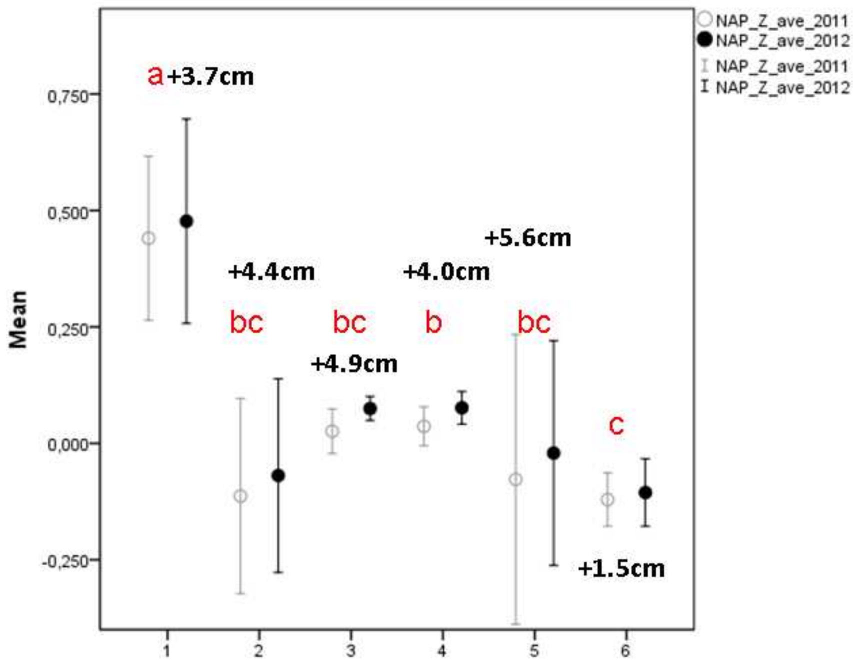


Figure 16: Change of mean elevation over time per vegetation type. Results of RM ANOVA, with vegetation type as between-subject factor. The X axis represents the vegetation types according to the 2011 TWINSPAN classification, the Y axes represents elevation in m above NAP. Open and filled dots represent mean values for 2011 and 201,2 respectively and error bars are the 95% confidence interval. Red letters indicate groups significantly different at p=0.05 according to Tukey HS post-hoc test. Additionally the average increase of the elevation per vegetation type is indicated, which however do not differ significantly.

6.2. Vegetation composition and driving factors for vegetation

The differences in the vegetation between 2011 and 2012 can be inferred from Fig. 17. This figure is identical to Fig. 13 however with the samples coded per PQ instead of per type. Fig. 18 summarizes the displacement of the centroids per type. This figure clearly shows that the temporal changes (indicate by the lengths of the arrows) are small compared to the spatial differences (indicated by the distances between the arrows). We used CCA (Canonical Correspondence Analysis) to test the significance of the change. In this test the PQs were used as 'random' (noise) variables and the year number was used as the only effect variable (in practice this is accomplished by declaring dummy variables for each PQ as covariables in Canoco). The change appeared to be highly significant (P<0.0001 after 9999 random permutations). Next, the significance of the change per vegetation type was determined. This is accomplished by stepwise addition of vegetation type * year number interaction terms to a model containing dummy terms for all PQs, and testing the significance of the difference after each step. The result is also given in Fig. 18, showing significant changes in types 1, 3 and 4, trends in types 2 and 6, and no change in type 5. The general trend in the diagram is upward, i.e. in the direction of indicators for wetter circumstances (compare Fig. 18) and this is especially the case in the drier types 1, 3 and 4. This may be an indication for wetter conditions in 2012, which is however contradicted by the significant increase of the Z coordinate between the two years. We do not have an explanation for this apparent contradiction.

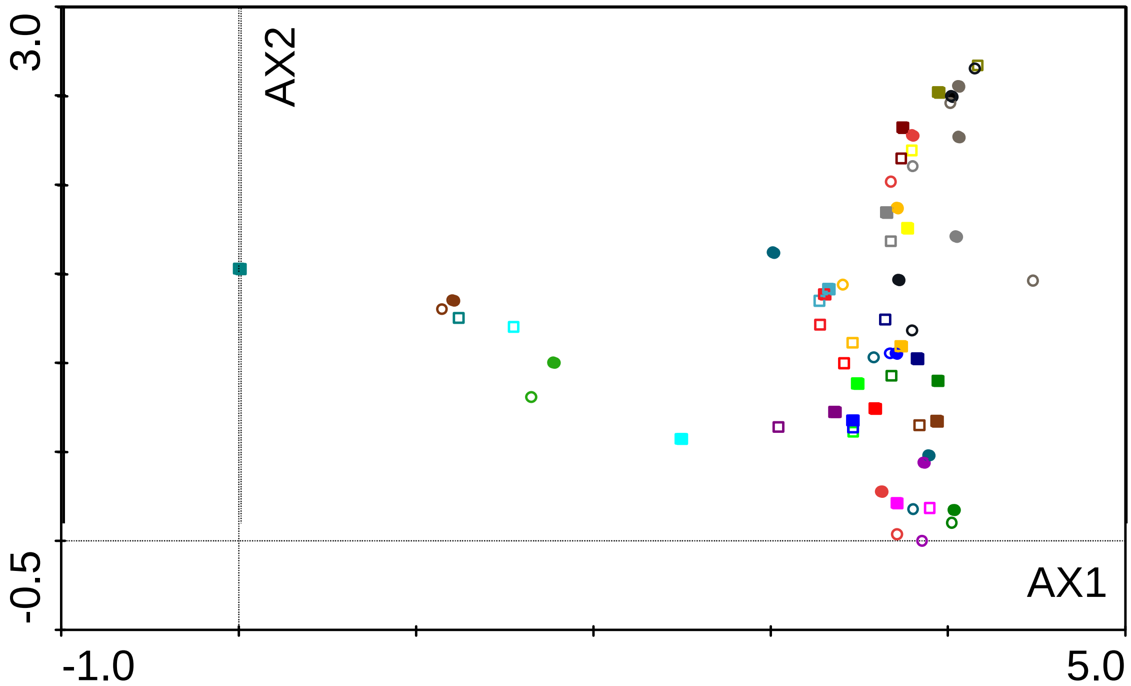


Figure 17: Displacement over time of the sample scores. Colour and shape of the symbols represent the PQs, open symbols = 2011, closed symbols = 2012. This plot can be overlaid with the plots in Figs. 14 and 15.

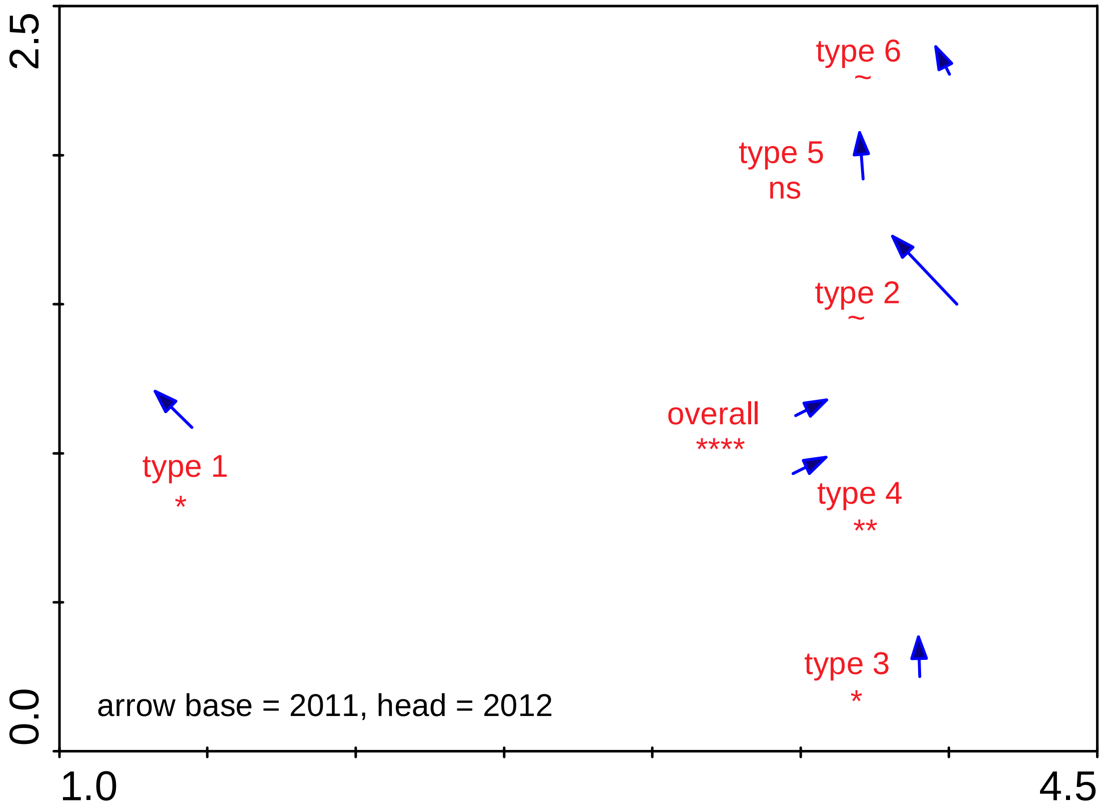


Figure 18: displacement over time of the centroids per type. Symbols below the types indicate significance levels: ****, P<0.0001; **, P<0.01; *, P<0.05; ~, P<0.1; ns, P>0.1. This plot can be overlaid with the plots in Figs. 14 and 15.

