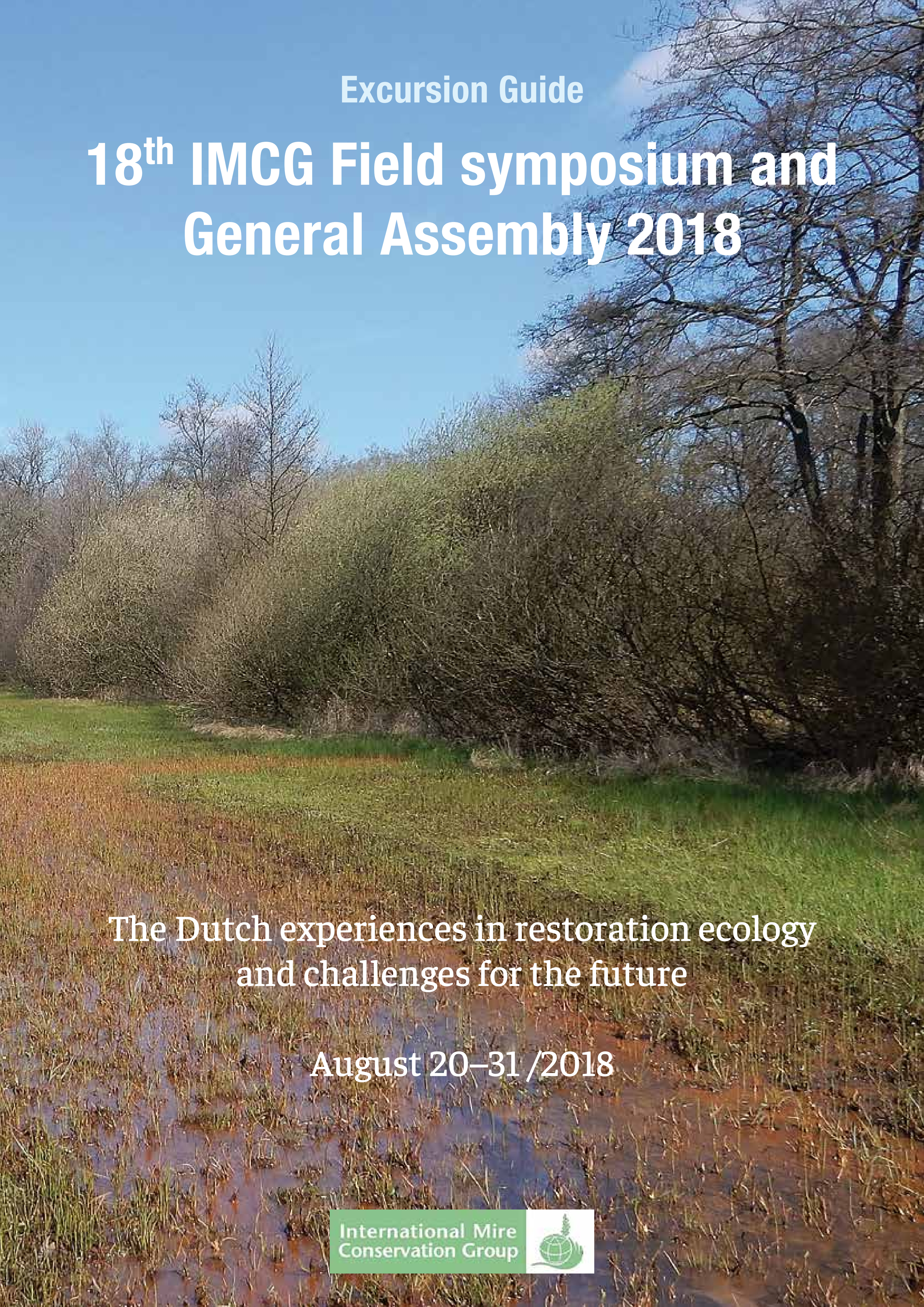
Excursion Guide

18th IMCG Field symposium and General Assembly 2018



The Dutch experiences in restoration ecology and challenges for the future

August 20–31 /2018

International Mire Conservation Group

Colofon

Excursion guide and book of abstracts of the IMCG symposium (22nd Aug 2018 Texel)

18th IMCG Field Symposium and General Assembly 2018
20 – 31 August 2018.

