Analysis of succession and the relation with hydrogeochemistry in a former tidal wetland in the Grevelingen, (the Netherlands) over a period of 43 years

What is the influence of soil development processes on the development of the vegetation in a former tidal wetland which is no longer inundated.

Supervisors: Prof. M.J. Wassen, Drs. M.J.J. van der Weiden

Different types of vegetation at the Slikken van Flakkee [1]

Tobias Kanters
3721787
Sustainable Development, track Global Change and Ecosystems
30 ECTS

[1] (Foto: Ilona Noorlander; https://boswachtersaanzee.wordpress.com/2016/05/31/voorjaar-op-de-slikken-van-flakkee)

Utrecht University

Summary

Deltas and estuaries are widely recognized as areas with important natural values that are under threat by human activities such as coastal defence. The Grevelingen estuary in the South West of The Netherlands was closed off from the North sea in 1971 to protect the area from disasters similar to the storm flood in 1953. The closing of the Grevelingen dam removed the tidal influence from coastal wetlands in the Grevelingen like the 'Slikken van Flakkee'. This started a new development leading to a new type of nature that was protected by the State Forestry Service by creating an nature reserve. In the northern part of the area, natural succession has led to the emergence of a diverse landscape containing forests and different types of grasslands. The southern part of the area which has been influenced by nature management in the form of extensive grazing and regular mowing has led to a more uniform landscape containing Red list plant species with high natural values.

The aim of this research is to determine which hydrogeochemical processes occur at the 'Slikken van Flakkee' area and what their influence is on the different vegetation types. Soil samples were collected from nine representative locations in the field and analysed in the laboratory. Vegetation data gathered since 1972 were analysed to determine the major trends in vegetation succession. We found evidence for desalination, pyrite oxidation and cation exchange. Desalination was the only hydrogeochemical process that had a significant effect on species composition. The observed difference between the vegetation types at the northern and the southern part of the area is due to the different management strategies.

A modelling study is recommended to gain insight into the past and future development of the hydrogeochemical conditions at the 'Slikken van Flakkee' to investigate whether the current management choices suffice to maintain the high valued Red list species in the area.

Preface

With my background as a marine biologist I have always been interested in the dynamics between human activity and ecosystems in coastal areas. Investigating the relationship between the effects of coastal defence measures was therefore a very interesting subject for my master thesis. During the research and the writing of my thesis I learned a lot about the dynamics between soil processes and ecosystem succession and I got fascinated by the unique species composition found in coastal wetlands. Even though data analysis using the statistical program R was not easy, I learned how gratifying it can be when you manage to visualize your data into insightful images. The whole thesis process also improved my planning and data management skills thanks to the useful advice from my daily supervisor Martin van der Weiden. All things considered I found that writing this thesis was a challenging activity during which I learned a lot about fieldwork, labwork and scientific writing and moreover confirmed my interest in the combination of scientific research and practical issues about how our activities as a society influence the world around us.

Content

List of Figures

List of Tables

1. Introduction

The intergovernmental Panel on Climate Change (IPCC) defines deltas as low lying coastal complexes that combine natural and human systems with a population density of 10 times the global average (Wong et al. 2014). Over the past 50 years, sediment reduction, relative sea level rise and changes in delta and river management have led to widespread degradation of deltas. This is expected to intensify as a result of increased coastal flooding, erosion and salt water intrusion because of global sea level rise (Wong et al. 2014).

After the disastrous stormflood of 1953 which killed 1800 people and which inundated thousands of hectares of land, the delta in the south west of the Netherlands was closed from the sea by the Delta works (Bannink et al. 1984). One of the open sea arms which was closed is the Grevelingen estuary (Figure 1). The closing of the Brouwersdam in 1971 changed the Grevelingen from an open sea arm to a salt water lake with no tidal dynamics (Bannink et al. 1984; van der Pluijm & de Jong 2003). Relatively elevated areas of the coastal wetlands in the Grevelingen which used to be diurnally inundated with salt water are now permanently dry while the lower zones are still permanently below the water level mean water level and regularly flooded (van der Pluijm & de Jong 2003; Van de Haterd et al. 2010).

The largest of these wetlands is the 'Slikken van Flakkee' area. Located along the northern shore of lake Grevelingen. The 'Slikken van Flakkee' consists of an area of 1500ha of former tidal wetlands which are now permanently above the mean water line (van der Pluijm & de Jong 2003). Since 1971, the northern and the southern part of the 'Slikken van Flakkee' have developed into different ecosystems. In the northern part, natural succession has led to the development of thickets consisting mainly of *Salix species, Hippophae rhamnoides,* and *Pteridium aquilinum*. The succession in the southern part, that had been managed by grazing with livestock (since about 1980) and regularly mowed, has led to species-rich grasslands including plant species that represent a high natural value and which are on the European Red list for endangered species (Bilz et al. 2011). This includes species such as *Parnassia palustris, Blackstiona perfoliatte ssp., Potentilla anserina* and orchid species like *Epipactis palustris* and *Dactilorhiza majalis spp.* (van der Pluijm & de Jong 2003). Grasslands of this composition are normally found in $CaCO_3$ rich dune valleys where hydrological and geochemical conditions are comparable to the conditions in the former tidal wetlands (van Haperen 2011). While the northern part of the 'Slikken van Flakkee' has been allowed to develop without human interference, the southern part has been subjected to cattle grazing. According to Van der Pluijm en de Jong (2003) the difference between the northern and southern part of the 'Slikken van Flakkee' is due to these different management styles of both areas (van der Pluijm & de Jong 2003). However, differences in vegetation communities in saline wetlands have also been linked to the hydrogeochemical processes in the soil (Ratas et al. 2003; Wu et al. 2011). Up to now no scientific research had been carried out in the 'Slikken van Flakkee' that could conclude on the relative impact of management versus hydrogeochemistry.

Besides the Grevelingen there are many other areas in the Netherlands where tidal influence have been banned. An example of such an area is the Krammer-Volkerak lake. This former tidal salt water system was cut off from the sea in 1987 and since then flushing with fresh water has changed it into a fresh water lake with a fixed water level (Tosserams et al. 2000). Soil development in the former tidal zone has been largely determined by the composition and the average particle size of the sediment. The relatively high plates are characterized by coarse sandy sediment and relatively fast desalination due to easy penetration and flushing by fresh rain water of the soil. The lower areas consist of finer sandy material with layers of clay leading to less flushing by fresh water and slower desalination (Tosserams et al. 2000). The soil water development at the former tidal wetlands of the Krammer-Volkerak lake has been modelled using the geochemical modelling tool PHREEQC (Parkhurst & Appelo 1999) by Appelo et al. (1998). For this model a sediment core from the dried up wetlands at the Krammer-Volkerak lake was oxidised completely using hydrogen peroxide in order to determine the reactions occurring naturally in the soil when it is aerated (Appelo et al. 1998).

The increased oxidation of the soil of a former tidal wetland can lead to the oxidation of pyrite (FeS_2), a common mineral in Dutch geological deposits (Roskam & Griffioen 2011). Pyrite oxidation has been found to cause severe acidification of pore water dyked wetlands in the Unites States (Portnoy 1999; Portnoy & Giblin 1997). The following reaction takes place when pyrite is oxidised:

$$FeS_2(s) + 15/4O_2 + 7/2H_2O \rightarrow Fe(OH)_3(s) + 2SO_4^{2-} + 4H^+ \qquad (1)$$

When sufficient amounts of carbonate are available in the environment, the acid produced by reaction (1) is neutralized by reaction (2) (Nicholson et al. 1988; Appelo et al. 1998).

$$FeS_2(s) + 15/4O_2 + 7/2H_2O + 4\,CO_3^{2-} \rightarrow Fe(OH)_3(s) + 2SO_4^{2-} + 4HCO_3^- \qquad (2)$$

After the carbonate is depleted, further acidification is buffered by the solution of calcium carbonate (3) leading to decalcification of the soil (Appelo et al. 1998).

$$CaCO_3(s)+H^+ \rightarrow Ca^{2+} + HCO_3^- \qquad (3)$$

A third hydrogeochemical process that can change pore water condition is cation exchange (Appelo et al. 1998). During this process cations that are sorbed to soil particles are exchanged between the particles and the pore water by reaction, for instance (4)

$$Ca^{2+} + Mg\text{-}X_2 \rightarrow Ca\text{-}X_2 + Mg^{2+} \qquad (4)$$

Ecological, geochemical and hydrological data need to be combined into one ecohydrogeochemical model to quantify the relationship between succession and soil development in wetland soils that are no longer inundated. Creating such a model, which can be used to quantify the effects of different management strategies, is the goal of the PhD research by drs. Martin van der Weiden (Van der Weiden 2015). Figure 2 shows the processes that are considered to determine the development of the soil and the vegetation for wetland ecosystems which are no longer diurnally inundated (Van der Weiden 2015). The current master thesis is set up as a pilot study to determine the relationship between vegetation and soil development at the 'Slikken van Flakkee' in the framework of the envisaged PhD thesis of van der Weiden.

The current master thesis work will combine existing data with actual measurements in the field. Data on vegetation development has been recorded on a yearly basis since 1973 by 'Rijkswaterstaat' and Anton van Haperen (Van Haperen, n.d.). Hydrological and meteorological data are available in the following two 'Rijkswaterstaat' reports:

- Slager, H., Fluijt, D.J. & Rook G.J., 1986. *Waterhuishouding en zouthuishouding van de Slikken van Flakkee*. Rapport nr. 198624abw, Rijksdienst IJsselmeerpolders, Afdeling Delta, Lelystad.
- Slager, H. & Visser j., 1990. *Abiotische kenmerken van de drooggevallen gebieden in de Grevelingen.* Flevobericht 312, 'Rijkswaterstaat' Directie Flevoland, Lelystad.

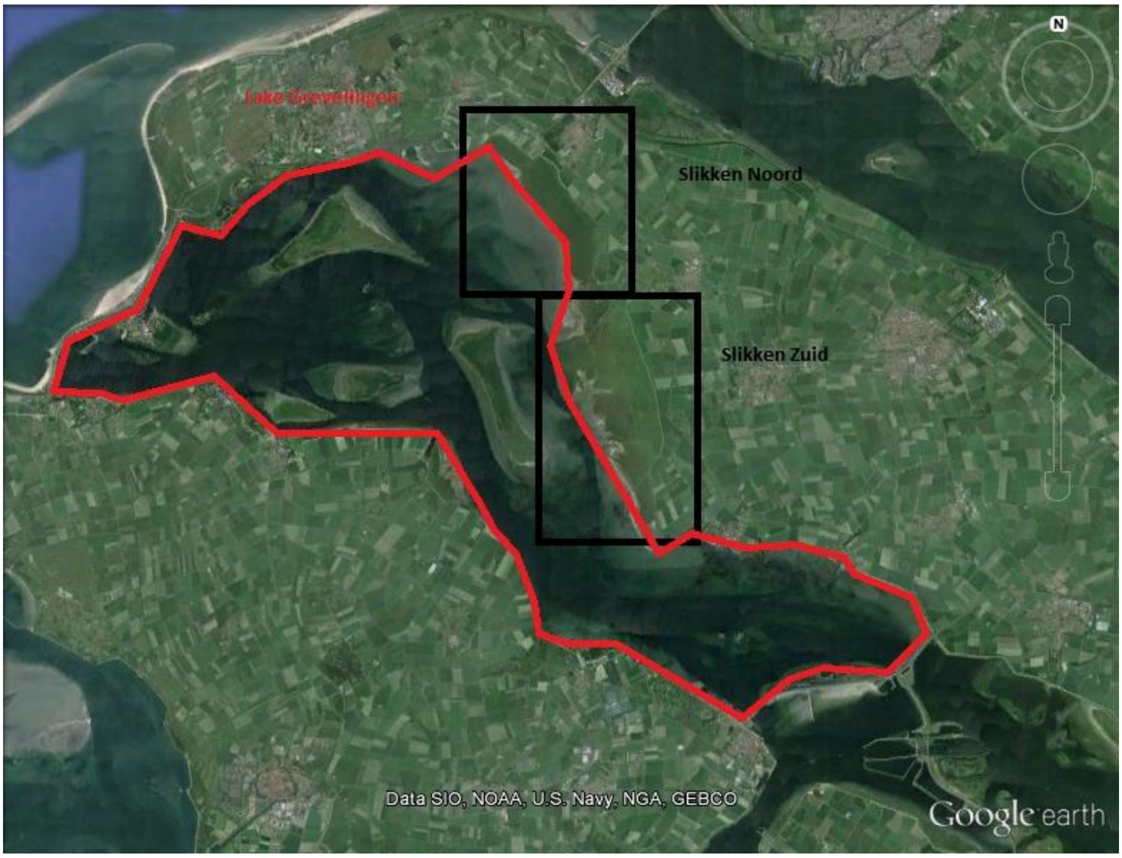


Figure 1: Lake Grevelingen (red) in the south west of the Netherlands and the two research areas (black).

Geochemical data will be obtained by taking soil and water samples at representative locations.