For an interpretation of these results, we need to use a priori knowledge about the Workummerwaard system. As the areas is under direct and constant influence of the lake (and it's fixed water tables), the elevation is strongly related with the distance from surface to the water table. Different vegetation types (e.g. marsh vegetation, wet meadow, dry meadow) occupy distinct positions in the elevation gradient (see Fig. 10). Since we did not measure any hydrological parameters, elevation (Z coordinate) and cover of open water are the only proxies for hydrological conditions in our analysis. Based on this analysis we concluded that the variability in the area's vegetation is mainly due to hydrological variability. Most probably, grazing is also an important factor for the area's vegetation (and possibly also one of the causes of the vegetation change), however we do not have quantitative animal density data that could be used as effect variables in a statistical model.

The change of the vegetation on the sand banks is most likely related to dynamics of the sediment (mainly erosion processes). We observed that some plots of this type that were located closes to the lake, were eroded or covered with fresh sediment in 2012, probably during the storms and flooding in autumn and winter. The changes in the short, wet meadow vegetation are most likely related to the high grazing pressure. Trampling of the soft, water-saturated soil results in local soil disturbances and patches of bare soil, which provide germination space for small, often short-living plants. Secondly, the grazing pressure is due to presence of geese in winter and spring. Geese favourably feed on short grass, efficiently remove almost all freshly growing shoots and keep the meadow very short. The study area hosts large overwintering population of geese, which was estimated to be c. 25 000 birds in 2011/2012 (for entire complex of meadows inside and outside of dikes, this population has increased from c. 8000 since 1990ties). Moreover geese tend to stay longer in the spring: in the 1990ties were staying in the area on average till April, while in 2012 were observed till beginning on June (per. comm. H. Pietersma, It Fryske Gea).

Also the change in the frequency of selected species, indicative for specific conditions supports the above-stated conclusions (see Fig. 19A). An increase of species of wet, open soil and species indicating brackish conditions was observed. At the same time the frequency of species of dry sand banks slightly decreased. A moderate increase of frequency of tall, wetlands plants is probably related to the late and less intensive grazing in 2012. At the same time we did not observe a consistent change of plant species richness, expressed as the mean number of species per plot (Fig. 19B). For most of the vegetation types there was no change in species richness over time. Such change was only found for types 4 (short, wet meadow vegetation: decrease of no. of species) and 5 (dry meadow type: increase of no. of species).

In summary, the effect of the sand nourishment on the vegetation composition is not clear and it would requires a longer monitoring period to assess such an effect.

A B

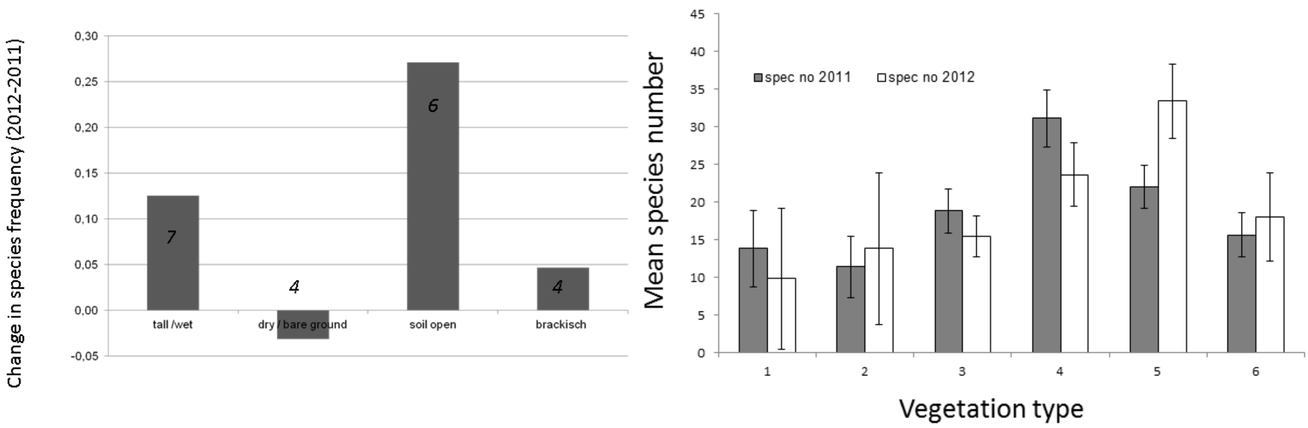


Figure 19: A: Change of the frequency of selected species between 2011 and 2012 (positive values indicate increase). The values are means of the several species of each group. The numbers in the columns indicate number of species used. Species used for calculation in each group: tall/wet: *Berula erecta, Bolboschoenus maritimus, Myosotis scorpioides, Phragmites australis (*small negative change*), Rorippa nasturtium-aquaticum, Schoenoplectus tabernaemontani, Veronica catenata*; dry/bare ground: *Tripleurospermum maritimum, Cirsium arvense, Geranium molle, Sedum acre*; open soil (wet): *Bidens cernua, B. tripartite, Juncus bufonius, Odontites vernus, Sagina procumbens*; brackish: *Centaurium pulchellum, Cotula coronopifolia, Glaux maritime, Spergularia marina*. B: Mean species richness per plot (4 m^2) in different vegetation types. Grey columns represent data of 2011, white columns of 2012. Error bars indicate standard deviation.

Photo 2: Grazing and trampling in the study area: grazing in 2011 in tall reed vegetation, relatively high number of animals (upper left); trampled soil in the soft soil in the short vegetation (upper right); high density of geese droppings in the short vegetation, indicating high grazing pressure (lower left); 'safe site' for plant germination and establishment in hoof print (lower right) (Photos: A. Klimkowska).

6.3. Additional remarks on vegetation

During the field work in 2012 we observed an increase in the abundance of algae in the shallow water and among the tall vegetation close to the location of the bio-dynamic dam (see Photo 3). This was only the case in a northern part of the area, on a limited stretch of the coast. It could indicate a higher nutrient availability in lake water.

We also observed many more (and larger) individuals of *Cotula coronopifolia (*Golden buttons) in 2012 than a year earlier (see Photo 3). It is a small, annual, salt-tolerant plant that indicates a wet, muddy (anoxic) soil and brackish water. This species is very rare on the Lake IJssel coast. We hypothesize that this increase of this species is due to the intensive grazing and trampling in 2011, as we observed these plants mainly in the hoof prints in the soft, moist, organic soil. We also observed several other species indicative for brackish conditions and open sites, wet, muddy soil.

We also observed evidence of recent shore erosion, where soil covered by dense vegetation was washed away (both short vegetation and reed stands), probably during strong storms. This shows that not only sand and shell banks are eroded (or covered with fresh or re-deposited), but also that sites with well-developed vegetation (see Photo 3). This indicates that the vegetation can withstand the water erosion and prevent soil erosion only to a certain extent. The "ecosystem engineering" working of this vegetation is thus probably only possible under low to moderate (wave, water and wind) erosion pressure.

Photo 3: Algae observed in the shallow water around bio-dynamic dam (upper left); *Cotula coronopifolia* - a relatively rare species indicating brackish conditions (upper right); resent soil erosion and washed away vegetation, located on the border between the sand shore and established vegetation; under shallow soil an accumulation of shells is visible (lower left); erosion of the root and rhizome mat of reed *Phragmites australis* on the lake coast (lower right)(Photos: A. Klimkowska).

6.4. *Vegetation structure and standing biomass*

We tested the differences in vegetation structure parameters between various vegetation types and between 2011 and 2012. We found no effect of time on mean vegetation height (simple ANOVA, effect of the vegetation type $p < 0.0001$, effect of time n.s., interaction term time x vegetation type n.s.). The cover of bare soil increased between 2011 and 2012, but the statistical analysis was not possible (Fig. 20A). Index of vegetation roughness was calculated as: [(cover of herbs * maximum plant height) - (cover of herbs * average plant height)]. We observed large variability of the vegetation roughness, but overall we did not find any changes of the vegetation roughness over time (Fig. 20B). Our results indicate that the variability in vegetation structure is naturally high in the study area. The vegetation structure differ per vegetation type, but also varies considerably within each type. The differences in vegetation structure over time are less pronounced. The mosaic of vegetation structure is also maintained by the grazing.

The biomass samples were collected during vegetation monitoring directly next to the PQs, a single sample for each PQ. Biomass was collected on 0.5 x 0.5 m plots, oven-dried (at 60 ^{o}C) and weighed. Biomass sampling was not possible on the sand banks and in the ditches or edges of the water puddles, due to scarce and very uneven vegetation. Sampling in such conditions would easily lead to overestimation of the biomass and would not be thus representative. In total 25 samples were collected.

The results are presented in Fig. 21. Biomass (dry weight) varied between 23.5 g m^{-2} and 1003.8 g m^{-2}, with the low values found in the short, wet vegetation dominated by *Agrostis stolonifera* (intensively grazed by geese), and high values found in the mosaic type of vegetation (type 6 with short and tall plants). The higher values generally agree with the biomass production found on mesotrophic to moderately eutrophic wet meadows, sedge meadows or fens with reed (Klimkowska 2009). The values at the lower end are in line with the standing biomass recorded on short grass vegetation in coastal salt marshes grazed by geese (van der Graaf 2006).