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Contents

The Dutch experiences in restoration ecology and challenges for the future

The Netherlands is densely populated and the development of infrastructures and intensification of agriculture in the sixties and seventies of the last century has destroyed or damaged most of our existing nature reserves. But this has also triggered much practical and fundamental research aimed at understanding the mechanisms of wet ecosystem decline in the Netherlands. During the eighties and nineties the government decided to buy out farmers in areas where modern agriculture was no longer viable and hand them over to nature conservation organizations. Such areas were then transformed into nature areas, by raising water levels and decreasing nutrient availability. During that period much knowledge was developed in restoring wet ecosystems that had been in former agricultural use.

We aim to show the participants areas where scientific and practical knowledge in Dutch restoration areas has developed.

★ Area that will be visited during the excursion.

Schedule of the 18th IMCG Field excursions

Detailed planning (28th July 2018):

Monday 20 August

Participants travel to Texel on their own. Participants arriving at Amsterdam Schiphol Airport take the train to Den Helder (close to Texel). From there take the shuttle bus to the Harbour and take the ferry boat to Texel. After arrival on Texel take the local bus to the town of Den Burg, which stops opposite of Stayokay (our accommodation on Texel). Adress: Haffelderweg 29, 1791 AS Den Burg. We will later provide a detailed travelling scheme. Travellers by car can park the car at the harbour for free.

19.00: Dinner at Stayokay Den Burg.

Tuesday 21 August

08.30: Departure with local busses (Texelhopper) to *De Slufter,* a near natural salt marsh and dune area. We will have a three hours walk through the area guided by experienced researchers and managers. We will take a bagged lunch from Stayokay.

12.30-13.30: Coffee at Restaurant De Slufter, eat lunch.

13.30: Departure with local busses to *De Hors (De Geul).*

14.00- 17.00: Excursion through De Hors with natural dune formation and dune slacks of different age. The excursion will be guided by experienced researchers that have studied the area.

17.00: Local bus back to Stayokay.

19.00: Dinner at Stayokay.

Wednesday 22 August

08.15: Local bus to Harbour, 10 minutes-walk to Research Institute NIOZ.

8.45: Start **IMCG-symposium** at NIOZ. Program will be provided later.

12.30-13.30: Lunch at NIOZ.

13.30-17.00: IMCG-symposium.

18.00: Local bus from Harbour to Stayokay in Den Burg.

19.00: Dinner in Restaurant De Lindenboom, Den Burg.

Thursday 23 August

08.30-9.30: Bus Travel from Den Burg to Texel Harbour, Ferry to Den Helder Harbour.

10.00-11.00: Travel by bus from Den Helder Harbour to *Eernewoude* (Friesland).

12.00-16.00: Boat trip (lunch on board) to wet meadow reserve surrounded by deeply drained polders. Guidance by local managers and experienced researchers that have studied the area.

16.00-17:00: Travel to Havelte (NIVON Hunehuis; Hunebeddenweg 1, 7973 JA Darp).

19.00: Dinner (close to Hunehuis).

Friday 24 August

08.30-09:30: Travel to village Oudemolen *(Drentsche Aa National Park).*

09.30-10.30: Coffee stop at OudeMolen regional office of Staatsbosbeheer. Introduction into Geohydrology by Enno Bregman.

10.30-13.00: Two stops in the National Park Drentsche Aa (De Heest). Guidance by local managers and experienced researchers that have studied the area.

13.00-14.00: Travel to *National Park Dwingelderveld* (Spier). Lunch packet in the bus.

14.00-17.30: Three-hour walk in the N. P. Dwingelderveld, the large wet heathland reserve in Europe. Discussion on hydrology of small heathland bogs. Guidance by local managers and experienced researchers that have studied the area.

17.30- 18.00: Travel from Dwingeloo to Havelte (Hunehuis).

19.00: Dinner (close to Hunehuis).

Saturday 25 August

08.30-9.00: Travel to Ossenzijl/Kalenberg (Overijsel). (address: Hoogeweg 27, 8376 EM Ossenzijl).

09.00-11.00: Two-hour walk at *Stobberibben* a well-studied terrestrialization fen in NW-Overijsel. Guidance by local managers and experienced researchers that have studied the fens here.

11.30-12.00: Travel to Wanneperveen.

12.00-16.00: Field excursion to *Veldweg, Kiersche Wijde and Meppelerdiep*, restored terrestrialization fens and flood meadows. Guidance by local managers and experienced researchers that have studied the fens.
16.00-16.30: Travel from the town of Meppel to Havelte.
18.00: Dinner (close to Hunehuis).