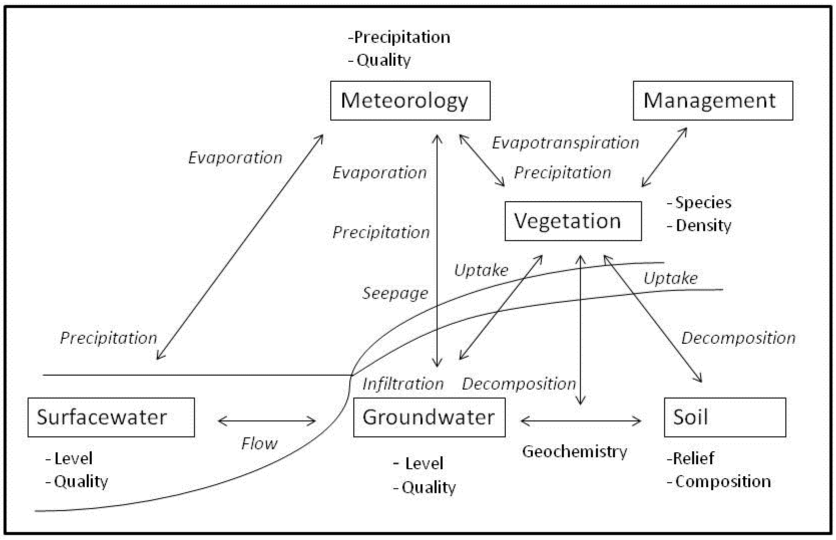


Figure 2: Conceptual diagram of interactions between hydrology, geochemistry and vegetation in dried up marine soils. Translated from Van der Weiden, 2015.

Problem definition

Coastal zones are areas with important ecosystem functions and high natural values. Protective measures against sea level rise like the Deltaplan in the Netherlands have led to changes in hydrology, geochemistry and ecology in former tidal ecosystems causing changes in ecosystem functioning. Areas that used to be diurnally inundated like the 'Slikken van Flakkee' are now permanently dryer and rarely flooded. Different geological conditions and management styles have led to the development of diverse ecosystems, some with high natural values. However, continuing hydrogeochemical processes like desalination and decalcification may lead to a loss of plant communities with high natural values and abundance of Red list species. In order to choose management measures that will contribute to the preservation of the highest natural values it is important to be able to predict the development of the hydrogeochemical conditions in the soil.

Aim

The aims of this research are:

1. to analyse the vegetation succession at the 'Slikken van Flakkee' since the closing of the Grevelingen from the North Sea which ended the diurnal flooding by the tides;
2. link vegetation succession to the hydrogeochemical development of the soil;
3. understand differences in succession and vegetation development between the northern and southern sub-area (the latter being mown and grazed and the former having no management).

Research Question

The main research question for this thesis is:

> How is the ecological succession of vegetation related to the hydrogeochemistry of the soil in this former tidal wetland?

To answer the main research question the following sub questions were formulated:

1. How has the vegetation at the 'Slikken van Flakkee' developed since the closing of the Grevelingen in 1971?
2. What are the current hydrogeochemical conditions at the 'Slikken van Flakkee'?
3. Which relationships exist between the direction of succession and hydrogeochemical conditions?
4. How is vegetation succession influenced by the different nature management choices at the 'Slikken van Flakkee?
5. Which measures can add to the preservation of vegetation communities with high presence of Red list plant species?

Hypothesis

We hypothesise that succession at the 'Slikken van Flakkee' is influenced by ongoing soil development which will lead to increasing desalination and a decrease in the buffering capacity of the soil due to decalcification. These processes are expected to lead to a decrease in the abundance in Red list plant species in the 'Slikken van Flakkee'. Differences in hydrogeochemistry between both (Northern and Southern) areas are expected to be an important driver for ecosystem development directions occurring at the 'Slikken van Flakkee' and need to be taken into account besides the different nature management styles (mowing, grazing) in order to understand the existing variation between the northern and southern part of the area.

Comments second reader proposal

The second reader had some comments on the proposal [2]. This comment is dealt with in the following chapters.

[2] Letter of University Utrecht, Dated March 31, 2016, Subject: Approval Research Proposal, Reference: EXCIE/2016/16.355 HI, Filename: 16.355_SD_GCE_Kanters_TJ_approval Research proposal.pdf.

2. Material & Methods

2.1 Ecological succession

The composition of the vegetation at the 'Slikken van Flakkee' has been monitored on a yearly basis at multiple permanent quadrants (PQ's) (appendix 1) using Braun-Blanquet recordings. Vegetation recordings started in 1972 and most of the monitored plots recorded annually. The Braun-Blanquet abundance scores of van Haperen were transformed into a Van der Maarel decimal cover scale (van der Maarel 1979). The difference in vegetation composition between the PQ's was determined by calculating the Bray-Curtis dissimilarity index (Formula 5) (Bray & Curtis 1957) using the *vegdist* function from the R package *vegan* (Oksanen et al. 2016).

$$BC_{(i,j)} = 1 - \frac{2C}{(A+B)} \qquad (5)$$

Where C is the sum of the minimum abundances of the various species defined as the abundance at the site where the species is rarest, A is the sum of the abundance of all species at PQ *i* and B is the sum of the abundance of all species at PQ *j* (Legendre & Legendre 1998).

The PQ's from the entire dataset of van Haperen (n=1799) were subsequently clustered with an average linkage cluster analysis using the *hclust* function from the R *vegan* package (Oksanen et al. 2016). The resulting dendrogram from cluster this analysis was then sorted manually to determine the dominant vegetation types and sub-types occurring in the area over the entire period.

2.2 Hydrogeochemistry

General geophysical and hydrological data were obtained from Slager et al., (1986) and Slager & Visser (1990) (Slager et al. 1986; Slager & Visser 1990).

To study the hydrogeochemical processes that occur at the 'Slikken van Flakkee', sediment samples were collected at nine locations representative for the different hydrological conditions (Slager & Visser 1990) and management styles in the area (

Table 1) (Van Haperen, personal communication). The samples were taken using an Akkerman sampler which takes sediment cores by hammering a stainless steel tube into the soil at the desired depth. An Edelman drill was used to reach the top of the sampling depth. The steel tube is then removed from the sampler and closed off from the air by a steel disc and plastic caps. The Akkerman sampler was rinsed with demineralised water after each sample. To minimize the amount of air coming into contact with the sample, aluminium tape was used to seal the plastic caps to the sediment core. Dissolved oxygen in groundwater was also planned to be measured in the field but eventually turned out not possible due to the unavailability of an oxygen meter and due to the applied sample technique.

Soil samples were taken at four different depths, 0-20 cm, 30-50 cm, 70-90 cm and 110-130 cm below ground level to gain insight into the hydrogeochemical processes occurring at different depths. Besides taking soil samples a soil profile (Figure 4) was created at every location using a gauge to determine thickness of the humus layer, the highest groundwater level and the lowest groundwater level. An indication of calcium carbonate content was determined using hydrochloric acid (HCl) in the field.

Figure 4: Photo of Soil profile at PQ 17 on June, 29, 2016.

Figure 3: Photo of content glovebag on June, 27, 2016.

The sediment cores were placed in a coolbox in the field and stored in a refrigerator at 5°C in the laboratory until sub samples were taken for further analysis. In order to maintain the redox situation of the sediments cores the sub-sampling was done is a glovebag filled with nitrogen gas at the 'Utrecht Castel' (laboratory of Utrecht University). The sediment cores, required materials and sub sample containers were placed in the glovebag which was flushed four times with N_2 gas until the oxygen level in the glovebag was reduced to ±5% of the normal oxygen concentration in the air (Figure 3).

Table 1: Height above NAP in 1986 (Slager et al. 1986) and management style at the investigated PQ's. Two series of samples were taken in the Southern part representing a series with a stable groundwater level (5-40cm under ground level) and a more dynamic groundwater level (0-80cm under ground level) due to the presence of an impermeable clay layer in the underground (Slager & Visser 1990).

Area	PQ	Height (cm + NAP)	Management
North	45	100	None
	49	35	None
	73	10	None
South (stable)	10	70	Grazing and Mowing
	58	35	Grazing and Mowing
	59	5	Grazing and Mowing
South (dynamic)	17	90	Grazing and Mowing
	22	10	Grazing and Mowing
	65	10	Grazing and Mowing

When the desired O_2 concentration was reached, the Akkerman cores were opened in the glovebag and the first centimetre of sediment was discarded. First, 30 grams of sediment were taken from the Akkerman cores and placed into an airtight glass bottle for iron (Fe) and manganese (Mn) oxy-hydroxide analysis. Another 30 gram was placed in a similar bottle for phosphorus (P) analysis.

Pore water samples were taken from the sediment core using a ceramic Rhizosphere CSS soil moisture sample. Because the sediment cores were too compact to insert the Rizon, a steel wire of the same diameter as the Rizon was inserted into the sediment core first. When the wire was removed, the Rhizon was inserted into the sediment and coupled to a 10ml syringe which was put under negative pressure. 1.5 ml of the pore water from the syringe was placed into a glass IC vial for anion analysis, 1.5 ml was placed in a 15 ml Greiner tube for sulphate (S^{2-}) analysis, 3 ml was placed in a glass test tube for dissolved organic carbon (DOC) analysis and 5.5 ml in another 15 ml Greiner tube which was subsequently acidified using 5.5 µl 65% suprapure nitric acid (HNO_3) for cation analysis. The S^{2-} sample was conserved using a 2% zinc-acetate (ZnAc) solution. A third 15 ml Greiner tube was filled with 6.5 ml pore water for alkalinity, ammonium (NH_4^+) and total nitrogen (N_{tot}) measurements. All samples were placed in a refrigerator at 5°C until they were analyzed. After the pore water sampling, 70 g of soil was removed from the top part of the sediment core and placed into an aluminium dish to determine the dry matter, calcium carbonate ($CaCo_3$), carbon (C), nitrogen (N) content and the grain size distribution of the sediment. In cases where it was impossible to obtain enough pore water from the Rhizon the sediment cores where transferred into a plastic centrifuge bottle with the air hole taped off to prevent oxidation and subsequently centrifuged for 30 minutes at 2.000 rpm in a Sorvall centrifuge. The centrifuge bottles were then taken back into the glovebag and the extracted pore water was divided over the remaining samples using a 10 ml syringe with a 45 µm filter. Eventually, we were able to collect sufficient pore water for all analyses.

The remaining sediment was then divided into two 50 ml Greiner tubes for pH and cation occupation analysis and a plastic bag for the rest material.

2.3 Laboratory analysis

pH and alkalinity were determined in the laboratory using an Orion 520A pH ion meter. After measuring the initial pH, a GRAN titration was performed to determine the alkalinity. The anion content of the pore water was determined by measuring fluoride (F^-), chloride (Cl^-), nitrite (NO_2^-), bromide (Br^-), nitrate (NO_3^{2-}), phosphate (PO_4^{3-}) and sulphate (SO_4^{2-}) concentrations using Ion Chromatography (Dionex IC). The acidified subsample was used to determine the cation content by measuring sodium (Na^+), potassium (K^+), magnesium (Mg^2), calcium (Ca^{2+}), iron (Fe), manganese (Mn) and strontium (Sr) concentrations with inductively coupled plasma optical emission spectrometry (ICP-OES). NH^{4+} and S^{2-} concentrations where determined spectrophotometrically using a Shimadzu UU 1800 spectrophotometer and DOC with a Shimadzu TOC-5050A total organic carbon analyser. Total nitrogen (N_{total}) concentration and electrical conductivity (EC-lab) were planned to be analysed but not measured due to time constraints.

The sediment samples were dried in an oven for 16 hours at 105°C to determine the dry matter content. $CaCO_3$, C and N content of the sediment samples were determined by TGA and CN analysis respectively. The S content could not be analysed because the CS Analyser was not available. All analysis were performed at 'Utrecht Castel'. Grain size, iron minerals and P analysis were also planned but eventually not possible within the timeframe of this master thesis. These measurements will be carried out separately.

2.4 Representation of pore water composition

Major ion concentrations in the pore water were used to create a Piper plot using the "Excel for hydrology" macro by the USGS (Halford, Keith 2005)In the Piper plot, the chemistry of the pore water is visualized by plotting the Ca^{2+}, Mg^{2+} and Na^+ plus K^+ cations and SO_4^{2-}, Cl^- and HCO_3^- plus CO_3^{2-} anions in two ternary plots which are combined into a diamond plot. The percentage of each ion is based on the total concentration of their respective group (cations or anions).

The water type was determined using the classification system by Stuyfzand (Stuyfzand 2012) (Figure 5). This systems creates a code based on the salinity (mg/l Cl^-), alkalinity (mg/l), cation and anion concentration (%) and Base Exchange Index.

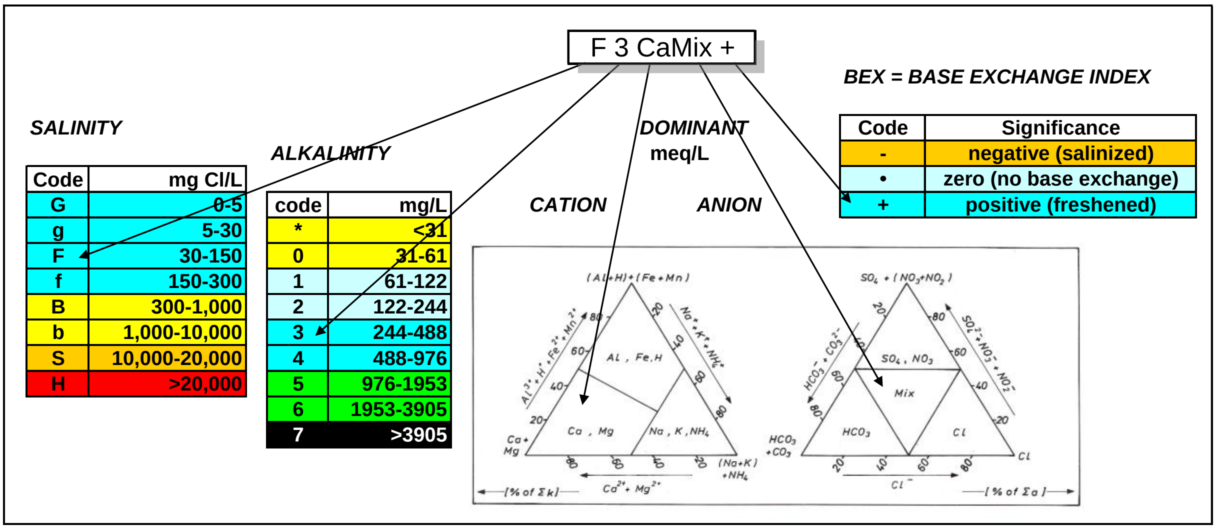


Figure 5: Explanation of water type determination using Hydrochemcal (HGC 2.1) Microsoft Excel spreadsheet (Stuyfzand 2012).