Aboveground biomass was significantly negatively correlated with elevation, with high values at low elevation and low values at high elevation (and in that sites grazed by geese) (Fig. 21). We did not find significant differences in biomass between the vegetation types.

Secondly we calculated a proxy for biomass by multiplying the herb cover percentage (expressed as fraction) by the mean vegetation height. This biomass proxy was compared with the measured biomass (Fig. 22). We found a strong relation between these two variables (R^2 linear = 0.828, $p<0.001$), justifying use of the biomass proxy, as a good approximation of standing biomass. Theoretically, the aboveground biomass could have an effect on increase of the elevation height (delta NAP Z), because of higher sedimentation in dense vegetation or because of faster growth and sediment fixation by plants. However, we did not find this effect (regression analysis, n.s.). In the next step, we tested if the biomass proxy changed over time (with biomass proxy for 2011 and 2012, and RM ANOVA analysis), but we did not find such an effect.

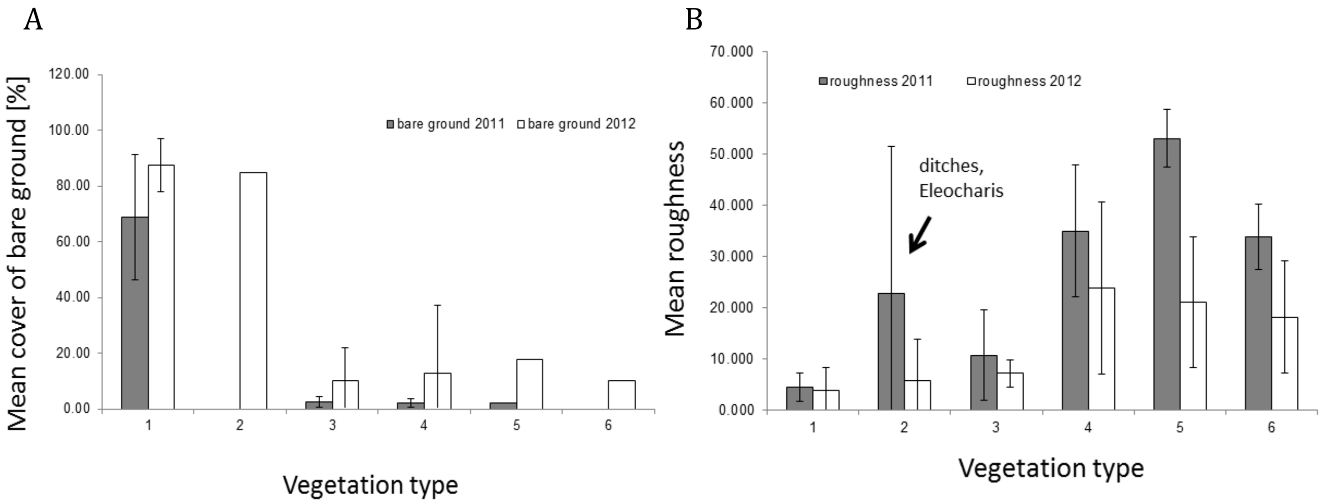


Figure 20: Selected vegetation structure parameters. Grey columns represent data of 2011, white columns of 2012. Error bars indicate standard deviation. A: Mean cover of bare ground per vegetation type. The statistical analysis were not possible because of too few data. Lack of column indicates that bare soil was not observed on the plots. Lack of standard deviation indicates only one plot with bare soil. B: Mean roughness per vegetation type.

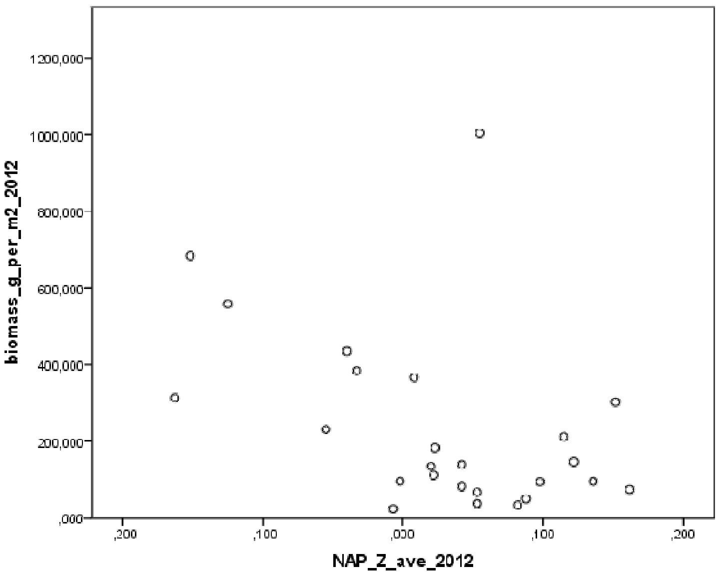


Figure 21: Standing biomass (dry weight in g per m^2) measures in 2012 plotted against elevation (m above NAP). Pearson Correlation coefficient -0.442, $p < 0.05$, n=25. Regression: R = 0.442, R^2= 0.195, F = 5.574, $p<0.05$. No trend line added.

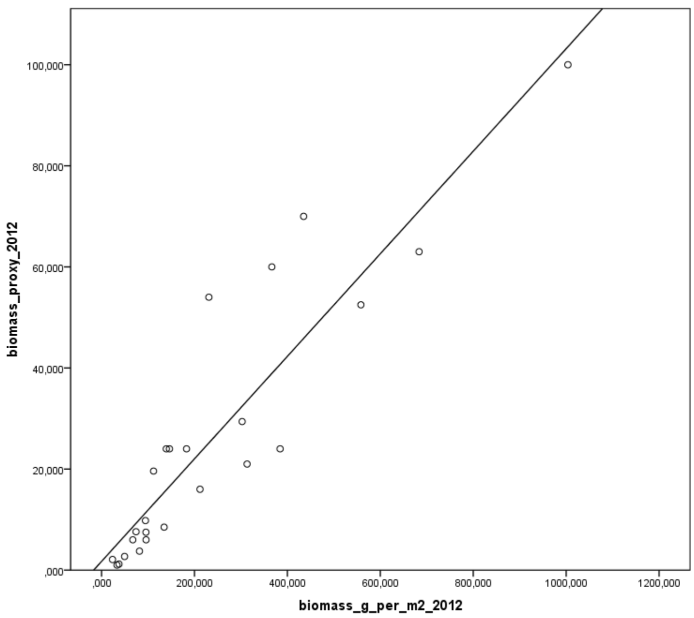


Figure 22: Correlation between measured biomass (X axis) and biomass proxy (Y axis). Pearson Correlation coefficient 0.910, $p < 0.001$, n=25. Regression: R = 0.910, R^2 linear = 0.828, F = 110.5, $p<0.001$.

We conclude that both the vegetation structure and aboveground biomass are affected by the same factors as vegetation composition: hydrological factors (and elevation) and most likely by grazing. In this study we did not include any measure of grazing intensity and hence, cannot quantitatively test the effect of grazing. However knowing the system of Workummerwaard this seems to be the most likely explanation.

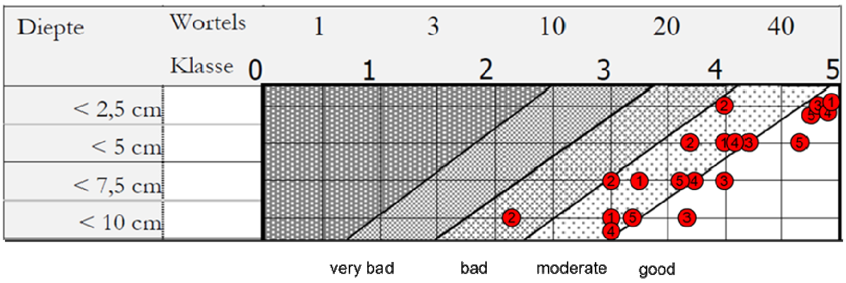
7. Root density evaluation

The results for rooting density evaluation for each transect and for the random points in the vicinity of the eco-dynamic dam are presented in Fig. 23. In this evaluation the rooting density is classified in four categories: good, moderate, bad, and very bad, according to the safety standards developed for vegetation on levees. Each plot was assigned to the category with the majority of the points (layers in which the rooting density was described). We used a conservative evaluation rule: in the case the plot had two points in the higher category and two points in the lower category, it was assigned to the lower category.

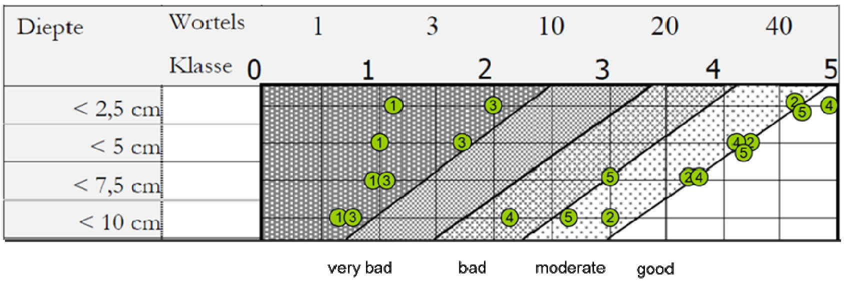
On transect 1 most of the plots were evaluated in category “moderate” (1,2,4,5) and one in category “good” (point 3). The erosion resistance of the vegetation in this transect can be described as relatively high. In transect 2, two plots were evaluated in category “very bad” (1,3) and the rest (2,4,5) in category “moderate”. In transect 3 the situation is more diverse: plots were evaluated in category “very bad” (2), in category “bad” (1,3,4,5), with the single –layer evaluations scattered over the graph. In general the erosion resistances of the vegetation in this transect can be described as low. In transect 4 most of the plots were evaluated in category “good” (2,4,5,6) and “moderate” (1,3). In this transect the erosion resistance of the vegetation was highest. In transect 5 the situation is very diverse: the plots were evaluated in category “good” (2), category “moderate” (4,5), category “bad” (3) and category “very bad” (1). The random points in the vicinity of the eco-dynamic dam were classified as category “moderate” (2,5,6), “bad” (1) and “very bad” (3,4).