Sunday 26 August

09.30-10.30: Travel to the village of Zwartemeer.
10.30-11.30: Coffee-stop at the visitors centre of the national nature conservation agency (SBB).
11.30-15.30: Four-hour walk through the restored *bog complex Bargerveen*, which is one of the best studied and most expensive restoration objects in the Netherlands. Guidance by local managers and experienced researchers that have studied this bog.
15.30-16.00: Travel to accommodation near Zwartemeer (Sportlandgoed; Verlengde van Echtenkanaal NZ 2, 7894 EA Zwartemeer).
18.30: Dinner at Sportlandgoed.

Monday 27 August

08.30-09.30: Travel to Wierdense Veld.
09:30-12.00: Field excursion to another large bog remnant *(Wierdense Veld)* that is well studied and where restoration measures have been taken since several decades. Guidance by local managers and experienced researchers that have studied this bog.
12.00-13.00: Travel to Glanerbrug.
13.00-16.30: Field excursion to *Aamsveen*, a partly restored bog at the border with Germany. Guidance by local managers and experienced researchers that have studied this bog.
16.30-17.30: Travel back to accommodation at Zwartemeer.
18.30: Dinner at Sportlandgoed.

Tuesday 28 August

08.30-09.00: Travel to first field excursion stop.
09.00-16.00: Field excursion to *Reest and Hunze river valleys*, with species-rich meadows and fen vegetation (Reest valley; Schrapveen) and re-development of fen meadows and mires from intensive agriculture lots in a river valley (Hunze valley).Visit to LOFAR telescopes in restoration area.
16:00: Travel back to accommodation at Zwartemeer.
18.00: Dinner at Sportlandgoed.

Wednesday 29 August

08.00-10.00: Travel from Zwartemeer to Tienhoven (Utrecht).
10.00-10.30: Coffee break in Cafe Het Olde Regthuys, Tienhoven
10.30-13.30: Three-hour walk in *Westbroek mires*, starting from Bert Bos-pad. The results of restoration works in fen area will be shown. Guidance by local managers and experienced researchers that have studied the fens.
13.30-14.30: Trip by bus to see the surrounding landscape including 6 meter deep former agricultural polder area (Betune Polder) that has been flooded and is now a drinking water reservoir for the city of Amsterdam. Lunch in the bus.
14.30-16.30: Boat tour (two boats) at *Nieuwkoopse Plassen.*
16.30-17.30: Travel to accomodation in Utrecht (Stayokay, Neude 5, Utrecht).
18.30: Dinner at Stayokay in Utrecht.

Thursday 30 August

08.30-9.30: Travel from Utrecht to the town of Zegveld where we visit an experimental research station on land use of peat soils (VIC; Oude Meije 18, Zegveld).
09.30-12.30: Mini-symposium on soil subsidence due to agricultural drainage and possible solutions.
12.30-13.30: Lunch at experimental station Zegveld.
13.30-14.30: Short visit to experimental rewetting site
14.30 Travel back to Accommodation at Stayokay Utrecht (Neude 5).
18.00: Dinner at Stayokay Utrecht.
20.00: *Evening walk* through the inner city of Utrecht. *Guides:* Peter Grootjans, Llewellyn Bogaers, Jos Verhoeven.

Friday 31 August

08.30-9.00: Walk to venue General Assembly IMCG, Academiegebouw, Domplein Utrecht.
09.30-12.30: General Assembly IMCG.
12.30- 13.30: Lunch.
13.30-14.30: Back to Stayokay Utrecht or drop of participants at Central (train) Station Utrecht. This is for participants that will travel home today. Utrecht Central Station has a direct connection to Schiphol Airport Amsterdam.