2.5 Relationship between vegetation composition and hydrogeochemistry

The relationship between species composition and the environmental factors at the selected PQ's was determined with a canonical correspondence analysis (CCA) (ter Braak & Verdonschot 1995) using the *CCA* function in the R *vegan* package (Oksanen et al. 2016).

CCA is a multivariate method which we used on cover/abundance data of species in the respective plots in 2015 and data on the environmental variables measured in the top layer (0-20cm) at the plots in 2016. Management was added to the model as a factor with two nominal values, Grazing and mowing and NoManagement. CCA extracts synthetic gradients as ordination axes from the measured environmental variables that maximise the niche separation among the species (Braak & Verdonschot 1995). Because CCA uses linear combinations of environmental variables that explain the species composition, it can be interpreted as a linear regression method to explain the ordination of the species composition within the investigated PQ's (ter Braak & Verdonschot 1995).

The final model explaining the differences in vegetation composition was determined by stepwise selection using the *ordistep* function in R *vegan* (Oksanen et al. 2016). This method uses Akaike's information criterion (AIC) to select the important environmental variables in the data. The significance of the resulting model was tested by an ANOVA-like permutation test with the *anova.cca* function in R *vegan* (Oksanen et al. 2016).

3. Results

3.1 Ecological succession

Cluster analysis of the vegetation data revealed 4 vegetation types which can generally be described as: species poor halophyte vegetation (1), *Salix* forests (2), *Rubus* thickets (3) and species rich grasslands (4). Type 2 and 4 were subdivided into 2 and 4 subtypes respectively (Table 2).

Vegetation type 1 is relatively poor in species and shows high presence of *Puccinellia maritima, Spergularia salina, Salicornia europaea* and *Suaeda maritima.* The two subtypes of the *Salix* forest are type 2A1 which consists mainly of *Salix caprea*, *Tussilago farfara* and *Pteridium aquilinium*. *Salix cinerea* and *Hippophae rhamnoides* are also present in type 2A. In type 2B *Salix cinerea* is the dominant species, *Salix caprea* is not present is this subtype. *Hippophae rhamnoides* also occurs in high numbers. Different species of grass like *Festuca rubra* and *Agrostis stolonifera* occur in subtype 2A but are not present in type 2B. Type 3 consists mainly of thicket species like *Rubus caesius*, *Cirsium arvense* and *Urtica dioica*. Common grasses in type 3 are *Poa trivialis* and *Elytrigia atherica*. The species rich grasslands of type 4 are characterized by the presence of *Agrostis stolonifera* and *Centaurium pulchellum*. Type 4A1 and 4A2 differentiate from type 4B and 4C by the presence of *Poa trivialis* and *Cirsium arvense*. 4A1 and 4A2 are separated by the presence of *Juncus gerardii* and *Trifolium fragiferum* in 4A1. *Festuca rubra, Festuca arenaria* and *Trifolium repens* are present in 4A2 and absent in 4A1. *Juncus gerardi* is a common species in type 4B which is further characterized by a high diversity of grasses and herbs including *Potentilla anserina, Leontodon autamnalis, Carex distans, Leontodon saxatalis* and *Lotus glaber*. This is also the vegetation type that includes rare and Red list species like *Parnassia pallustris, Epipactis pallustris, Dactylorhiza incarnata* and *Dactylorhiza majalis*. Type 4C is separated from the other vegetation types of group 4 by the presence of halophyte species such as *Puccinellia maritima* and *Spergularia salina*. Other important species in type 4C include *Juncus gerardii, Plantago coronopus, Aster tripolium, Parapholis strigosa* and *Glaux maritima.*

Figure 6 shows the development in space and time of the different vegetation types. At the northern part of the area, species poor halophyte vegetation is the dominant vegetation type in the first years. *Rubus* thickets are found closest to the dyke and remain the dominant vegetation type in this zone during all the recorded years. The *Salix* forests start do develop from 1979 onwards and eventually dominates the elevated zone starting with type 2B. After 1985, type 2A begins to develop in the highest lying zone of the *Salix* forests and slowly replaces type 2B. Spatially this zone is bordered by a transition zone between 2B and the grassy vegetation. Type 4A1 starts to develop in the more elevated part of the area in 1975 and succeeds type 1 as the years proceed, spatially confining type 1 to a few PQ's near the shore. The succession in the grasslands between the forest and the shore goes from type 4A1 to type 4C. After the year 2000, type 4B slowly becomes the dominant grassland vegetation in the northern part. The succession in the southern part of the 'Slikken van Flakkee' begins with type 4A2 and 1. Type 1 is succeeded by type 4A1 except for a few PQ's at the shoreline which develop into type 4C. After 1985, type 4B is dominating. Eventually replacing type 4A1 and 4A2 entirely. In 2015, all the PQ's in the southern area have developed into 4B except for only one PQ with type 1 and only three PQ's with type 4C.

For a more detailed overview of the succession at the 'Slikken van Flakkee',see the analysis of the succession by van Haperen (van Haperen, n.d.).

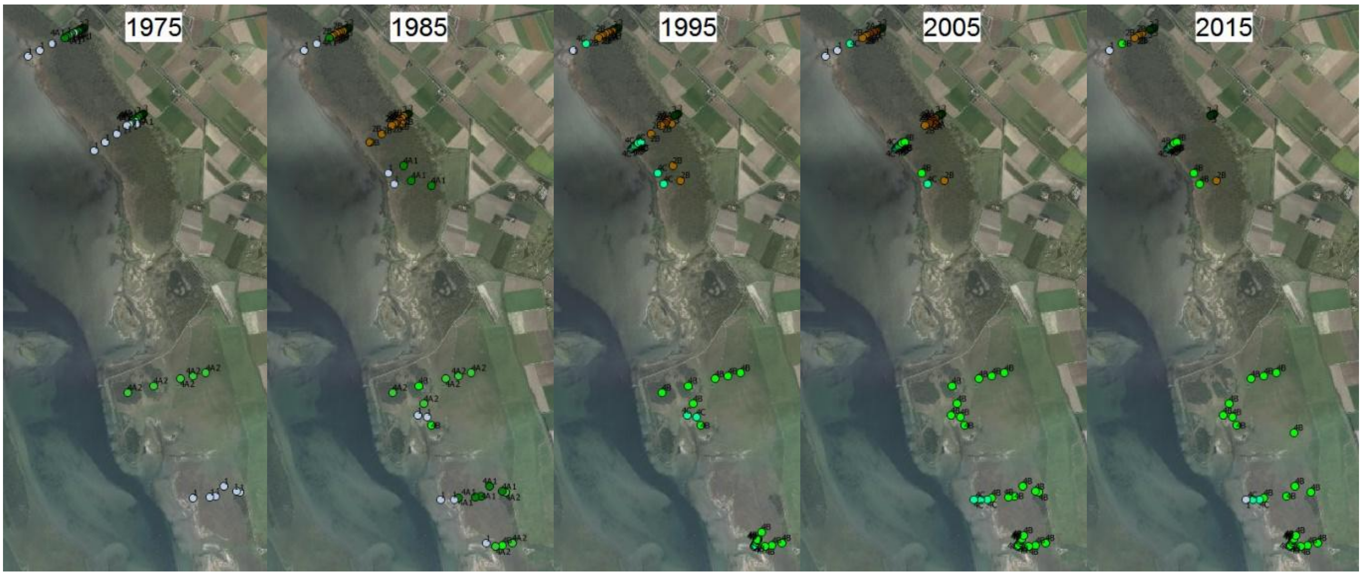


Figure 6: Time slices of the vegetation types at the 'Slikken van Flakkee' from 1975 to 2015 in 10 year steps. Note: not all PQ's were recorded every year. For a yearly representation of the different vegetation types see appendix 3.

Legend	
Vegetation Type	**Code**
SPH (species poor halophytes)	1
Forest	2B
Forest	2A
Thickets	3
SRG (species rich grassland)	4A1
SRG (species rich grassland)	4A2
SRG (species rich grassland)	4B
SRG (species rich grassland)	4C

Table 2: Synoptic table indicating the presence (cover/abundance) of species in the different vegetation types. I = low presence (Van der Maarel score 1-3) , II = intermediate presence (Van der Maaral score 4-6), III = high presence (Van der Maarel score 7-9). Species with low presence are omitted. For a more detailed representation see appendix 2. Type 4B includes Red list species representing a high nature value like *Blackstonia perfoliata s. spinosa, Parnassia palustris, Epipactis palustris, Dactylorhiza incarnata, Dactylorhiza majalis* and *Euphrasia stricta*.

Vegetation type	**1**	**2A**	**2B**	**3**	**4A1**	**4A2**	**4B**	**4C**
Number of PQ's	**265**	**111**	**282**	**283**	**188**	**118**	**397**	**209**
Puccinellia distans s. distans	II							
Puccinellia maritima	III							III
Spergularia salina	III							II
Suaeda maritima	III							II
Salicornia europaea	III							II
Salix caprea			III				I	
Salix cinerea		III	II					
Pteriduim aquilinum			II					
Hippophae rhamnoides		III			II		I	
Calamagrostis epigejos		III	II		II		II	
Moss (div)		II	I	II	II	II	II	
Salix repens		II	I				I	
Eupatorium cannabinum		I	II		I			
Phragmites australis		II	I				I	
Rubus ceasius		II	II	III				
Cirsium arvense				II				
Poa trivalis			II	II	II	II		
Holcus lanatus				II	II			
Urtica dioica				II				
Galium aparine				II				
Agrostis stolonifera		I	I		III	III	III	III
Centautium pulchellum					II	II	II	II
Festuca rubra F. arenaria					II	III	III	
Poa pratensis				I	II	II	II	
Juncus gerardii					II	II	III	III
Parapholis strigosa					I		I	II
Aster tripolium					I		II	II
Plantago coronopus	II				I	I	I	II
Lolium perenne					I	II		
Trifolium repens						III	II	
Trifolium fragiferum						II		
Lotus glaber						I	III	
Juncus articulatus							II	
Potentilla anserina							II	
Leontodon autamnalis							II	
Carex distans							II	
Cares extensa							I	I
Glaux maritima							I	II
Elytrigia athenica								I

3.2 Hydrogeochemical conditions

The hydrogeochemical conditions at PQ 49, 45 and 73 in the northern part of the 'Slikken van Flakkee' and PQ 10, 58, 59, 17, 22 and 65 in the southern part were sampled in June 2016.

The concentrations of major ions in the pore water were used to create a Piper diagram (Figure 7) and to determine the water types (Table 3) in the investigated plots.

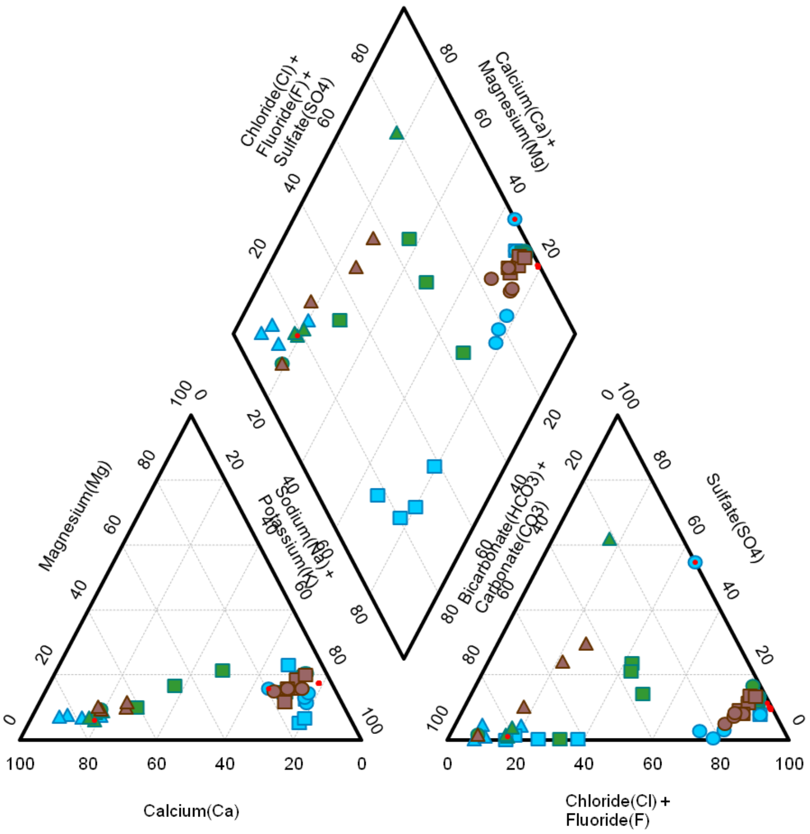


Figure 7: Piper diagram of the major ion composition of the pore water. ▲, ■ and ● represent PQ 45, 49 and 73 at the northern part of the 'Slikken van Flakkee'. ▲, ■ and ● represent PQ 10, 58 and 49 and ▲, ■ and ● represent PQ 17, 22 and 65 at the stable and dynamic zone of the southern part respectively. The red dots are different ratio's of rainwater and water from lake Grevelingen. The two ternary plots show the cation and anion concentrations. The diamond a matrix transformation of the anions and cations.

Table 3: Chemical water types in the various PQ's at different depths, classification according to Hydrochemcal 2.1 (Stuyfzand 2012).