In general the sparse vegetation on the sand and shell banks, and the vegetation in very wet or inundated places lower in the landscape (e.g. lower than the summer water levels in IJsselmeer) showed the lowest rooting densities and therefore the least erosion resistance. The two transects in the northern part of the study area (1 and 4) were mostly characterized as ‘good’ or ‘moderate’. These are also the transects that do not include sand banks. Most likely the erosion processes in this part of the area are less intensive. In the other three transects (2, 3 and 5) the situation varied and was in general classified as ‘ bad’ or ‘moderate’. Based on the root density evaluation, it seems that the part of the area most vulnerable to erosion is located around transect 2, close to the lake.

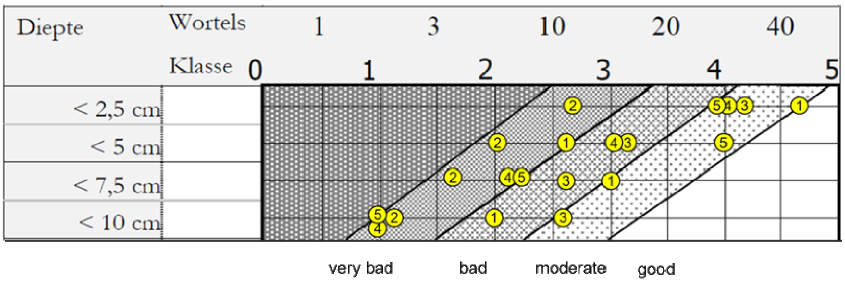
Transect 1



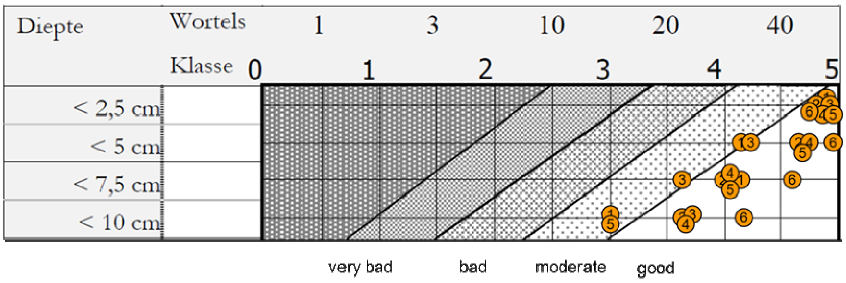
Transect 2



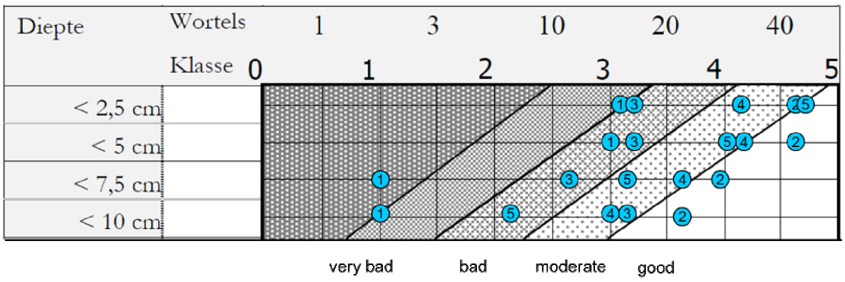
Transect 3



Transect 4



Transect 5



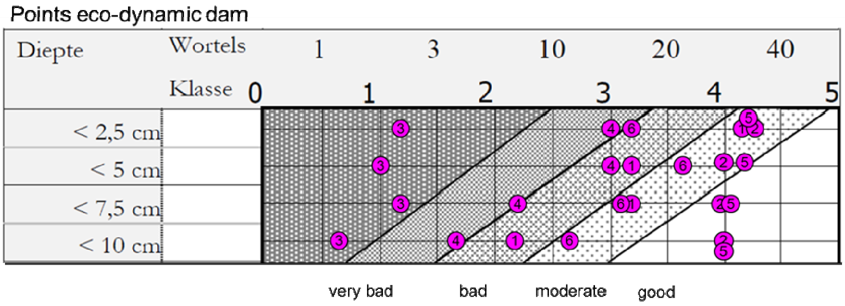


Figure 23: Results of the rooting density evaluation. The numbers in the circles indicate the plot locations in each transect, with number 1 for the plot closest to the water and 5 or 6 for plot furthest away from water line; L50 to L55 are the random points. For each point there are four circles, that correspond to sample depth; evaluation was performed in 4 layers, 2.5 cm each, up to the depth of 10 cm.

8. Root biomass evaluation

In section 7 we presented the results of the root density evaluation, according to the safety standards developed for vegetation on levees. The vegetation on dikes usually consists of short, homogenous grassland, only accidently inundated in winter and mown or grazed with sheep. However, the vegetation in our study area is much more heterogeneous, consisting of moist and wet meadow types, marshy vegetation, brackish meadows and pioneer species of sand banks or muddy puddles. The root systems and plant growth forms of such vegetation differ from the situation in the mesic meadows (usually established from the seeds mixtures by men) on dikes. Consequently we suspect that the standard safety standards evaluation procedures are insufficient in the natural vegetation of the Workummerwaard. Therefore we used a direct evaluation of root biomass as an alternative method which might provide a better understanding of the differences between the vegetation types in terms of erosion safety and soil erosion resistance.

The estimation of the belowground biomass is labour-intensive, required separate fieldwork and could not be carried out within the monitoring project. This additional work was accomplished in the framework of a student internship project co-organized by Stichting Bargerveen (Nijmegen) and Radboud University Nijmegen (carried out by Baiba Bekiša, supervised by dr. Agata Klimkowska), and supported by the terrain manager 'It Fryske Gea'.

8.1. Set-up of the study and sampling methods

The present study aims at evaluating the root biomass in different vegetation types and its relation with the aboveground biomass. We expected differences in above- and belowground biomass in the studied vegetation types, due to differences in elevation and related to the presence of anoxic conditions in the lower sites that are often or continuously inundated; or related to the soil substrate; or due to nutrient availability. Anoxic soil conditions limits root development and forms a stress factor for vegetation growth.

Belowground and aboveground biomass were sampled in four main vegetation types. The selection of the vegetation types was based on the variability of vegetation structure. These were also proposed as four functional types, located along the elevation gradient and likely to differ in their role in erosion prevention.
The following four vegetation types were sampled:

- (1) vegetation on sandy banks, in sites that are in the process of being colonized by vegetation (called 'bank'),
- (2) marsh vegetation, with relatively tall and productive plants (called 'tall vegetation', sites with moderately tall and dense vegetation were selected, as stands of a dense reed are not extensive in the area),
- (3) open, short and wet meadow vegetation with *Agrostis stolonifera* and *Carex nigra* (called 'short vegetation'),
- (4) drier meadow type with *Festuca rubra*, located at the foot of a dike but not on the slope of the dike itself (called 'dike vegetation').

Biomass was sampled in 5 transects, spread over the northern part of Workummerwaard (see Figs. 24 and 25). The position of these transects was deliberately different from the transects used for the vegetation monitoring, in order to avoid disturbance and undesired effects on the monitoring plots. Nevertheless the results are fully comparable, as they were taken in similar vegetation types and located in the same area. Four plots (of c. 5 x 5 m) were established on each biomass sampling transect– each in a different vegetation type. Within each vegetation type sampling plots were located randomly. In total 20 plots were established, resulting in 5 replicates for each vegetation type. Also the elevation of the plots was measured by DGPS (vertical accuracy of ±2 cm). In each plot 5 sub-measurements were taken and averaged in order to account for the variability in the micro and meso-relief.

Belowground biomass was sampled with a 8-cm diameter soil volume sampler. This type of soil corer was chosen because of the expected variability of the root systems and the abundance of species with thick and bulky roots (e.g. *Phragmites australis*) (see Sollie 2007, van den Wyngaert 2001). On each plot five soil cores were collected at random to a depth of 20cm in 10cm intervals (organic soil layer 0-10 cm and mineral layer 11-20 cm) and bulked into one sample per each soil layer. Deeper samples (21 -30 cm) were only collected in tall vegetation (with *Phragmites australis* and *Schoenoplectus tabernaemontani*). Deeper layers were not sampled everywhere because in this area sand usually occurs at a depth of 10-15 cm and below this depth we did not find much roots, except of in the tall vegetation. Roughly 80-90% of the roots occur in the topsoil layer of 0-30 cm, which is normal for productive, mesic, temperate grassland (Jackson et al. 1996). It can be expected that in wet meadows and in wetland the rooting depth is even less.