14.30: End of IMCG field trip and General Assembly

IMCG Symposium 22nd August NIOZ Texel

Time	Speaker	Title
8.45-9.00	Opening Symposium	
9.00-9.20	Stephan Glatzel	Ecosystem dynamics in the Pürgschachen Bog, Austria
9.20-9.40	Tanya Lippmann	Vegetation and vegetation management play a role on the net greenhouse gas budget of rewetted peatlands
9.40-10.00	Weier Liu	Estimating Greenhousgas emission from vegetation maps after rewetting (Drentsche Aa valley, NL)
10.00-10.20	Samer Elshehawi	Natural isotopes identify groundwater flows in the Drentsche Aa Brook Valley, The Netherlands
10.20-10.40	Timofey Orlow	Regional peat depth estimation measured with GPR
10.40-11.00	coffee break	
11.00-11.20	Zhao-Jun Bu	Effect of simulated herbivory on the performance of two peat mosses
11.20-11.40	Beverley Clarkson	Resilience of a raised bog remnant impacted by lowered water tables and nutrient inputs
11.40-12.00	Anders Lyngstad	From raised bogs to razed bogs – threatened lowland mires in Norway
12.00-12.20	Ulrich Graf & Angéline Bedolla	Effects of cattle exclosure and partial rewetting on bog vegetation: the case of Schwaendital Bog
12.20-12.40	Marina Abramchuk	Water regime of Zvaniec mire - implications for nature conservation management
12.40-13.00	Agata Klimkowska/ Wiktor	Microbial communities in the soils in natural and restored fen peatlands – relevance for restoration
13.00-14.00	lunch	
14.00-14.20	Piet-Louis Grundling	Building resilience into South Africa's peatlands to couple with climate change: is it an option?
14.20-14.40	Eric Munzhedzi	Progress towards peatland conservation in NW Province, South Africa: setbacks and successes
14.40-15.00	Jason Le Roux	The wetland inventory of Swaziland: reporting on the first peatland discoveries
15.00-15.20	Siew Yan Lew	Peatland Management in Southeast Asia
15.20-16.00	thea break	
16.00-16.20	Jan Peeters & Andreas Haberl	Paludiculture in the Baltics
16.20-16-40	Tapio Lindholm	The Finnish-Russian Working Group on Nature Conservation; cooperation in mire protection
16.40-17.00	Monica Sofia Maldonado	Peruvian High Andean Peatlands
17.00-17.20	Aaron Pérez-Haase	Pyrenean mires in protected areas: main threats and conservation actions
17.20-17.40	Eulàlia Pladevall-Izard	Response of engineering plant species to experimental conditions in pryenean fens
18.00	Depature	

Poster presentations

Country	Author	Title
South Africa	Althea Grundling	Peatlands under pressure
Latvia	Mara Pakalne	Peatlands in Latvia
Germany	Michael Trepel	Challenges for water Management in German Peatlands
Germany	Tatiana Minayeva	Indication of peatland restoration success: examples and challenges
Netherlands	Gert-Jan van Duinen	Paludiculture in the Deurnsche Peel

The Hors on the Wadden Sea Island of Texel; dune slacks with rare fen species

Ab Grootjans, Annemieke Kooijman

Tuesday 21st August 08.30-17.00

The Hors on the island of Texel

The Hors on the south-eastern tip of the island of Texel (52°59’N, 4°44’E) is a very young and almost natural dune area with a very broad beach plain (Figure 1), enabling the natural formation of embryonic dunes (Figure 2).

The newly formed dune ridges can enclose parts of the beach, thus preventing flooding with sea water.

In groundwater discharge areas fresh water dune slacks develop, which have a vegetation type that resembles that of rich fens (Lammerts & Grootjans 1998).

Some of these slacks are not entirely natural, as they are enclosed by several sand dikes that were created artificially by the coastal protection agency (RWS) in the mid-1970’s. But The Hors now has a series of parallel dune slacks of different ages, covering a total live span of a few hundred years (Ballarini *et al.* 2003, Oost *et al.* 2012, see also figure 3).

Apart from an very interesting geomorphology

Figure 1. Impressions of the Hors at the Wadden Sea island of Texel. Upper left: view from the dunes to the Hors with embryonic dune in the background. Upper right; primary slack enclosed by a young dune rich. Lower left: very young dune slack (2 years old) with some precipitation of iron, indicating groundwater influence. Lower right: flowering individuals of Liparis loeselii.