Depth (cm - groundlevel)	Area					
	North		South (stable)		South (dynamic)	
	PQ	Watertype	PQ	Watertype	PQ	Watertype
10	45	F4CaHCO3+	10	F2CaHCO3	17	g3CaHCO3
40		F4CaHCO3+		g3CaHCO3+		F3CaHCO3
80		F4CaHCO3+		g3CaHCO3		F3CaMix+
120		f4CaSO4+		g3CaHCO3+		F3CaHCO3+
10	49	f4CaHCO3	58	B5NaHCO3+	22	b3NaCl
40		B4CaMix+		f5NaHCO3+		b4NaCl
80		B4CaMix+		f5NaHCO3+		b4NaCl
120		B4NaCl+		F5NaHCO3+		S4NaCl+
10	73	b4NaClo	59	b4NaCl-	65	b4NaCl
40		S4NaCl+		b5NaCl+		b5NaCl-
80		S4NaCl		b5NaCl+		b5NaCl
120		S4NaCl+		b5NaCl		b5NaCl

The chemical water type of the pore water differs substantially between the investigated PQ's. The main pattern shows the occurrence of NaCl water types at PQ 73, 59, 22 and 65 reflecting the influence of the saline Grevelingen water on the water quality. PQ 73 shows an increase in salinity below 40 cm (8.700 mg/l Cl^- - > 15.000 mg/l Cl^-) while PQ's 59 and 65 have a quite similar salinity over the entire 120 centimetre depth profile (3.700 mg/l Cl^- - 5.700 mg/l Cl^-). The salinity at PQ 22 shows an increase between 80 and 120 cm (8.400 mg/l Cl^- - 12.000 mg/l Cl^-). PQ's 45, 49, 10 and 17 which are situated relatively far from the shore show a $CaHCO_3$ water type in the top layer. At PQ 45 the water type stays the same till a depth of 120 cm where it changes to $CaSO_4$. The water type at PQ 49 changes after the first 40 cm to CaMix and again to NaCl at a depth of 120 cm indicating that desalination and decalcification have progressed less far compared to PQ 45. The water type at PQ 10 remains stable with only a slight decrease in salinity after the first 40 cm. The situation at PQ 17 is similar to PQ 10 except for a slight increase in salinity after the first 40 cm. PQ 58 has a $NaHCO_3$ water type which decreases slightly in salinity with increasing depth.

The pH differs only slightly between 6,8 and 8,4 in all pore water samples (Figure 8). At PQ 49, 45 and 73 in the northern part of the area and 58 and 59 in the southern part the pH increases slightly with increasing depth. pH decreases with depth at PQ 10, 17, 22 and 65. The alkalinity of the pore water generally increases after the first 20 cm.

To determine whether pyrite (FeS) oxidation is taking place at the 'Slikken van Flakkee' the sulphide concentrations were compared to the amount of SO_4 that is expected due to the fraction of sea (Grevelingen) water in the pore water samples. Figure 9 shows the amount of SO_4 measured with the Ion Chromatograph compared to the expected amount based on the ratio between SO_4 and Cl^- in fresh and seawater. The deepest point at PQ 45 and all points at PQ 45 and 73 have SO_4 concentrations lying above the expected amount due to the sea water content (shown by the Ratio Fresh – Sea line). In the southern part of the area PQ 17 shows SO_4 excess at 40 and 80 cm depth. PQ 22 shows a SO_4 excess which increases with depth.

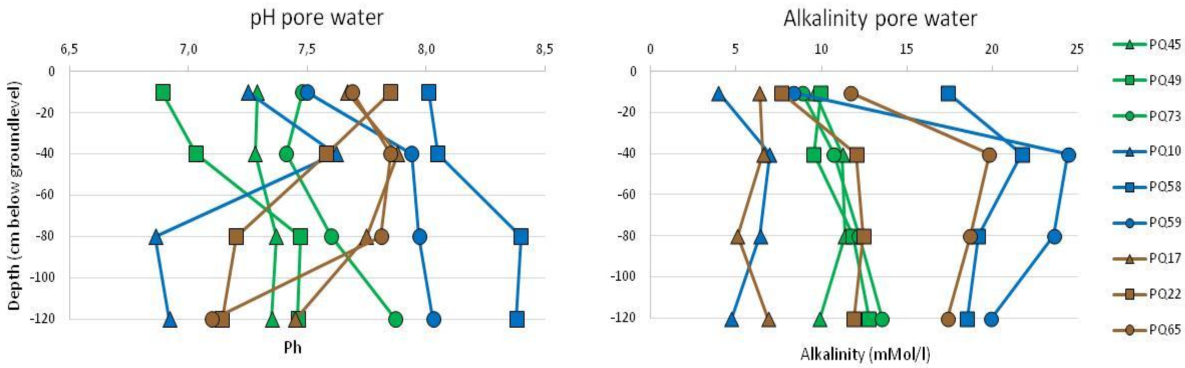


Figure 8: pH and alkalinity of the pore water at different depths for each PQ.

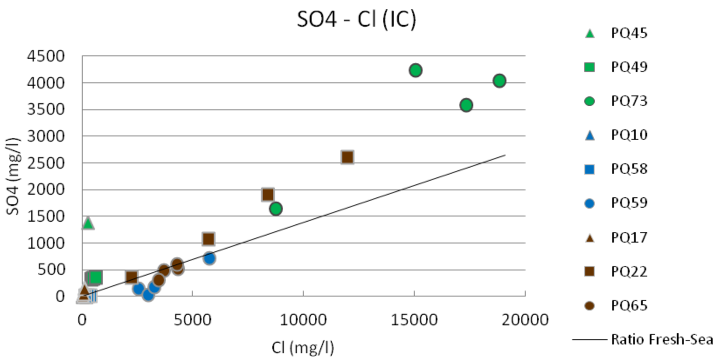


Figure 9: Scatterplot of the Cl and SO_4 content of the pore water samples compared to the expected ratio based on the mixing between sea and fresh water. The Ratio Fresh-Sea line shows the expected SO_4 concentration based on the amount of Cl. Sulphate values above the Ratio Fresh-Sea line are an indication for occurring pyrite oxidation. Cl and SO_4^{2-} concentrations in fresh (30 mg/l Cl^- and 6 mg/l SO_4^{2-}) and seawater (19.100 mg/l Cl^- and 2.640 mg/l SO_4^{2-}) are based on literature values (van Wirdum 1991; Van Breukelen et al. 1998).

The alkalinity (HCO_3^-), Ca^{2+}, K^+, Mg^{2+}, Na^+, SO_4^{2-} and Fe concentrations were normalised to the Cl^- concentrations and plotted against the Cl^- (meq/l) concentration on a logarithmic scale to provide insight into the macro-chemical processes that occur in the soil at the ‘Slikken van Flakkee’ when the salinity decreases (Figure 10). Trends were visualized by including the moving average in the plot.

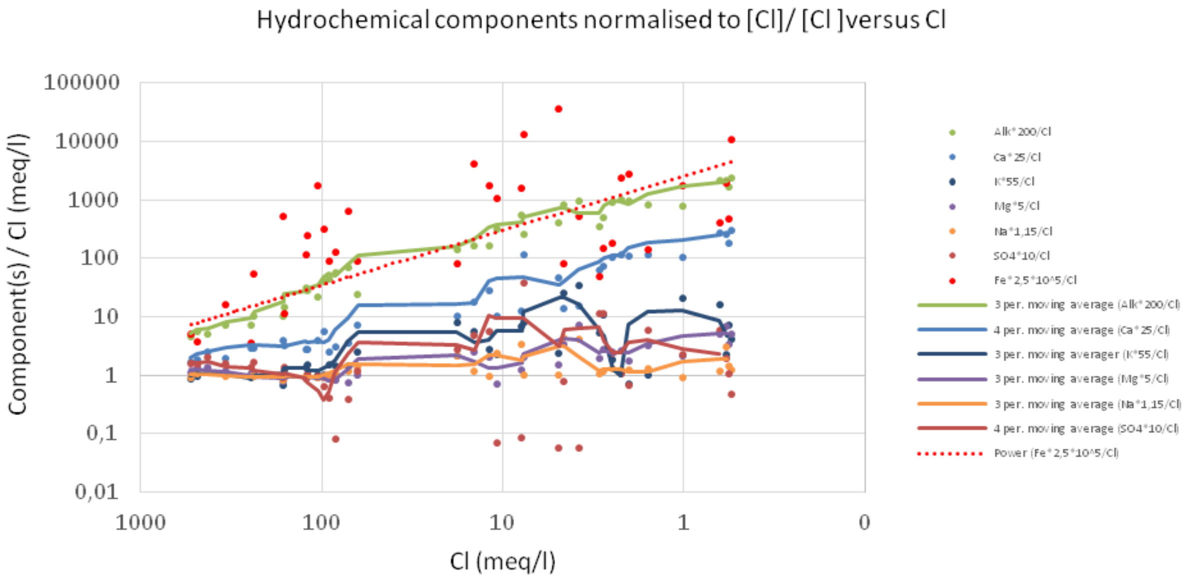


Figure 10: Major chemical components of pore water normalised to the Cl^- concentration (meq/l) plotted against the Cl^- concentration (meq/l) with moving average of each component. Cl^- is assumed stable so deviations from the Component(s)/Cl = 1 line on the y-axis by other components with decreasing Cl^- concentrations on the x-axis indicate hydrogeochemical processes in the soil. Increasing alkalinity and Ca^+ show the dissolution of $CaCO_3$, increasing Fe and SO_4 are an indication of pyrite oxidation and fluctuations in Na^+, K^+, Mg^{2+} and Ca^{2+} indicate cation exchange between the pore water and the sediment.

The pore water in the entire 'Slikken van Flakkee' area consisted of a mixture of about 80 % seawater and about 20 % riverwater before the closing of the Grevelingen (Slager et al. 1986) so the assumption is made that the normalised ion concentrations were equal to the Cl^- concentration. Because Cl^- is a conservative ion which does not react with other elements as the soil is flushed with rainwater and desalinizes, changes in the relative concentrations of the pictured pore water components indicate several hydrochemical processes.

Pore water samples were checked for ionic balances which were generally within the accepted range (Stuyfzand 2012). However the ionic balance for the deepest sample (120cm) at PQ 49 and 22 and at the shallow sample (20cm) at PQ 17 show relatively high deviations. This is possibly due to the dilution of the deep samples which was necessary in order to decrease the Cl^- content for IC analysis. The sample from PQ 17 was also diluted in order to obtain sufficient material for analysis. For all pore-water results see appendix 4.

The increase in alkalinity and Ca^+ show the solution of $CaCO_3$ as the salinity decreases. The increase in Fe concentration is an indication of pyrite oxidation. The slight lowering in the relative concentrations of Mg^{2+}, Na^+ and K^+ ions between 1000 and 100 meq/l Cl^- is an indication of cation exchange between the pore water and the soil.

Results for the chemical features of the soil are shown in Table 4. The dry matter content of the top layer is around 50% in all PQ's. Deeper samples have a dry matter content around 80%. C and N show the highest values in the top layers. While $CaCO_3$ content is generally the lowest in the top layer. All results from the soil analysis are given in appendix 5.

Table 4: Dry matter content in % of fresh weight and C, N and $CaCO_3$ content (% of dry weight).

Area	PQ	Depth (cm -groundlevel)	Dry Matter	C	N	$CaCO_3$
North	45	10	48	10,33	0,53	2,56
		40	78	2,26	0,07	8,03
		80	80	1,32	0,01	9,09
		120	82	1,19	0,00	7,75
	49	10	51	8,73	0,36	2,68
		40	80	1,18	0,01	7,17
		80	80	0,99	0,01	6,29
		120	81	1,25	0,01	8,63
	73	10	63	7,22	0,26	2,29
		40	84	0,82	0,01	3,68
		80	84	0,85	0,01	3,82
		120	82	1,06	0,01	4,69
South (stable)	10	10	42	18,39	1,12	1,75
		40	83	1,11	0,03	6,15
		80	81	1,00	0,01	7,00
		120	81	1,12	0,01	8,08
	58	10	46	12,71	0,70	2,48
		40	80	1,21	0,01	7,61
		80	80	1,22	0,01	7,59
		120	81	2,03	0,01	13,77
	59	10	45	11,95	0,57	1,41
		40	79	1,10	0,01	6,14
		80	82	1,32	0,01	8,31
		120	80	1,59	0,01	9,14
South (dynamic)	17	10	49	12,10	0,78	0,95
		40	83	1,05	0,02	6,16
		80	83	0,87	0,01	6,16
		120	80	0,95	0,01	6,46
	22	10	43	11,40	0,66	2,84
		40	79	1,46	0,03	8,08
		80	81	1,13	0,01	7,62
		120	80	1,20	0,01	7,06
	65	10	52	7,53	0,39	2,71
		40	79	1,41	0,02	7,51
		80	80	1,53	0,02	8,83
		120	81	0,95	0,01	5,49

3.3 Relationship between vegetation type and hydrogeochemical conditions in 2015

A selection of environmental variables from the top layer (0-20 cm) of the soil was used to determine the relationship between the vegetation type recorded in 2015 and the environmental conditions in 2016. Variables that were selected for analysis are pH, Ca^{2+}, Cl^- and HCO_3^- concentrations, SO_4^{2-} excess, $CaCO_3$ and N content, water level (GHG) and management.

Figure 11 shows four different environmental zones at the 'Slikken van Flakkee': the part of the area without any management, relatively high Ca^{2+} and Cl^- concentrations, SO_4^{2-} excess and high $CaCO_3$ content (lower left side of the diagram), the northern part with a lower water table (upper left side of the diagram), the part with management by grazing and mowing and a high nitrogen content of the soil (upper right side of the diagram) and the southern part of the area with relatively high Cl concentrations and slightly higher pH values.