Samples were transported to the lab as soon as possible, stored cool, and processed within few days after sampling, to minimize the risk of decomposition. Roots were separated from the soil by washing with water on a series of sieves (Tufekcioglu et al. 1999). Afterwards the samples were oven-dried at 70 ^{o}C for 48 hours and weighed (Ping et al. 2010). Samples processed in this way provide information about the moderate and larger size roots, but not about the fine root fraction (< 1 mm diameter), which are fragile and mechanically destroyed during transport and processing and possibly also decompose within a few hours after sampling.

Together with the root sampling, the aboveground biomass was sampled by clipping all standing vegetation (excluding mosses) on the same sites as root sampling or in the direct vicinity in the same vegetation type. All vegetation was clipped near to the soil surface and the dominant species were noted. Sampling was carried out on 4-5 quadrates of 0.5x0.5 m. Their values were averaged and a single value per plot was used. Per vegetation type we thus collected 24 sub-samples, in total 96 sub-samples. Biomass was oven-dried at 70 deg. C for 48 hours and weighed. Sampling was carried out at the end of May 2012. The time of root sampling is not restricted to a certain time of the year, but the aboveground biomass should be standard sampled at peak standing crop, which in the study area is probably about end of June. The aboveground biomass records are thus not fully representative, but can indicate relative differences between vegetation types and can be used for comparison of above- and belowground biomass, as they were collected at the same sites and in the same time.

Also a soil chemical analysis were carried out, in order to evaluate the pH, nutrient availability and salinity effects on the vegetation. Soil samples for chemical analysis were collected in the same plots as the belowground biomass sampling. The samples were collected to a depth of 0-10 cm with a 5-cm diameter soil corer. Each soil sample consisted of five pooled subsamples. Additionally, at 4 plots the soil samples were also collected in a deeper layer (10 - 20 cm) to test if salinity differed between shallow and deep soil layers. This effect was expected to be homogenous in the study area (Cl is known to be a mobile, and the study area is frequently flooded and directly affected by the lake water regime). Soil was analysed for pH, PO_4, K, Na, Cl in water extract; pH, NH_4 and NO_3 in KCl extract; and plant-available P-Olsen, and total concentrations of N, P, C, Ca, S (for details on methods see Bekisa 2012). Here we only present some relevant results of the soil chemical analysis.

8.2. Results of the root biomass evaluation

Elevation height varies within each vegetation type but significant differences in elevation between vegetation types were found only between the sand bank and the other vegetation types (Fig. 26). The scarce vegetation of sand banks was found on the most elevated sites (mean height 0.32 m above NAP), but also the dry meadow (dike) vegetation has rather high position (mean 0.16 m above NAP). The tall (wetland) vegetation occupied the lowest sites (mean 0.04 m above NAP) and the short vegetation took an intermediate position with mean 0.10 m above NAP.

The above- and belowground biomass, as well as the soil chemical analysis were averaged for each site and each vegetation type, and the differences between the means were tested with one-way ANOVA (SPSS 19.0). Normal distribution of the biomass data were checked prior to the analysis. We found significant differences between the vegetation types in terms of aboveground biomass (Fig. 27A), which was highest and relatively variable in tall vegetation, and was significant different ($p < 0.01$) from all other vegetation types. The aboveground biomass in sand bank vegetation was significantly higher than in short vegetation ($p < 0.04$). This was probably related to the fact that the sampling in the sand banks was carried out in the spots already colonized by vegetation but also to the high grazing intensity in the short meadows (mainly by geese, rabbits and later in the season by cattle).

We also compared the aboveground biomass of the two sampling periods (May, together with the root sampling, and June, together with the vegetation sampling of the PQs, Fig. 28), and did not find significant overall differences. The sampling was not done in the same plots, but in the same vegetation types, except the bank vegetation (which was not sampled later in the season).

The higher aboveground biomass on the bank and tall vegetation types was probably related to a higher availability of nutrients, which is supported by the soil chemical analyses. The nutrient availability on the sand banks was probably influenced by the nutrient input from the lake: from the organic material deposited during floods and from nutrients dissolved in lake water. A relatively low aboveground biomass can be explained by intensive grazing by geese, especially early in the season (in total 11-25 000 geese in the area). According to It Fryske Gea, geese populations of *Branta* *leucopsis* and *Anser anser* are increasing every year and they leave the winter grazing areas late (in 2012 in the beginning of June).

The belowground biomass (0-10 and 11-20 cm combined) was remarkably greater than aboveground biomass in all vegetation type (Fig. 29). The belowground biomass is contributing more to the biomass production than aboveground biomass according to Turner et al. (2004) and Dwire et al. (2004) and our study shows similar results.

The differences between vegetation types were less obvious: we found significant difference between belowground biomass in bank vegetation and dike vegetation types ($p < 0.04$). The belowground biomass of dike vegetation was relatively highest, most probably due to the absence of anoxia stress. The low root biomass in bank vegetation is probably related to a stressful environment because of frequent flooding, droughts and little or none organic soil layer. The low belowground biomass of bank vegetation was also related to a low vegetation cover, low abundance of grasses and presence of annual plant species that usually have a less developed root system. During the field work, we noticed that bank vegetation and tall marsh vegetation have simple and long roots or rhizomes, while other vegetation types produce a dense root mat.

The vertical distribution of belowground biomass was distinctive for all vegetation types, but significant differences were only observed in the upper soil layer (Fig. 30). Significant differences in root biomass in the topsoil layer were found between the bank vegetation versus short and dike vegetation ($P < 0.01$ and $P < 0.001$, respectively), and for the tall vegetation versus short and dike vegetation ($P < 0.05$ and $P < 0.05$, respectively). For all vegetation types the belowground biomass in the top 10 cm was higher compared to the deeper layer (10-20 cm). In the deepest layer (20-30 cm) roots were sampled only for the tall vegetation and therefore no comparisons could be made. In the tall vegetation we found roots in the deep soil layer, but with a low biomass (7.6 ± 3.0 kg m^{-3} dw.) and this layer had the smallest contribution to belowground biomass.

The species dominating in tall vegetation: *Phragmites australis, Schoenoplectus tabernaemontani, Scripus maritimus, Mentha aquatica,* and other species have rather vertical network of long and stout rhizomes (Dwire et al. 2004). Due to their rhizome with well-developed aerenchyma, roots can reach in deeper soil layers and these species produce a fairly high belowground biomass in low oxygen or anoxic environments. For that reason, the bank and tall vegetation has a higher root biomass in the depth of 10-20 cm. In contrast, the root biomass in the drier vegetation types (short and dike vegetation) was concentrated in the first 10 cm of the soil surface. In general, grassland species do not have extensive belowground structures and have shallow roots that extend horizontally near the soil surface (Dwire et al. 2004, Tilman & Wedin 1991). This is the case for the grassland species such as *Trifolium repens, Bellis perennis, Festuca rubra* found in our study area. Bakker's (2003) study on the impact of large and small herbivores on vegetation dynamics revealed that grazing by small herbivores can stimulate the production of belowground biomass (especially for grasses).

The correlation (Person correlation test) between the biomass of above- and belowground was weak and not significant (Pearson's $R= 0.049$, $P= 0.838$).

Photo 4: Samples of roots from the top soil layer in short vegetation (upper left); samples of roots from deep soil layer in tall vegetation (upper right); fresh sandy sediment deposited in the winter season 2011/2012 (lower left); patterns of soil erosions in the water puddles, the die-back of vegetation after long time inundation and the 'step' between puddle and meadows vegetation are visible(lower right) (Photos: B. Bekisa; A. Klimkowska).

Figure 24: Location of the root biomass sampling points (blue dots), in relation to the PQs (red dots), northern part of the study area. Vegetation types are B: bank, T: tall, S: short, D: dike. The number (B1, T1, etc.) indicates the transect number. Background: high resolution aerial photo of the Workummerwaard, taken in early spring 2011 for monitoring project.

Figure 25: Location of the root biomass sampling points (blue dots), in relation to the PQs (red dots), southern part of the study area. Background: high resolution aerial photo of the Workummerwaard, taken in early spring 2011 for the monitoring project.

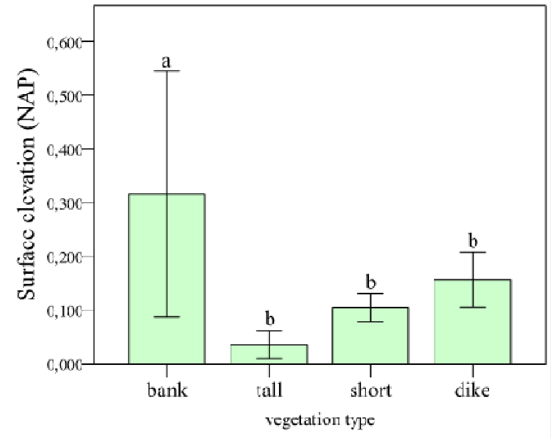


Figure 26: Elevation (m above NAP) of vegetation types. Error bars represent SD of the mean (n= 5), and different letters denote a significant difference level between types (p<0.05), tested with post-hoc LSD test (one-way ANOVA).