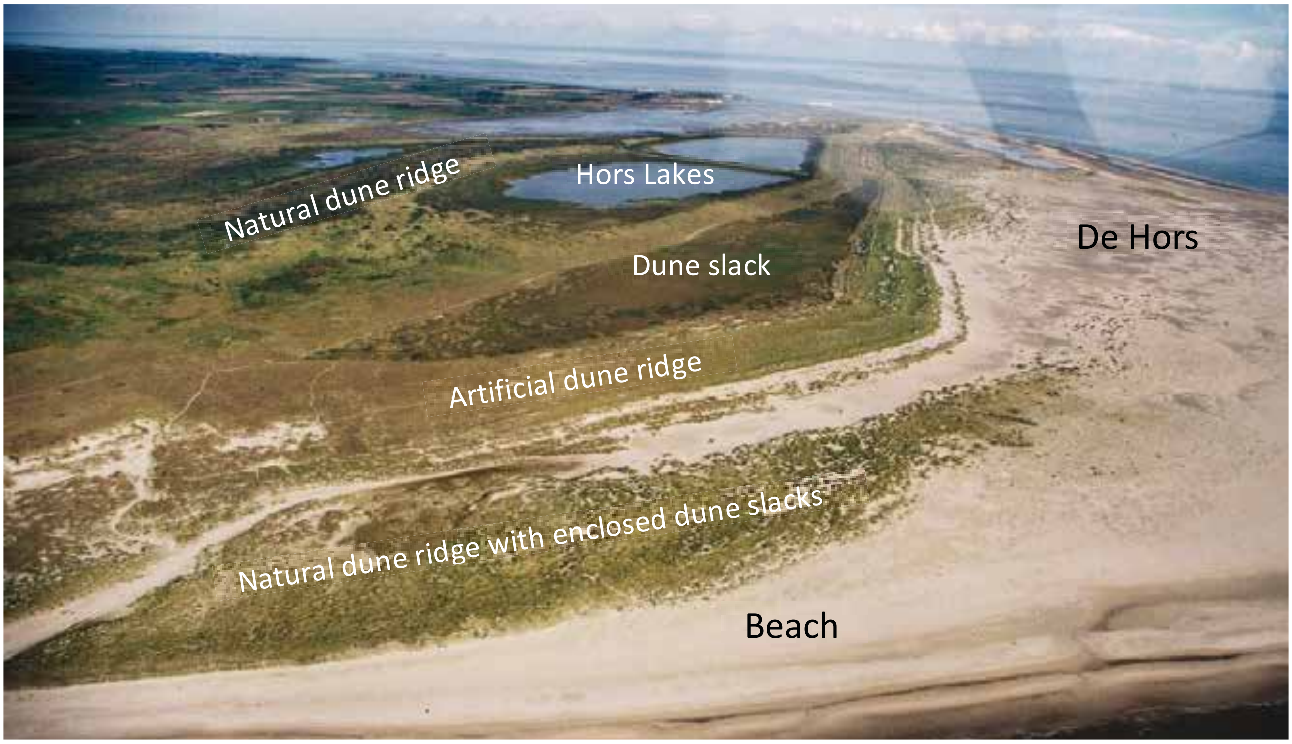


Figure 2. Overview of the Hors (on the left), the Hors lake, (background) and on the left the southern part of the main island of Texel (Photo: Staatsbosbeheer 2005).

Figure 3. Overview of the southern part of Texel, showing the dune ridges of various age, starting in the 13th century until now (the Hors in the south. After Jager & Kikkert (1998) Staatsbosbeheer 2014). In the 17th century the southern part of Texel was a natural harbour, where the bulk of the Dutch fleet was stationed.

this dune area is also famous for the occurrence of thousands of individuals of the typical fen species *Liparis loeselii*, which is a small orchid which occurs on all Dutch Wadden Sea islands and also on the German island of Borkum. It thrives in wet dune slacks on mineral soils (Jones & Etherington 1992, Lammerts & Grootjans 1998, Oostermeijer & Hartman 2014).

It is much better known as a very rare and highly protected orchid of low-productive, rich fens (Wheeler *et al.* 1998, Wotavová *et al.* 2004, Pawlikowski 2008, Oostermeijer & Hartman 2014). *Liparis loeselii* has a wide distribution, ranging from the northeast of the United States and Canada, to northern and Central European countries, Russia and even several localities in Siberia. It has been listed in Annex II and Annex IV of the Council Directive 92/43/EEC on the Conservation of natural habitats, thus making it a priority species for conservation in most European countries.

Dune slack development

In order to estimate the age of dunes and dune slacks in the Hors area, we used information of aerial photos (Figure 4), as well as topographic -and vegetation maps (Sharhudin 2014, Kooijman *et al.* 2016).

Figure 4. Map shows sampling locations in dune slack of different ages at the southern part of Texel.

Occurrence of *Liparis loeselii* in dune slack succession seres

Oostermeijer & Hartman (2014) found that the population life span of the species in coastal dune slacks was generally very short, between 5-15 years. Favorable conditions recorded for *L. loeselii* populations include a high pH (6-7) combined with low availability of nutrients (Wheeler 1998). On the Dutch and German Wadden Sea islands such conditions are present when exfiltrating groundwater is present with relatively high concentrations of calcium and bicarbonate (Grootjans *et al.* 2015).