In 2015, PQ 45 consisted of *Salix* forest (type 2A) which occurs where the water level is slightly lower in the no-management zone. The vegetation type at PQ 73 was species rich grassland with a relatively high abundance of halophytes (type 4C). This vegetation occurs close to the shore where the Cl^- and Ca^{2+} concentrations are high and pyrite oxidation is occurring. The rest of the PQ's had species rich grassland vegetation (type 4B) with a high abundance of herb species like *Trifolium repens, Lotus glaber* and *Leontodon autamnalis.* Remarkably, in the southern part of the area, with management by grazing and mowing, type 4B occurs over a wide range of environmental conditions while it is restricted to a zone with relatively fresh water and slightly higher ground water levels in the northern part of the area.

A stepwise selection analysis was performed to identify the most important environmental factors that determine the occurrence of the different vegetation types. In the resulting model only management and Cl^- concentration were selected as significant explaining variables. A further CCA was carried out in which only these factors were taken into account as constraining factors. The result from this analysis (Figure 11 and Figure 12) confirms that the difference in vegetation composition at the 'Slikken van Flakkee' is more strongly correlated to management style and salinity than to any (other) hydrogeochemical variables in the area. The relatively high eigenvalues of the axes demonstrate that a large part of the species variance in explained by the environmental variables that were included in the analysis.

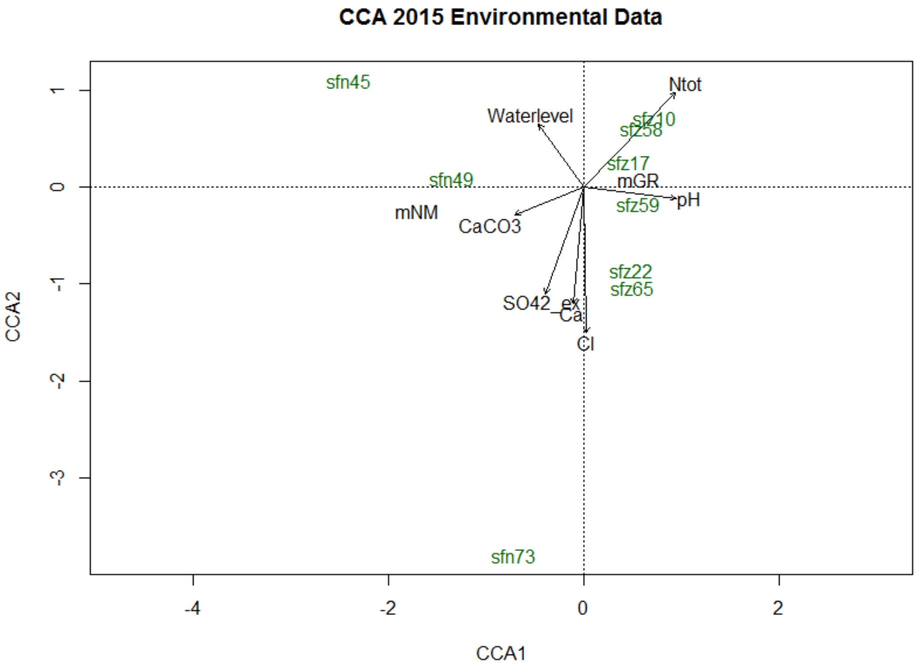


Figure 11: Canonical Correspondence Analysis showing correlation between vegetation type and a selection of hydrogeochemical variables of the top 20 cm of the soil (indicated by arrows) and management type (nMN = no management, mGR = grazing and mowing) at the investigated PQ's displaying 100% of the inertia. Eigenvalue: axis 1 = 0,74 , axis 2 = 0,45 . sfn and sfz represent the northern and southern part respectively. The number corresponds to the PQ number. sfn 49 consists of vegetation type 2A, sfn 73 of type 4C and all other PQ's of type 4B (table 2). The location of the PQ's within the plot is determined by the weighted average of the species abundance within the PQ's.

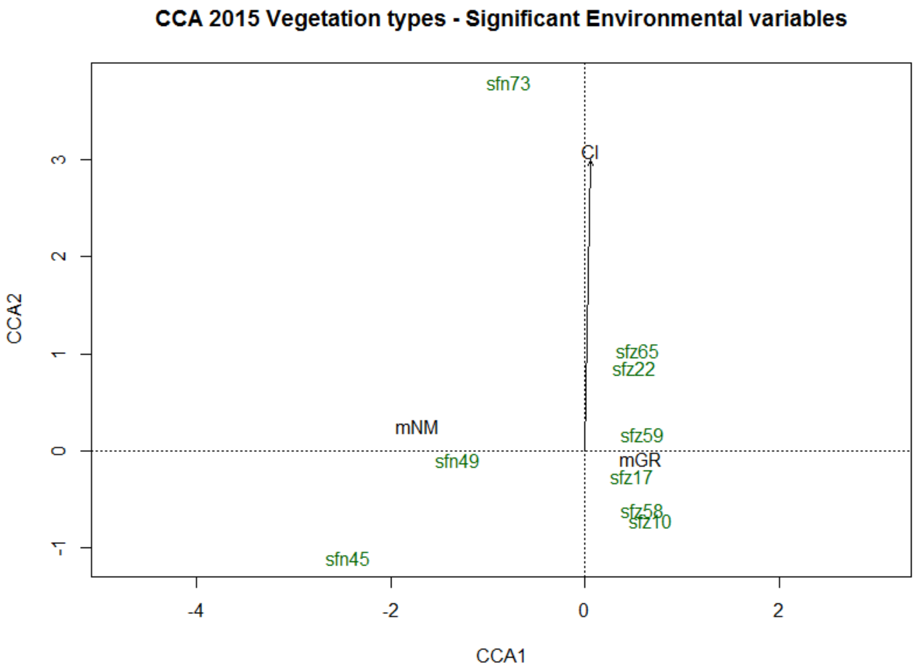


Figure 12: CCA showing correlation between vegetation type and important environmental variables (Cl^- in the top layer and management) determined by stepwise selection. Cl^- is represented by the arrow and management type by mNM (No Management) and mGR (Grazing and mowing). Eigenvalue: axis 1 = 0,59; axis 2 = 0,36. Model explains 45% of the variance. Permutation test significant (P < 0,01).

4. Discussion

The aim of this project was to analyze the succession of the vegetation that has taken place at the 'Slikken van Flakkee' since the tidal influence was removed by closing the Grevelingen estuary from the North Sea in 1971 and to find the hydrogeochemical processes that occur in the former tidal wetlands. Furthermore, the effects of the different nature management strategies on the succession in the two sub-areas at the 'Slikken van Flakkee' were analyzed.

Vegetation types and Succession

The trends found in the succession of the vegetation show gradual change over time from species poor halophyte vegetation in the 19 seventies to a *Salix* forest and species rich grassland vegetation at the northern sub area. The *Salix* forest ecosystem develops in the more elevated part of the area where the salt content of the pore water has decreased relatively fast. In the lower lying part of the area where the salt content is still high, succession leads to species rich grasslands. In the southern part of the 'Slikken van Flakkee' species poor halophyte vegetation develops into species rich grassland vegetation with an increase in species with time. Eventually this leads to a uniform ecosystem which includes several rare species that are on the European Red list. The different vegetation types that are present right after the removal of the tides in the southern sub-area are due to the sowing of rye and grass species (van Haperen n.d.). Our results are in keeping with general trends found in the first ten years in other former tidal wetlands in the Netherlands with an extiensive spread of *Agrostis stolonifera* followed by a gradual rise of *Salix spp.* within the northern sub-area and a gradual saturation of characteristic species for new wetlands in the southern sub-area due to biomass removal by grazing and mowing (Joenje & Verhoeven 1993).

Hydrogeochemistry

The hydrogeochemical processes that were identified at the research area confirm the hypothesis that desalination and pyrite oxidation (Figure 9) occur in the soil. The variation in different chemical water types (Table 3, Figure 7) indicates that desalination and pyrite oxidation proceed in different rates within the research area. The hypothesized difference in hydrogeochemical conditions, pyrite oxidation and decalcification, between the northern and southern part of the area has not been observed in our data. The difference in chemical watertype seems mainly determined by elevation and influence of saline Grevelingen water within the respective sub-areas. The predicted acidification due to pyrite oxidation that was found in other former tidal wetlands (Portnoy 1999; Portnoy & Giblin 1997) has not been observed in our area however (Figure 8). This is most probably due to the high $CaCO_3$ content of the soil. The relatively low $CaCO_3$ content in the top layer can be explained by the formation of a humus layer and by decalcification due to humic acids produced by plant roots and microbiological processes in the top soil. We found that cation exchange takes place with increasing desalination.

Relationship between Vegetation and Hydrogeochemistry

We could not find any evidence for the hypothesis that the difference in vegetation composition between the northern and southern sub-areas is driven by environmental factors other than the different nature management styles being practiced. The variation within the northern part is influenced mainly by differences in desalination. Other processes like pyrite oxidation and decalcification are present within the area but were not significantly correlated to the vegetation type (Figure 11 and Figure 12). Grazing and mowing have a stronger influence on the development of the vegetation than the hydrogeochemical processes in the southern sub-area. In this area grazing and mowing have led to a landscape with much less variation in vegetation structure and composition compared to the northern part of the area. However, the resulting vegetation type 4B (Table 2) is highly valued for its nature conservation value since it contains European Red list species which represent the highest natural value.

Limitations

The results of this master thesis need to be interpreted in the light of several limitations. First, it should be considered that differences in depth below the saturation level are not certain since the bore hole tended to collapse once the samples were taken from below the ground water level. Changes that occur above the saturated soil are more certain. Furthermore, since our sampling date represents only one point in time in the ongoing soil processes, it is not possible to be certain about how these processes have developed over time since the tidal influence has been removed or how they will proceed in the future. To gain a more detailed insight in the evolution of these processes with time, hydrogeochemical modeling is required.

Furthermore, because we were only able to investigate three PQ's in the northern sub-area there may be relationships between vegetation type and environmental conditions in the remaining PQ's that are now left undetected. It should also be noted that at several PQ's in the southern sub area, vegetation type 1 and 4C exist at the edge of lake Grevelingen in 2015, indicating that water composition can have an influence on the vegetation at the saline end of the salinity gradient. This limits the validity of our results in the saline part of the southern sub-area. To gain more insight in the environmental factors driving the variation within the area, the hydrogeochemical conditions should be investigated at more PQ's. However, since the investigated PQ's are representative for the main vegetation types we might expect that these analyses will yield quite similar results.

Management advice

In order to maintain the species with high natural values within the southern part of the research area the management by grazing and mowing should be continued in order to prevent the occurrence of natural succession towards shrubs and woodlands. If the grazing and mowing is stopped the more elevated parts are predicted to develop into a *Salix* forest ecosystem. The vegetation type which contains the valuable species will probably still occur but at a much smaller zone, probably only at sites where the water level is too high for the forests to develop and the salt concentration is low enough for the Red list species. Whether continuing pyrite oxidation and decalcification will eventually lead to a decrease in pH and acidification to such an extent that might cause the Red list species to decline should be investigated by the aforementioned modeling using a geochemical model like PHREEQC. In the case that these processes occur, an optional choice might be to reintroduce the tides. However, this might decrease the zone where vegetation type 4B is able to persist due to an increase in salinity in the lower part of the area.

5. Conclusions

The main aim of this research was to study the differences in vegetation succession between the northern and southern sub-areas at the 'Slikken van Flakkee' by analyzing the vegetation data set compiled by Anton van Haperen and 'Rijkswaterstaat'. This data set was subsequently compared to current hydrogeochemical data obtained by analyzing soil and pore water from nine representative locations within the 'Slikken van Flakkee' area.

Our data suggests that the difference in the vegetation succession between the northern and southern area is mainly due to the different styles of nature management between the sub-areas, i.e. no management in the northern and grazing and mowing tin the southern area. The variation within the northern sub-area is explained by differences in salt content of the pore water. Other chemical processes like pyrite oxidation and decalcification were also observed. However, these processes apparently did not have a significant influence on the development of the different vegetation types. Further research into the development of the hydrogeochemical conditions is required to determine whether the current nature management choices are sufficient to maintain the presence of valuable Red list species in the area.

6. Acknowledgements

I would like to thank Anton van Haperen for making the vegetation data he collected at the 'Slikken van Flakkee' available for this master thesis project, showing us the research area and helping with the fieldwork. 'Staatsbosbeheer' for granting us access to the area and providing a four-wheel drive. I also want to thank all the analysts and lab supervisors at 'Utrecht Castel' for helping with the preparation and analysis of our samples, and Aat Barendregt and Iris Pit for lending us the fieldwork equipment. Finally I would like to thank professor Martin Wassen for the supervision and the tips concerning the cluster analysis, and Martin van der Weiden for the daily supervision and all the help with the planning, fieldwork, sample preparation and analysis of the hydrogeochemical data during the project.

7. Literature

Appelo, C.A.J., Verweij, E. & Schäfer, H., 1998. A hydrogeochemical transport model for an oxidation experiment with pyrite/calcite/exchangers/organic matter containing sand. *Applied Geochemistry*, 13(2), pp.257–268.

Bannink, B.A., Van der Meulen, J.H.M. & Nienhuis, P.H., 1984. Lake grevelingen: From an estuary to a saline lake. An introduction. *Netherlands Journal of Sea Research*, 18(3-4), pp.179–190.

Bilz, M. et al., 2011. *European Red List of Vascular Plants*, Available at: http://data.iucn.org/dbtw-wpd/edocs/RL-4-016.pdf.

Braak, C.J.F.F. ter & Verdonschot, P.F.M.M., 1995. Canonical correspondence analysis and related multivariate methods in aquatic ecology. *Aquatic Sciences*, 57(3), pp.255–289. Available at: http://link.springer.com/10.1007/BF00877430.

Bray, J.R. & Curtis, J.T., 1957. An Ordination of the upland forest community of southern Wisconsin.pdf. *Ecology Monographs*, 27, pp.325–349.