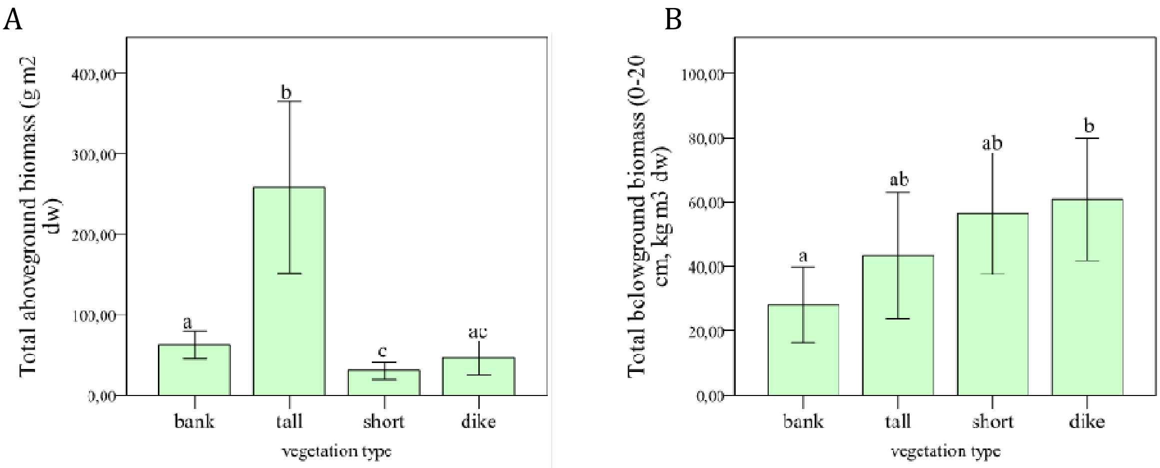


Figure 27: A: Mean aboveground biomass (mean ± SD) in g m^{-2} dry weight tested with one-way ANOVA, n=4 or 5. B: Mean belowground biomass, cumulative in 0-20 cm soil layer (mean ± SD) in kg m^{-3} dry weight tested with one-way ANOVA, n=5. Different letters indicate significant differences according to LSD tests (p < 0.05).

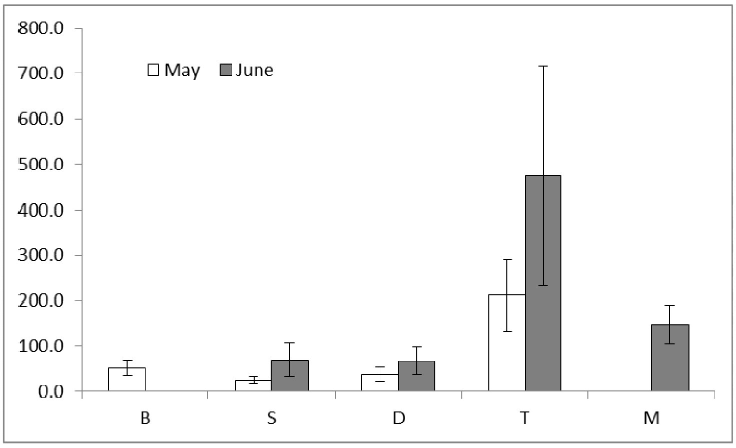


Figure 28: Mean aboveground biomass (mean ± SD) in g m^{-2} dry weight for the two sampling dates in 2012. Vegetation types: B: bank, S: short, D: dike, T: tall, M: moderate tall. White columns = May sampling; grey columns = June sampling; error bars indicate the SD of the mean. Sampling in May: 5 replicates, 24 subsamples per type; in June (vegetation reclassified to be consistent with the earlier sampling): S n=7, D n=3, T n = 9, M n=6.

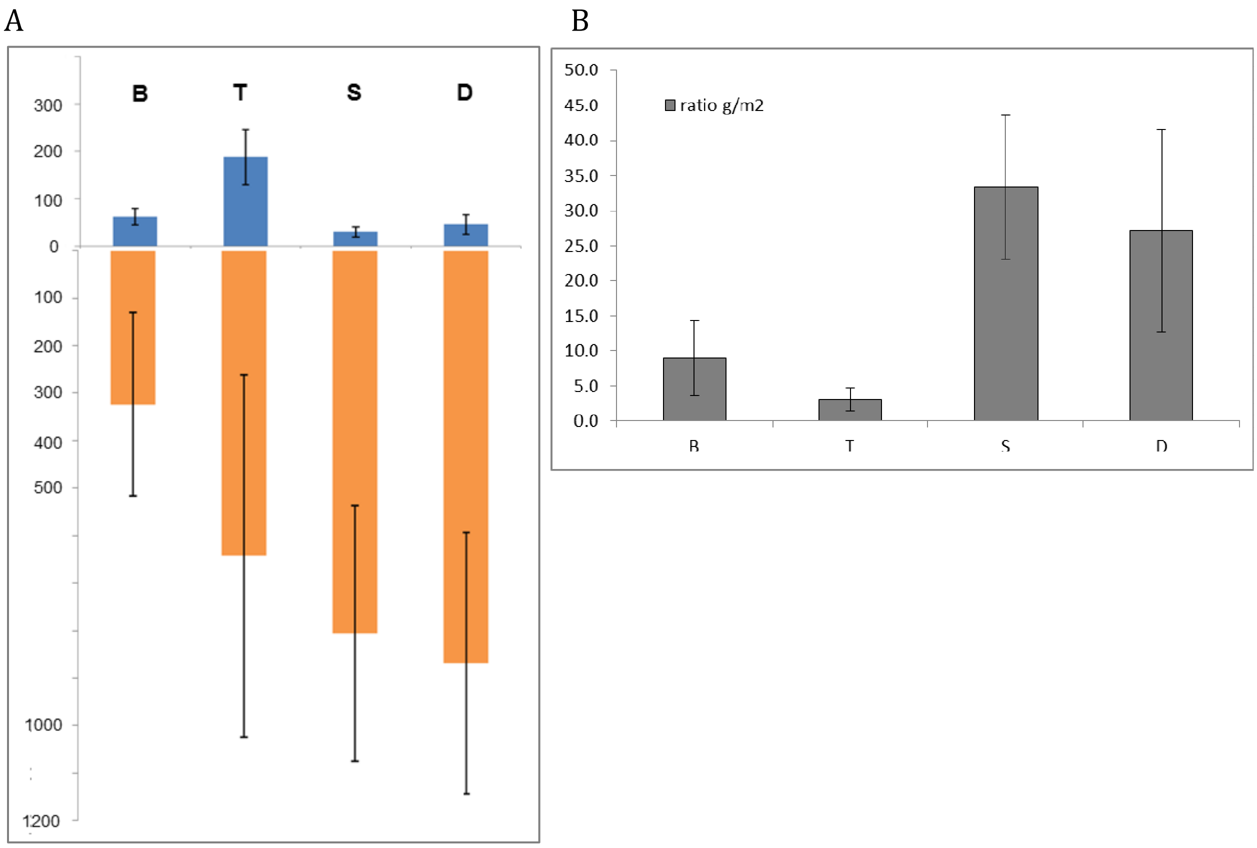


Figure 29: A: Aboveground and belowground biomass in 0-20 cm soil layer (mean ±1 SD, n = 5), expressed in the same units [g m^{-2} dry weight]. B: Belowground to aboveground biomass ratio per vegetation type (mean ±1 SD, n = 5). Vegetation types: B: bank vegetation, T: tall vegetation, S: short meadow, D: dike vegetation (drier meadow type).

In the regression analysis we did not find any relation between belowground biomass and elevation. However, we found a significant relation between the aboveground biomass and elevation (Fig. 31), if the bank vegetation plots were removed from the model. The bank vegetation was sampled on relatively elevated sites compared with the rest of the area and the standing biomass there might not be fully representative, because of the patchy vegetation. The regression model confirms the relation that was found in the section 6.4 (using the records from vegetation monitoring plots). More elevated sites (short and dike vegetation) were heavily grazed by geese before and during sampling, and thereafter less standing vegetation was found on these sites, which could have influenced this relation. Concerning the belowground biomass, the only significant correlation was found with soil pH (Fig. 32), where root biomass decreases with higher soil pH, which could be also associated with a lower nutrient (P) availability.

The results of soil chemical analysis were tested for differences between the vegetation types with one-way ANOVA, with post-hoc LSD tests. The factors that deviated from normal distribution were transformed in order to improve the normality (log-transformed, Cl square root transformed). Paired t-test was applied to test differences between the topsoil organic layer (0-10 cm) and lower-laying mineral layer (10-20 cm). All statistical analysis were performed in SPSS version 19.0 (SPSS, Chicago, Illinois, USA).

Some of the characteristics of the study site can be explained by biogeochemical processes. Our results cannot be directly compared with other studies, because the studied area has been strongly disturbed and changed by man. Probably old succession stages of dune slack is the system most similar to ours, as both systems have similar abiotic characteristics: poor to moderately rich in nutrients, high pH and high calcium concentration. In terms of measured soil chemical parameters we found little differences between the vegetation types. The main differences existed between the bank vegetation and other types. The soil of bank vegetation had a higher pH, lower total N content, and seemed to be richer in phosphate (PO4 and Olsen-P, but the differences in Olsen-P were not significant; see Fig. 32). In general the Olsen-P concentration in the organic soil was corresponding with c. 800 μmol/l which is consistent with the values found in the Dutch marshlands (from 300 to 800-1200 μmol/l). Because of relatively high pH (>7) and high Ca concentrations the availability of phosphate is limited. This is also a factor that most likely limits the site productivity.

The total N content was higher in tall, short and dike vegetation and lower in bank vegetation, which was related to low organic matter content. The average nitrogen concentrations indicate that the study site is moderately nutrient poor, compared to the other wetlands types, for example wetlands in the river floodplains in the Rhine-Meuse estuary (Loeb et al. 2008). The concentrations of the nitrogen forms (NH_4 and NO_3) did not differ significantly among the other vegetation types. Total S, Na and Cl concentrations indicated the system still has some salinity gradient. On average chloride and sodium concentration in the organic soil exceeded 700 μmol/l, and 860 μmol/l respectively, in the studied area, corresponding with low to moderate salinity. No significant differences between the soil depths were found (0-10 cm and 10-20 cm). We found lower Cl concentration in the soil of sand banks than in other vegetation types, most probably related to a more frequent flooding with lake water. The same pattern as for the Cl concentration was observed also for the S and Na concentration. This indicated moderately brackish conditions, comparable to e.g. salinity in dune slacks on Texel, ranging between 182 and 7464 µmol/l for chloride concentrations (Van de Craats 2012). A remnant of the salinity from the past is thus still present in the system, which also explains the fact that some species indicative of brackish meadows and marshes are still present in the vegetation.

A multivariate analysis indicated generally more eutrophic conditions and higher pH in the tall vegetation and higher concentrations of chloride in the short meadows and at the foot of the dike (results not shown). This salinity gradient was reflected by presence species such as *Glaux maritima* and *Juncus gerardii*. Further analysis indicated that the variation in the vegetation composition was significantly correlated with only two factors: pH and NH_4 concentration. Full data and description of the results are given in the student rapport (Bekisa 2012).

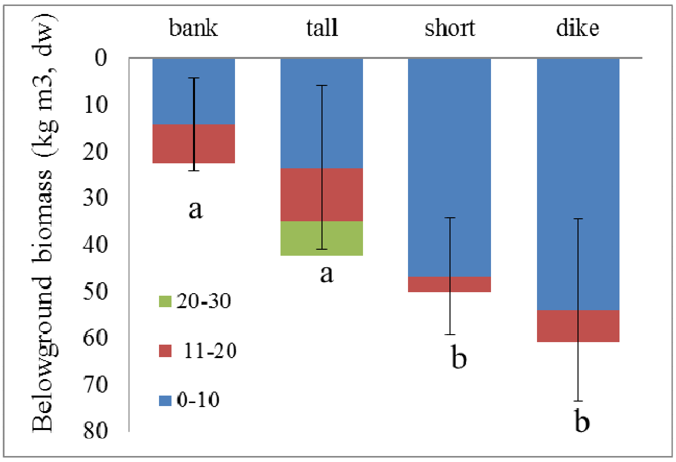


Figure 30: Vertical distribution of root biomass [kg m^{-3} dry weight] for the vegetation types (n=5). Different letters denote a significant difference between mean groups for the first soil layer (tested with one-way ANOVA and post-hoc LSD tests, a significance level at $p < 0.05$). Error bars indicate a standard deviation of the mean for the first soil layer. The second layer had no significant differences.

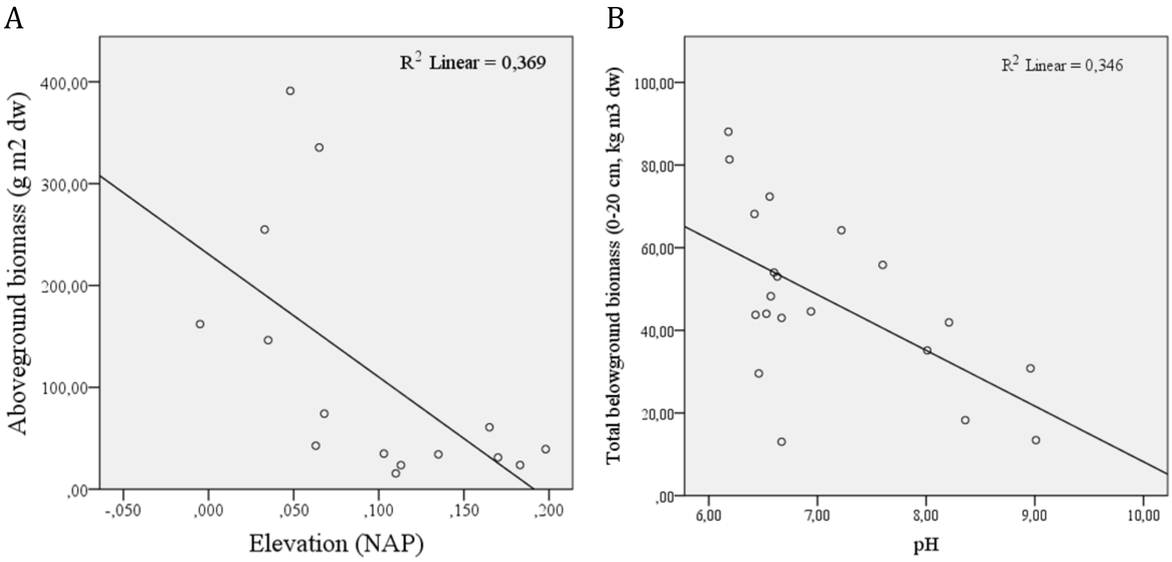


Figure 31: A: Regression of aboveground biomass (g m^{-2} dw., n=5 or 4) on elevation (m above NAP, n=5), R^2 linear = 0.34, p = 0.016. B: Regression of belowground biomass (kg m^{-3}, n=5) on soil pH (pH units, n=5), R^2 linear = 0.35, p = 0.006.

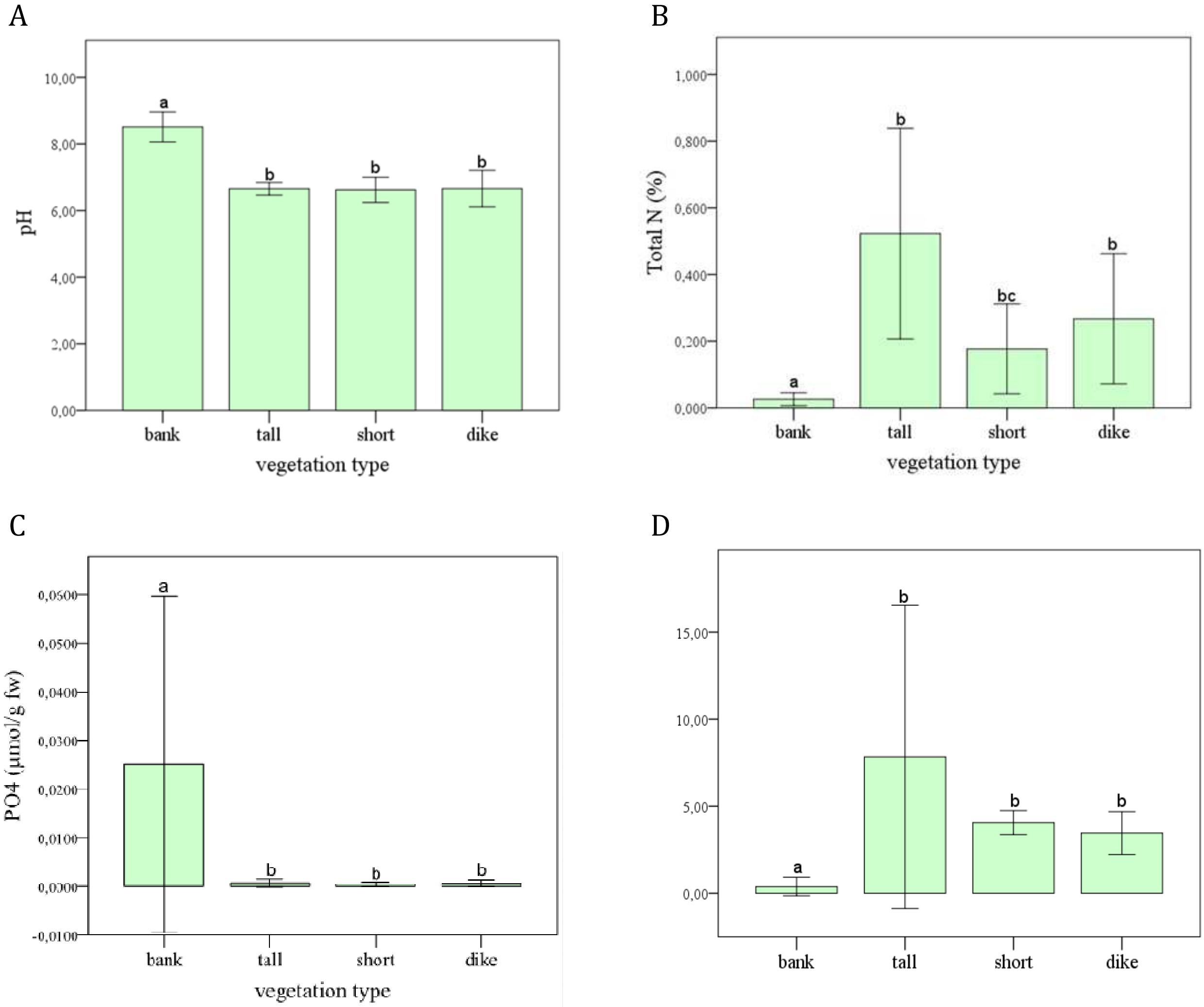


Figure 32: Soil chemical characteristics: pH (A); total nitrogen content (in %) (B); concentration of mineral PO4 (C); and concentration of Cl in µmol/g dw (D), in different vegetation types. Means ± SD are presented (n=5). Differences between groups were tested with one-way ANOVA ($p < 0.05$) and multiple comparisons with LSD test, different letters indicate a significant difference between means ($p < 0.05$).