Van Breukelen, B.M., Appelo, C.A.J. & Olsthoorn, T.N., 1998. Hydrogeochemical transport modeling of 24 years of Rhine water infiltration in the dunes of the Amsterdam Water Supply. *Journal of Hydrology*, 209(1-4), pp.281–296.

Halford, Keith, J., 2005. ExcelForHydrology.

van Haperen, A., Dertig jaar vegetatiesuccessie en stuweelontwikkeling op de Slikken van Flakkee (Grevelingen, ZW Nederland). *In preperation*.

van Haperen, A., 2011. *Een wereld van verschil landschap en plantengroei op de Zeeuwse en Zuid/Hollandse Eilanden*. PhD thesis Wageningen University.

Van de Haterd, R.J.W. et al., 2010. *Herintroductie getij in de Grevelingen en effecten op natuur in intergetijdengebieden*,

Joenje, W. & Verhoeven, B., 1993. Wetlands of recent Dutch embankments. *Hydrobiologia*, 265(1-3), pp.179–193.

Legendre, P. & Legendre, L., 1998. *Numerical Ecology. Second English Edition*,

van der Marel, E., 1979. Transformation of cover-abundance values in phytosociology and its effects on community similarity. *Vegetatio*, 39(2), pp.97–114.

Nicholson, R. V, Gillham, R.W. & Rearddn, E.J., 1988. Pyrite oxidation in carbonate-buffered solution : 1 . Experimental kinetics. , 52, pp.1077–1085.

Oksanen, A.J. et al., 2016. Vegan: Community Ecology Package. *R. Package version 2.4-0*, https://cr.

Parkhurst, B.D.L. & Appelo, C. a J., 1999. User's Guide To PHREEQC (version 2) — a Computer Program for Speciation, and Inverse Geochemical Calculations. *Exchange Organizational Behavior Teaching Journal*, D(Version 2), p.326. Available at: http://downloads.openchannelsoftware.org/PHREEQC/manual.pdf.

van der Pluijm, A. & de Jong, D., 2003. *Oerbos en savanne in de Grevelingen: de twee gezichten van de Slikken van Flakkee : 30 jaar vegetatieontwikkeling op de Slikken van Flakkee (Grevelingenmeer) 1972-2001*,

Portnoy, J.W., 1999. Salt marsh diking and restoration: biogeochemistry implications of altered water hydrology. *Environm. Managem.*, 24(1), pp.111–120.

Portnoy, J.W. & Giblin, A.E., 1997. Effects of historic tidal restrictions on salt marsh sediment chemistry. *Biogeochemistry*, 36(3), pp.275–303.

Ratas, U. et al., 2003. A landscape-geochemical approach in insular studies as exemplified by islets of the eastern Baltic Sea. *Landscape Ecology*, 18(2), pp.173–185.

Roskam, G. (Deltares) & Griffioen, J. (TNO), 2011. Een verkennende studie naar sporenelementen in pyriet in Nederlandse geologische afzettingen. *TNO-rapport*, (TNO-060-UT-2011-02229).

Slager, H., Fluyt, D.J. & Rook, G.J., 1986. Waterhuishouding en zouthuishuiding van de slikken van Flakkee. *Ministerie van Verkeer en Waterstaas, Rijkdienst voor de IJsselmeerplders - Lelystad: RIJP*, (RIJP-rapport; 1986-24 Abw), p.40.

Slager, H. & Visser, J., 1990. De abiotische kenmerken van de drooggevallen gebieden in de Grevelingen. *Ministerie van Verkeer en Waterstaat, Rijkswaterstaat, Directie Flevoland.*, Flevoberic(ISBN 90-369-1065-X), p.47.

Stuyfzand, P.J., 2012. Hydrochemcal (HGC 2.1), for storage, management, control, correction and interpretation of water quality data in Excel ® spread sheet. , 244(KWR-report BTO.2012.244(s)), update of 2012 report (2014)).

Tosserams, M., Lammers, E.H.R.R. & Platteeuw, M., 2000. Het Volkerak-Zoommeer De ecologische ontwikkeling van een afgesloten zeearm. *RIZA rapport: 2000.024*, 1, p.169.

Van der Weiden, M.J.J., 2015. Ecohydrogeochemie van drooggevallen buitendijkse gebieden. *Dissertatievoorstel*.Utrecht University.

van Wirdum, G., 1991. Vegetation and hydrology of floating rich-fens.PhD thesis University of Amsterdam, *Datawyse, Maastricht (ISBN 90-5291-045-6).*, p.310.

Wong, P.P. et al., 2014. Coastal systems and low-lying areas. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Changend Sectoral Aspects. Contribution of Working*, pp.361–409.

Wu, T. et al., 2011. Plant distribution in relation to soil conditions in Hangzhou Bay coastal wetlands, China. *Pakistan Journal of Botany*, 43(5), pp.2331–2335.

8. Appendices

Appendix 1: Map of the PQ’s at the ‘Slikken van Flakkee’.

Figure 13: Map of the PQ’s at the Slikken van Flakkee where the vegetation has been recorded since 1972. Red dots represent the PQ’s that were analyzed during this master thesis for hydrogeochemical compositions.

Appendix 2. Heatmap.

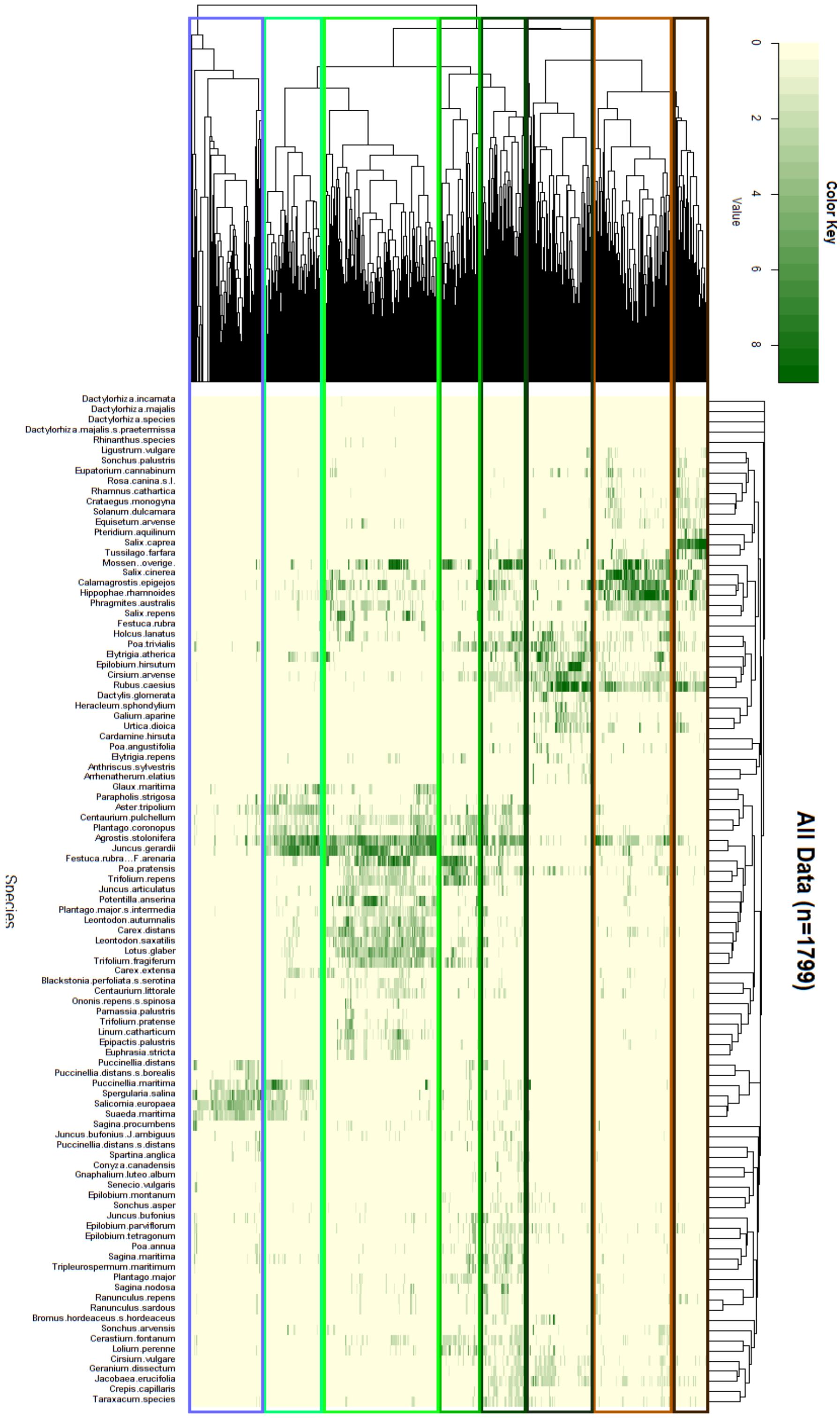
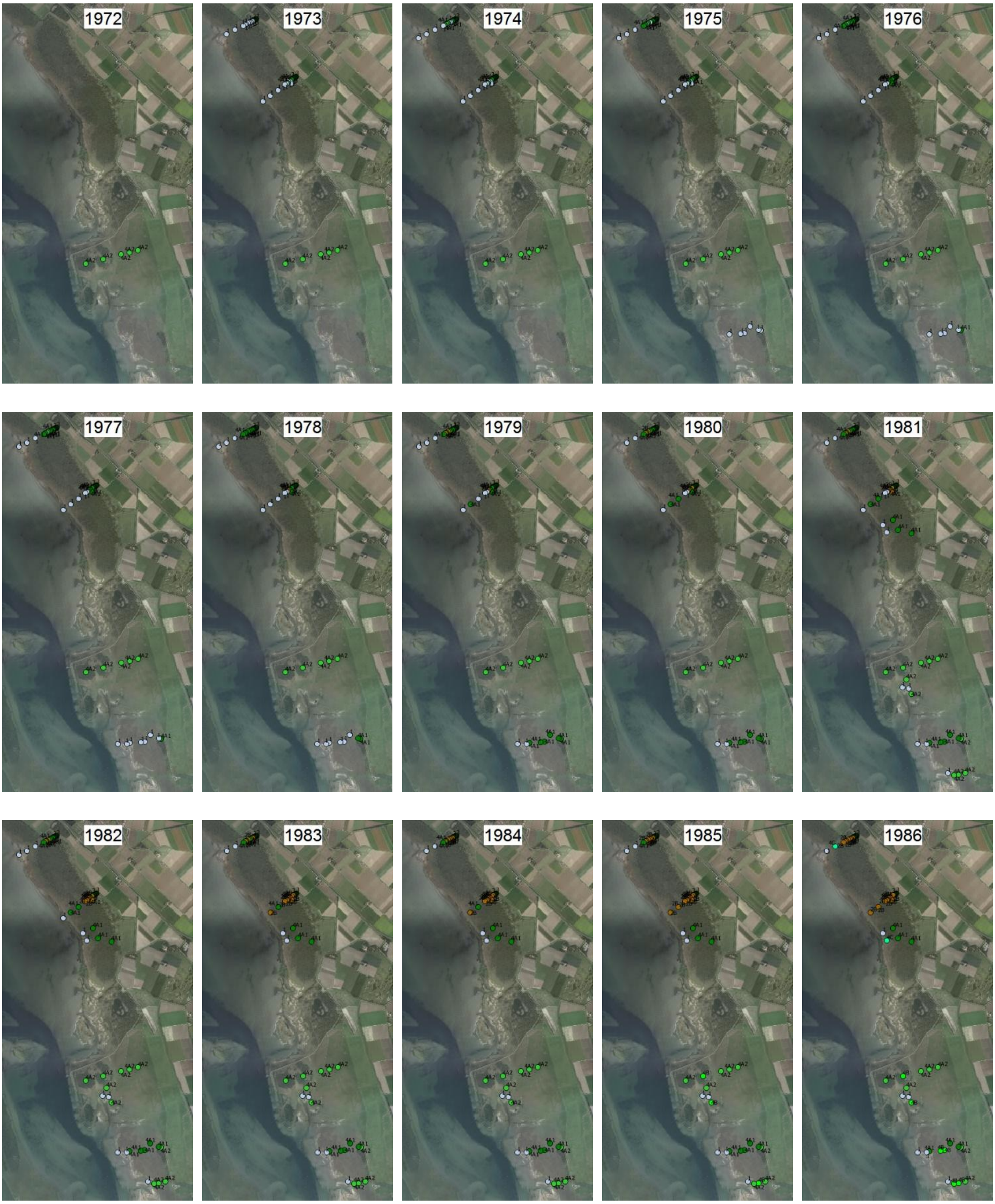
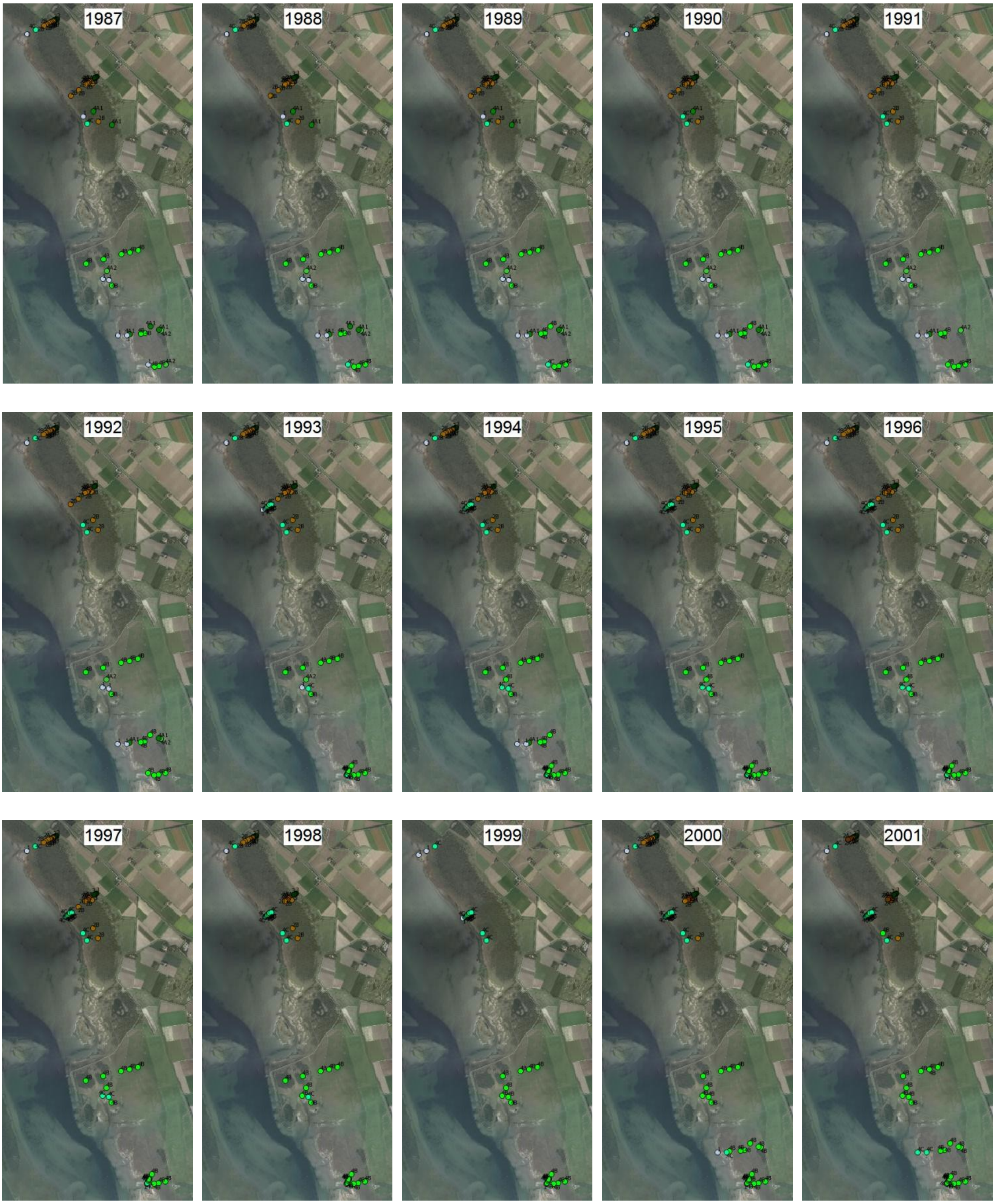