8.3. Discussion and conclusions

Wetlands act as natural buffers against water and wind erosion. However, the effectiveness of such buffers depends on several factors such as the size of the area, slope and vegetation type. In Lake IJssel the water table is 0.20 m below mean sea level (m.s.l.) in summer, while during the rest of the year, a level of 0.40 m below m.s.l. is maintained (Rijkswaterstaat and Ministry of Infrastructure and the Environment 2011). This controlled hydrological system suggests that vegetation experiences flooding during storms in winter, early spring and in the autumn, and most of the erosion and sedimentation probably occurs at such occasions. But also high water tables may occur in summer, causing anoxic conditions in the shallow soil layers. This could limit the vegetation's ability to reduce wave energy and prevent erosion, compared to a more natural system. On the other hand, this is probably a factor that reduces the productivity of the system, and thereby allows the maintenance of a diverse habitat for meadow birds. Hypothetically, the vegetation in a coastal area can act as an ecosystem engineer by improving the sedimentation or by fixing the sediment (Jones et al. 1994, Bruno 2000; French & Reed 2001). In general, taller and more rough vegetation (in terms of aboveground biomass) was found to slow down the current velocity, reduce wave energy and trap sediments more effectively than short or scarce vegetation, and thus had a higher contribution to coastal protection (Wolters et al. 2005; Borsje et al. 2011). Vegetation that promotes an increase of elevation also prevents shoreline or dike from erosion (Borsje et al. 2011). Some of the proposed mechanisms involve colonization of bare sediment by plants and fixation of the sediment by their roots.

Many studies have focused on the effects of aboveground biomass in protecting soil against erosion, but little attention is given to the belowground biomass. The importance of roots for resistance against erosion have been stressed in literature (Gyssels & Poesen 2003, 2005; Baets et al. 2005,2007). All studies found that roots as well as shoots contribute to the reduction of soil erosion rates if topsoil has a dense root mat, particularly in the case of low aboveground biomass. Roots forming dense mats are important for stabilizing and protecting the soil against being washed away during floods and storms. In general, shallow but dense root networks are more favourable and effective to prevent water erosion than deep and sparse root systems. Moreover, it is emphasized by these authors that once the aboveground biomass disappears (in winter or due to grazing), only roots can offer resistance to erosion by water. While aboveground plant biomass decreases the flow velocity, dense root layer holds soil particles in place, bind soil particles at the soil surface and increase the surface roughness (Gray & Sotir 1996). However, other studies emphasized that while vegetation (and its roots) may result in coastal protection, at the same time, biotic elements cannot secure a full provision of this type of ecosystem service e.g. under high erosion energies in extreme weather conditions (Koch et al. 2009). There are limits what could be expected from these types of ecosystem engineering effects of vegetation.

In this study we found that roots in the short and dike foot vegetation occur in a dense and uniform mat in the top 10 cm of the soil. These would provide a relatively high protection against soil erosion. The root biomass of the bank and tall vegetation seems to be least effective in coastal protection due to a lower biomass and a different distribution of roots in soil (deeper and less dance). However, on the other hand, during the growing season, the high standing plant biomass in tall vegetation would contribute to slowing down waves and flow velocity. The belowground biomass found in our study was low in comparison to the root biomass (live + dead) in the 0-30 cm measured in salt marshes by Turner et al. (2004), where it ranged from 1612 to 6608 g m^{-2}. On the other hand salt marsh systems are often rich in nutrients because of their clay soils and are dominated by plants adapted to salinity stress.

The results of the root biomass study more or less agree with the conclusions of the root density evaluation, although they emphasize that in terms of soil erosion prevention (1) the tall vegetation has a lower than expected value, (2) the short vegetation (under impact of grazing) has a moderate value, although the long-time inundation and anoxic conditions in shallow puddles result in a limited soil erosion prevention capacity. The erosion prevention by short vegetation is probably also limited to moderate erosion energy. The sparse vegetation on banks and vegetation, laying lower in the landscape (ditches, puddles), had the lowest rooting density and, therefore, the least erosion resistance. The exact energy thresholds for the various vegetation types and a range of the values of energy during flooding and storms occurring in the area are not known and should be studied in the future.

We observed that soil erosion has different forms in the study area. The dynamics of sedimentation and erosion on the sand and shell banks are very obvious. In the short vegetation a pattern of shallow water puddles occurs, which are situated lower in the landscape, with no or little aboveground biomass and, consequently, with little roots. These structures are remnants of old drainage ditches and creeks that were present on sand banks and coastal marshes. A network of shallow water puddles arises probably from wave erosion in shallow, open water, combined with dieback of the vegetation during long-term inundation and anoxia. In these puddles water stagnates for a longer period after heavy rainfalls or floods. Due to the action of wind and waves the edges of the puddles are exposed to erosion, producing sharp 'steps' of c. 10-20 cm. This kind of erosion could stimulate faster erosion during the winter and spring storms.

From these results we conclude that roots help to protect the dike and foreland from erosion, but with higher wave energy and more intensive storms most probably roots would be insufficient to prevent the erosion processes. Most likely, a mosaic of tall and short vegetation fulfils best the function of soil erosion prevention in the area, due to differences in allocation of above- and belowground biomass. This also stresses the importance of evaluating the entire vegetation and elevation gradient of such coastal areas, and not e.g. focus only on one particular type of vegetation or one section of the landscape.

9. Synthesis and recommendations

The monitoring was carried out on 5 transects, with 5-6 permanent monitoring plots (PQs) on each transect. Additionally several PQs were established around bio-dynamic dam. On all plots the vegetation composition, vegetation structure and local elevation height were recorded in June 2011 and 2012. Additionally data on root density and above and belowground biomass was collected in the study area.

The effects of the sand nourishment on vegetation are not clear and a longer period of vegetation monitoring is required for a reliable evaluation. After collecting data in the following years we can gain a better understanding of the vegetation development in the areas and possibly separate the impact of the sand nourishment from natural development and effects of other factors such as grazing.

The vegetation of Workummerwaard is heterogeneous, moderately species-rich and represents an interesting (from the ecological and landscape point of view) gradient situated along the elevation gradient. It consists of several types of grassland and wetland vegetation, and includes species indicating fresh and brackish conditions. The processes strongly affecting the vegetation include hydrological regime (flooding, water table variation), erosion and sedimentation and locally intensive grazing. On the basis of the analysis of the vegetation and its change over time we conclude that the vegetation in the area is mainly driven by hydrological factors and by occurrence of soil disturbance, either sedimentation and erosion, or related to grazing. These results can be, however, incomplete, because we did not include direct measurements of hydrological parameters, soil chemistry, or grazing pressure in the analysis. Change was detected mainly in the vegetation of the sand banks and short, wet meadow vegetation. The changes of the vegetation on the sand banks is most likely related to dynamics of the sediment, mainly erosion. The changes in the short, wet meadow vegetation are most likely related to the high grazing pressure.

The vegetation structure and aboveground biomass were both very variable in the area and even within the same vegetation type, which can be expected in the presence of heavy grazing. We did not find any significant temporal change in the vegetation structure or aboveground biomass, neither any relation between the vegetation structure and a change in the elevation.

The analysis of the elevation measured in the vegetation indicated an increase over time (i.e., between 2011 to 2012). Such an increase seems to occur on all transects and in all vegetation types, although not in the same extent. However, the observed change is small, also in view of the measurement accuracy and the variability of micro-relief, and it is impossible to formulate strong conclusions after such a short monitoring period. At best we can speak about a trend for increase of elevation, which cannot be clearly ascribed to sand nourishment or sediment transport.

Based on the root density evaluation we conclude that the northern part of the study area has a ‘good’ or ‘moderate’ erosion safety. Most likely the erosion processes in this part of the area are less intensive. In the central and southern part of the study area the situation was variable but mostly had a ‘ bad’ or ‘moderate’ erosion safety. Based on the root density evaluation, it seems that the central part of the area (around transect 2, close to the lake) is most vulnerable to erosion.

Vegetation in coastal areas can act as an ecosystem engineer by improving the sedimentation or fixing the sediment. Many studies found that the root system can contribute to a reduction of erosion rates if the topsoil has a dense root mat, particularly in the case of low aboveground biomass. Some of the proposed mechanisms involve colonization of the bare sediment by plants and fixing the sediment by their roots. From our study on belowground biomass we conclude that roots help to protect the dike and foreland from erosion, but with higher wave energy or intensive storms roots would be insufficient to prevent the erosion. Most likely, a mosaic of tall and short vegetation fulfils best the function of soil erosion prevention, due to differences in allocation of biomass above- and belowground biomass. This stresses the importance of evaluating the entire gradient of the vegetation and elevation of such coastal areas, and not e.g. focus only on one particular type of vegetation or one section of the landscape. Study on the root biomass provided additional insight in the functioning of the area.

Photo 5: Vegetation mosaic and the system of Workummerwaard (Photo: A. Klimkowska).

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