Figure 14: Visual representation of all the vegetation recordings since 1972 at the Slikken van Flakkee with dendrogram (average clustering) and the important species. Vegetation types are indicated with colored rectangles. Blue = type 1, darkbrown = type 2B, lightbrown = type 2A, brown/green = type 3, darkgreen – blue/green = type 4A1, 4A2, 4B and 4C. Color key shows the cover percentage of the species in van der Maarel scale (1 = 0,1%, 2 = 1%, 3 = 3%, 4 = 5%, 5 = 12,5%, 6 = 28,5%, 7 = 37,5%, 8 = 62,5% and 9 = 87,5%).

Appendix 3. Development vegetation 1972-2015.




1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001

Legend	
Vegetation Type	**Code**
SPH (species poor halophytes)	1
Forest	2B
Forest	2A
Thickets	3
SRG (species rich grassland)	4A1
SRG (species rich grassland)	4A2
SRG (species rich grassland)	4B
SRG (species rich grassland)	4C

Research:	**Ecohydrogeochemistry of Former Tidal Areas**	Back to Content
Area:	*Grevelingen, Slikken van Flakkee*	
Author:	*M. van der Weiden, T. Kanters*	
Date:	*August 12, 2016*	
File:	*Slikken_van_Flakkee_Data_Processing_??.xlsx*	
Sheet:	***Results Water***	
Description:	*Results of Water Analyses*	
Instruction:	*NA*	
Source:	*Authors*	

Nr	Area	PQ	High / Low / Salt	Location X	Y	Z (cm below groundlevel)	Samplecode	E. Conductivity Field (mS/cm)	pH Lab	Na^+ mg/l	K^+ mg/l	Mg^{++} mg/l	Ca^{++} mg/l	Sr mg/l	NH_4^+ mg/l	F^- mg/l	Cl^- (IC) mg/l	Cl^- (ICP-OES) mg/l	Br^- mg/l	HCO_3^- mMol/l	HCO_3^- mg/l	CO_3^{2-} mg/l	SO_4^{2-} (IC) mg/l	SO_4^{2-} (ICP-OES) mg/l	S^{--} Measured mg/l
1	Slikken Noord	45	High	60071	424256	-10	SvF-45-0,10		7,29	50,9	1,0	8,6	178,4	0,6	1,70	0,3	71	1	0,4	9,60	586	0	6,6	8,7	0,005
2		45				-40	SvF-45-0,40		7,28	55,4	1,8	13,9	203,4	0,8	0,73	1,0	77	2	0,7	11,21	684	0	11,3	9,1	0,005
3		45				-80	SvF-45-0,80		7,37	63,8	3,3	15,4	205,1	0,9	0,24	1,5	85	1	0,7	11,38	694	0	27,7	26,6	0,006
4		45				-120	SvF-45-1,20	3,5	7,35	152,7	44,1	38,5	708,5	2,8	1,36	1,1	271	3	1,2	9,89	603	0	1.373,8	1.396,1	0,004
5	Slikken Noord	49	Low	59744	424098	-10	SvF-49-0,10		6,89	97,1	8,3	18,5	185,3	0,6	0,12	0,3	174	48	0,6	9,96	608	0	1,4	7,2	0,010
6		49				-40	SvF-49-0,40		7,03	232,9	22,9	58,4	270,1	1,5	0,63	1,0	420	136	1,1	9,56	583	0	317,7	324,9	0,003
7		49				-80	SvF-49-0,80		7,47	342,5	58,3	87,8	201,0	1,7	0,56	1,2	507	214	1,6	11,84	722	0	338,1	350,7	0,004
8		49				-120	SvF-49-1,20	5,6	7,46	761,1	99,2	91,7	151,0	1,5	4,19	1,0	635	1.061	2,2	12,75	778	0	358,6	389,3	0,006
9	Slikken Noord	73	Salt	60428	422584	-10	SvF-73-0,10		7,48	4.739,7	163,1	648,2	561,7	4,6	0,09	1,4	8.735	9.154	22,7	8,87	541	0	1.645,6	1.899,3	0,001
10		73				-40	SvF-73-0,40		7,41	9.282,6	347,0	1.392,0	842,6	9,0	0,12	1,9	15.073	17.194	50,3	10,70	653	0	4.229,5	4.584,0	0,003
11		73				-80	SvF-73-0,80		7,60	9.573,7	323,8	1.457,6	723,0	8,2	3,78	0,6	18.856	17.743	67,4	12,19	744	0	4.038,5	4.188,2	0,078
12		73				-120	SvF-73-1,20	50,6	7,87	10.125,2	337,6	1.528,0	719,3	8,4	6,33	0,6	17.334	18.630	64,6	13,51	824	0	3.573,3	4.324,2	0,004
13	Slikken Zuid (dynamic)	17	High	62494	417501	-10	SvF-17-0,10		7,67	36,3	0,9	9,8	121,6	0,3	1,35	0,6	20	8	0,0	6,39	390	0	5,3	1,4	0,003
14		17				-40	SvF-17-0,40		7,88	40,4	1,2	12,6	145,6	0,6	0,92	0,6	55	10	0,1	6,58	401	0	44,6	57,0	0,005
15		17				-80	SvF-17-0,80		7,75	62,5	11,0	13,8	146,8	0,9	1,49	1,7	101	12	0,3	5,07	309	0	163,2	171,2	0,006
16		17				-120	SvF-17-1,20	1,6	7,45	64,6	21,5	18,6	164,4	1,1	1,75	0,7	97	13	0,3	6,87	419	0	148,3	161,9	0,011
17	Slikken Zuid (dynamic)	22	Low	61806	417423	-10	SvF-22-0,10		7,85	1.742,8	112,2	154,8	367,0	2,6	0,23	0,8	2.244	3.115	4,2	7,63	466	0	349,2	526,0	0,013
18		22				-40	SvF-22-0,40		7,58	3.127,7	139,9	364,6	425,7	3,7	1,66	1,4	5.724	5.875	16,9	12,04	735	0	1.070,6	1.068,5	0,005
19		22				-80	SvF-22-0,80		7,20	4.594,5	174,2	643,1	550,8	5,3	7,54	0,8	8.399	8.728	25,6	12,44	759	0	1.902,4	1.922,1	0,004
20		22				-120	SvF-22-1,20	22,25	7,14	6.621,8	257,0	967,7	516,2	6,3	35,25		11.965	12.659	36,4	11,90	726	0	2.604,7	2.699,9	0,464
21	Slikken Zuid (dynamic)	65	Salt	62206	416754	-10	SvF-65-0,10		7,69	1.892,2	76,8	230,6	326,1	2,3	1,43	1,4	3.707	3.544	9,3	11,68	713	0	488,5	311,9	0,000
22		65				-40	SvF-65-0,40		7,85	1.817,5	71,0	219,3	438,1	2,6	1,11	1,1	3.453	3.668	9,1	19,83	1.210	0	301,0	483,9	0,002
23		65				-80	SvF-65-0,80		7,81	2.342,1	118,5	272,1	269,8	2,3	2,57	0,8	4.320	4.390	11,4	18,68	1.140	0	517,4	518,1	0,004
24		65				-120	SvF-65-1,20	14,6	7,10	2.372,8	127,2	275,8	266,4	2,2	7,24	1,1	4.280	4.331	11,5	17,38	1.060	0	602,8	600,7	0,006
25	Slikken Zuid (stable)	10	High	61808	419214	-10	SvF-10-0,10		7,25	18,2	14,9	5,3	85,9	0,2	0,04	0,2	36	976	0,0	3,97	242	0	11,2	9,3	0,000
26		10				-40	SvF-10-0,40		7,62	14,9	7,2	7,8	134,7	0,4	0,04	0,2	22	11	NR	6,94	423	0	18,4	16,4	0,005
27		10				-80	SvF-10-0,80		6,86	13,5	1,7	6,9	132,8	0,5	0,17	0,2	19	9	0,1	6,40	391	0	1,3	0,62337	0,006
28		10				-120	SvF-10-1,20	1,05	6,92	16,4	2,9	4,6	84,0	0,3	0,25	0,2	20	14	0,1	4,74	289	0	2,8	0,42697	0,009
29	Slikken Zuid (stable)	58	Low	61301	418805	-10	SvF-58-0,10		8,01	514,1	16,9	18,5	89,2	0,6	0,09	1,5	379	172	0,5	17,37	1.060	0	3,6	9,7	0,006
30		58				-40	SvF-58-0,40		8,05	530,6	38,7	24,0	80,7	0,6	0,12	2,6	275	115	0,6	21,71	1.325	0	3,2	4,4	0,005
31		58				-80	SvF-58-0,80		8,40	394,5	83,1	38,2	50,6	0,5	0,08	1,8	160	75	0,5	19,18	1.170	0	17,5	33,0	0,003
32		58				-120	SvF-58-1,20	2,6	8,38	317,7	93,1	67,9	47,7	0,6	0,13	1,3	133	61	0,4	18,50	1.129	0	1,0	2,5	0,004
33	Slikken Zuid (stable)	59	Salt	61208	418614	-10	SvF-59-0,10		7,50	2.666,5	78,7	304,7	513,3	3,3	0,29	0,6	5.759	5.507	14,8	8,34	509	0	707,1	676,9	0,001
34		59				-40	SvF-59-0,40		7,94	1.688,1	74,4	132,8	203,6	1,6	0,14	1,2	2.542	2.612	5,7	24,41	1.489	0	136,3	146,5	0,048
35		59				-80	SvF-59-0,80		7,97	1.778,7	87,0	165,2	208,9	1,9	0,14	1,3	2.982	2.932	6,4	23,59	1.439	0	32,9	41,9	0,014
36		59				-120	SvF-59-1,20	14,1	8,03	1.874,8	99,7	190,6	185,0	1,9	0,35	1,1	3.250	3.151	7,6	19,91	1.215	0	178,1	160,3	0,011
101	Seawater							19.800	8,2	11000	400	1320	420				19.800				145		2775		
102	Riverwater Rhine/Meuse							124	7,7	69,18	5,89	10,4	74,05				124				157		67		
103	Grevelingenwater (G)							16.000		8.888,9	323,9	1.067,1	353,2				16.000				147,3		2252,01		
104	Rainwater (R)									2,2	0,2	0,3	0,6				3,9						6,4		

Nr	NO_3^- mg/l	NO_2^- mg N/l	P_{tot} mg/l	PO_4^{3-} mg/l	SiO_2 mg/l	Fe_{tot} mg/l	Mn_{tot} mg/l	Al mg/l	DOC mgC/l	Ionbalance 1) Sum Cations (SC) meq/l	Sum Anions (SA) meq/l	((SC-SA) / (SC+SA)) * 100 (%)	Total Dissolved Solids mg/l	Ratio's Ca*25/Cl meq/l	Mg*5/Cl meq/l	Na*1,15/Cl meq/l	K*55/Cl meq/l	Cl meq/l	SO4*10/Cl meq/l	HCO3*200/Cl meq/l	Fe*250000/Cl meq/l
1	0,5	0,2	0,17		23,1	0,6	0,85	0,122	35,4	12,00	11,77	0,9	1.019	110,56	1,77	1,26	0,73	2,01	0,68	954,02	2.847,36
2	0,5		0,14		19,2	0,6	1,44	0,456	16,0	13,87	13,68	0,7	1.111	116,71	2,63	1,28	1,15	2,17	1,08	1.030,97	2.388,06
3			0,15		18,4	0,05	0,19	0,328	12,2	14,39	14,43	-0,2	1.147	106,59	2,64	1,33	1,92	2,40	2,40	947,99	186,66
4	0,4		0,15		23,2	11,1	3,56	1,562	28,6	46,90	46,21	0,7	3.307	115,54	2,07	1,00	8,10	7,65	37,39	258,55	13.002,67
5	0,5		0,17		25,9	19,5	1	0,427	75,8	15,94	14,91	3,3	1.329	47,21	1,55	0,99	2,38	4,90	0,06	406,72	35.631,02
6	0,5		0,14		16,3	2,3	1,14	0,568	36,7	29,16	28,10	1,9	2.021	28,40	2,03	0,98	2,71	11,86	5,58	161,20	1.728,66
7	0,5		0,16		17,5	6,5	0,6	0,612	34,0	33,93	33,25	1,0	2.371	17,54	2,53	1,20	5,73	14,30	4,92	165,60	4.057,50
8	0,7		0,43		32,0	0,2	0,06	0,431	31,1	50,96	35,80	17,5	2.877	10,52	2,11	2,13	7,79	17,90	4,17	142,42	80,56
9	21,1	14,9	0,12	NR	11,3	0,1	0,1	0,806	94,3	291,70	289,93	0,3	17.324	2,84	1,08	0,96	0,93	246,38	1,39	7,20	3,63
10	21,1	3,8	0,12	NR	9,4	0,0	0	1,526	52,7	569,21	524,34	4,1	31.996	2,47	1,35	1,09	1,15	425,14	2,07	5,03	0,00
11	21,1	4,4	0,01	NR	21,2	0,3	0,3	1,429	42,9	580,93	628,49	-3,9	35.883	1,70	1,13	0,90	0,86	531,85	1,58	4,58	5,05
12	21,0	4,5	0,03	1,1	21,0	0,2	0,1	1,365	34,1	611,01	577,20	2,8	34.589	1,84	1,29	1,04	0,97	488,92	1,52	5,53	3,66
13	0,6	0,4	0,56	0,2	9,0	0,125	0,1088	0,052	79,6	8,56	7,09	9,4	795	274,20	7,30	3,28	2,40	0,55	2,00	2.310,73	2.017,08
14	0,6		0,18		8,3	0,025	0,0213	0,315	29,7	10,14	9,11	5,3	787	116,61	3,32	1,30	1,05	1,56	5,97	844,73	141,10
15	1,4	0,5	0,18		5,0	0,016	0,0046	0,207	20,2	11,55	11,43	0,5	869	64,24	1,99	1,10	5,45	2,85	11,91	355,58	49,77
16	0,6		0,16		10,4	0,047	0,17	0,361	20,6	13,20	12,74	1,8	1.000	74,90	2,80	1,18	11,04	2,74	11,27	501,66	152,67
17			0,20		12,6	0,6	2,58	0,799	20,4	109,85	78,24	16,8	5.506	7,23	1,01	1,38	2,49	63,29	1,15	24,11	89,12
18			0,12		10,9	0,2	1,6	0,785	13,5	191,02	195,86	-1,3	11.641	3,29	0,93	0,97	1,22	161,46	1,38	14,91	11,09
19			0,14		12,6	1,4	1,5	1,099	25,7	285,21	289,01	-0,7	17.117	2,90	1,12	0,97	1,03	236,92	1,67	10,50	52,91
20			0,05		32,9	0,6	0,3	1,259	21,4	401,95	403,63	-0,2	23.788	1,91	1,18	0,98	1,07	337,50	1,61	7,05	15,92
21			0,14		27,2	20,2	1,3	0,544	67,6	120,36	126,48	-2,5	7.657	3,89	0,91	0,91	1,03	104,56	0,97	22,34	1.726,33
22			0,15		26,5	3,4	1,3	0,72	62,7	121,00	123,55	-1,0	7.703	5,61	0,93	0,93	1,03	97,40	0,64	40,72	312,56
23			0,07		32,3	1,6	0,4	0,588	34,4	140,97	151,36	-3,6	9.106	2,76	0,92	0,96	1,37	121,86	0,88	30,66	117,55
24			0,08		37,4	3,3	0,5	0,549	31,6	142,98	150,70	-2,6	9.116	2,75	0,94	0,98	1,48	120,71	1,04	28,79	244,76
25	0,8	0,2	0,69	0,2	7,0	0,2	0,0383	0,32	5,0	5,91	5,24	6,0	436	105,95	2,17	0,90	20,72	1,01	2,30	784,90	1.792,87
26	2,0	NR	0,14	NR	9,7	0,029	0,0281	0,257	13,9	8,20	7,99	1,3	675	268,97	5,12	1,19	16,14	0,62	6,12	2.220,90	409,03
27	0,4	0,0	0,15	NR	10,6	0,7	0,53	0,326	14,4	7,88	6,99	6,0	615	307,13	5,28	1,25	4,33	0,54	0,48	2.372,31	10.786,55
28	0,4	0,0	0,21	NR	7,6	0,03	0,06	0,119	15,1	5,38	5,38	0,0	466	186,41	3,38	1,46	7,26	0,56	1,05	1.687,13	473,27
29	2,2	0,1	0,19	NR	25,2	1,3	0,23	0,128	142,3	28,82	28,26	1,0	2.468	10,40	0,71	2,40	2,22	10,70	0,07	324,77	1.046,32
30	2,7	0,3	0,20	NR	26,3	1,4	0,05	0,267	43,3	30,13	29,72	0,7	2.420	12,97	1,27	3,42	7,01	7,76	0,08	559,23	1.637,58
31	2,3	0,1	0,45	0,2	23,3	0,042	0,0198	0,238	25,4	24,96	24,18	1,6	2.006	14,00	3,49	4,38	25,92	4,51	0,81	850,85	83,61
32	2,2	0,0	0,52	0,3	33,6	0,2	0,0091	0,088	21,4	24,18	22,38	3,9	1.882	15,81	7,42	4,22	34,81	3,76	0,06	983,34	523,52
33	11,3		0,14	NR	45,1	9,5	3,3	0,804	39,2	169,15	185,71	-4,7	10.710	3,94	0,77	0,82	0,68	162,43	0,91	10,27	523,09
34	2,2	0,5	0,09	NR	37,2	5,1	0,7	0,236	142,8	96,63	99,05	-1,2	6.672	3,54	0,76	1,18	1,46	71,71	0,40	68,08	636,79
35	21,3	0,6	0,00	0,7	44,9	1,2	0,3	0,286	134,2	103,67	108,79	-2,4	7.101	3,10	0,81	1,06	1,46	84,10	0,08	56,09	127,75
36	21,3	0,6	0,60	2,3	48,1	0,9	0,3	0,199	105,7	109,07	115,68	-2,9	7.332	2,52	0,86	1,02	1,53	91,66	0,40	43,44	87,91
101	1,3		0,06		4,4	0,002	0,005			618	619	-0,1	35.866	0,94	0,97	0,99	1,01	558,49	1,03	0,85	0,03
102	73		1,11		5,8	0,24	0,07		4	8	9	-5,9	588	26,41	1,22	0,99	2,37	3,50	3,99	147,13	614,37
103	15,1473		0,263		4,67	0,048	0,0176						29.053	0,98	0,97	0,99	1,01	451,30	1,04	1,07	0,95
104	14,2		0,03		0,5	0,11	0,01		1,5				28	6,80	1,12	1,00	2,56	0,11	12,11	0,00	8.952,96

Explanation

1) Calculated with HGC

NR	No Result
	Detectionlimit / 2
	Minimum value
	Not planned
	IC
	ICP-OES
	Large deviation
	(To be) calculated

Legenda (Conditional formatting for highlighting analytical errors or lacking data)

Conditional formatting with ΣC = sum cations, ΣA = sum anions, in worksheets 3-6

Cell colour	no colour	tan	orange	no colour	tan	orange
if:	| IB | (%)			ΔEC-meas (%)		
ΣC+ΣA >8 meq/L	<4	<8	≥8	<4	<8	≥8
ΣC+ΣA = 2-8 meq/L	<6	<12	≥12	<6	<12	≥12
ΣC+ΣA <2 meq/L	<10	<20	≥20	<10	<20	≥20

IB (%) = 100 (ΣC-ΣA) / (ΣC+ΣA) **ΔEC-meas (%) = 100 (EC_{MEAS} - EC_{CALC}) / EC_{MEAS}**

Appendix 4. Results Water.

<u>Remark</u>: Results are not fully final due to some minor dilution corrections yet to be performed.

Appendix 5. Results Soil.

Research:	**Ecohydrogeochemistry of Former Tidal Areas**	**Back to Content**
Area:	*Grevelingen, Slikken van Flakkee*	
Author:	*M. van der Weiden, T. Kanters*	
Date:	*August 12, 2016*	
File:	*Slikken_van_Flakkee_Data_Processing_??.xlsx*	
Sheet:	***Result Soil***	
Description:	*Results of Soil Analyses*	
Instruction:	*NA*	
Source:	*Authors*	

Nr	Area	PQ	High / Low / Salt	Location X	Y	Z (cm below groundlevel)	Samplecode	Dry matter content 1) %	$CaCO_3$ (TGA) % DS	Organic matter (Humus) (TGA) % DS	Organic Carbon (CN Analyzer) % DS	N_{total} (CN Analyzer) % DS	Ratios C/N
1	Slikken Noord	45	High	60071	424256	-10	SvF-45-0,10	47,68	2,56	18,0	10,33	0,53	19
2		45				-40	SvF-45-0,40	78,18	8,03	2,5	2,26	0,07	33
3		45				-80	SvF-45-0,80	80,28	9,09	0,5	1,32	0,01	100
4		45				-120	SvF-45-1,20	81,76	7,75	0,4	1,19	0,00	247
5	Slikken Noord	49	Low	59744	424098	-10	SvF-49-0,10	51,44	2,68	15,7	8,73	0,36	24
6		49				-40	SvF-49-0,40	80,28	7,17	0,6	1,18	0,01	100
7		49				-80	SvF-49-0,80	79,61	6,29	0,5	0,99	0,01	83
8		49				-120	SvF-49-1,20	81,18	8,63	0,5	1,25	0,01	115
9	Slikken Noord	73	Salt	60428	422584	-10	SvF-73-0,10	63,13	2,29	12,9	7,22	0,26	28
10		73				-40	SvF-73-0,40	83,98	3,68	0,7	0,82	0,01	99
11		73				-80	SvF-73-0,80	84,31	3,82	0,7	0,85	0,01	101
12		73				-120	SvF-73-1,20	81,68	4,69	0,9	1,06	0,01	94
13	Slikken Zuid (dynamic)	17	High	62494	417501	-10	SvF-17-0,10	42,32	1,75	35,0	18,39	1,12	16
14		17				-40	SvF-17-0,40	82,57	6,15	0,8	1,11	0,03	44
15		17				-80	SvF-17-0,80	81,09	7,00	0,4	1,00	0,01	101
16		17				-120	SvF-17-1,20	81,43	8,08	0,4	1,12	0,01	109
17	Slikken Zuid (dynamic)	22	Low	61806	417423	-10	SvF-22-0,10	45,96	2,48	22,4	12,71	0,70	18
18		22				-40	SvF-22-0,40	80,50	7,61	0,6	1,21	0,01	142
19		22				-80	SvF-22-0,80	80,19	7,59	0,6	1,22	0,01	163
20		22				-120	SvF-22-1,20	80,99	13,77	0,7	2,03	0,01	223
21	Slikken Zuid (dynamic)	65	Salt	62206	416754	-10	SvF-65-0,10	45,31	1,41	22,1	11,95	0,57	21
22		65				-40	SvF-65-0,40	79,20	6,14	0,7	1,10	0,01	81
23		65				-80	SvF-65-0,80	81,58	8,31	0,6	1,32	0,01	117
24		65				-120	SvF-65-1,20	79,86	9,14	0,8	1,59	0,01	155
25	Slikken Zuid (stable)	10	High	61808	419214	-10	SvF-10-0,10	49,17	0,95	23,6	12,10	0,78	15
26		10				-40	SvF-10-0,40	82,89	6,16	0,7	1,05	0,02	46
27		10				-80	SvF-10-0,80	82,65	6,16	0,4	0,87	0,01	92
28		10				-120	SvF-10-1,20	80,39	6,46	0,5	0,95	0,01	75
29	Slikken Zuid (stable)	58	Low	61301	418805	-10	SvF-58-0,10	43,06	2,84	21,3	11,40	0,66	17
30		58				-40	SvF-58-0,40	79,41	8,08	1,0	1,46	0,03	52
31		58				-80	SvF-58-0,80	80,54	7,62	0,4	1,13	0,01	88
32		58				-120	SvF-58-1,20	80,06	7,06	0,7	1,20	0,01	86
33	Slikken Zuid (stable)	59	Salt	61208	418614	-10	SvF-59-0,10	52,21	2,71	13,9	7,53	0,39	20
34		59				-40	SvF-59-0,40	79,48	7,51	0,9	1,41	0,02	63
35		59				-80	SvF-59-0,80	80,40	8,83	0,8	1,53	0,02	74
36		59				-120	SvF-59-1,20	80,81	5,49	0,5	0,95	0,01	102

Explanation

1) Soil sample not saturated due to lower waterlevel and due to porewater sampling.

(light green)	Analytical result
(bright green)	Average of Duplo
(light blue)	Calculated

Remark: Results of Dry Matter content are not fully final due to some minor weight corrections yet to be performed.