Our results showed that the window of opportunity for *L. loeselii* to establish a population was relatively short, less than 20 years (Figure 5), but this species was able to take advantage of this short window. Populations of this orchid were able to colonize newly formed slacks at very early stages. Two years after a slack had become vegetated, *L. loeselii* was already able to establish a small population.

Sometimes the orchid was able to establish its population even before the formation of a slack was completely finished. This indicates that *L. loeselii* is a well-dispersed species, and can colonize a new site easily, as suggested by Jones (1998). The short window of opportunity for *L. loeselii* during natural vegetation succession in the Hors area could only be extended modestly (ca. 5-10 years) by a management regime of annual mowing in the oldest dune slacks.

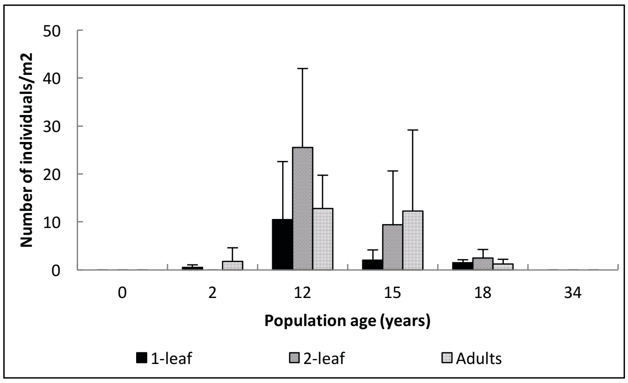


Figure 5. Population structure of *L. loeselii* according to age of population on the Hors, Texel. Error bars in the bar graph indicate standard deviation. 1-leaf represent young immature individuals. 2-leaf individual are also young, but have not yet flowered. Adults have flowers.

In comparison, populations on a beach plain on the German Wadden Sea island of Borkum survived for more than 30 years without any management intervention (Petersen 2003). This species was first seen at this German site in 1985 and a population with many individuals still exists there today (3,000-10,000; Grootjans *et al.* 2017).

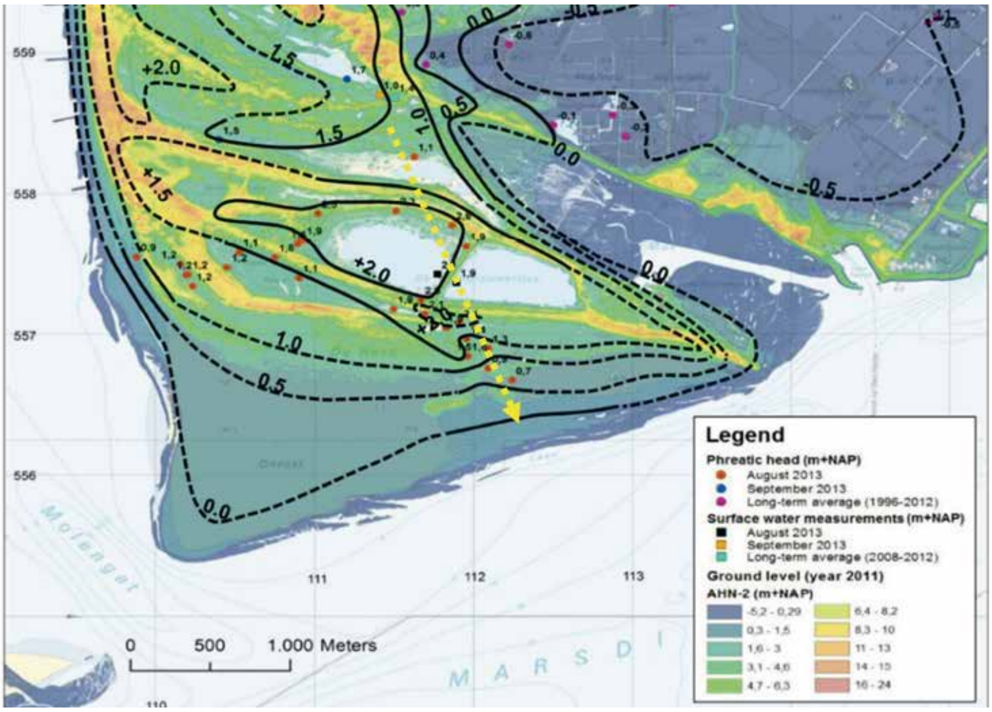
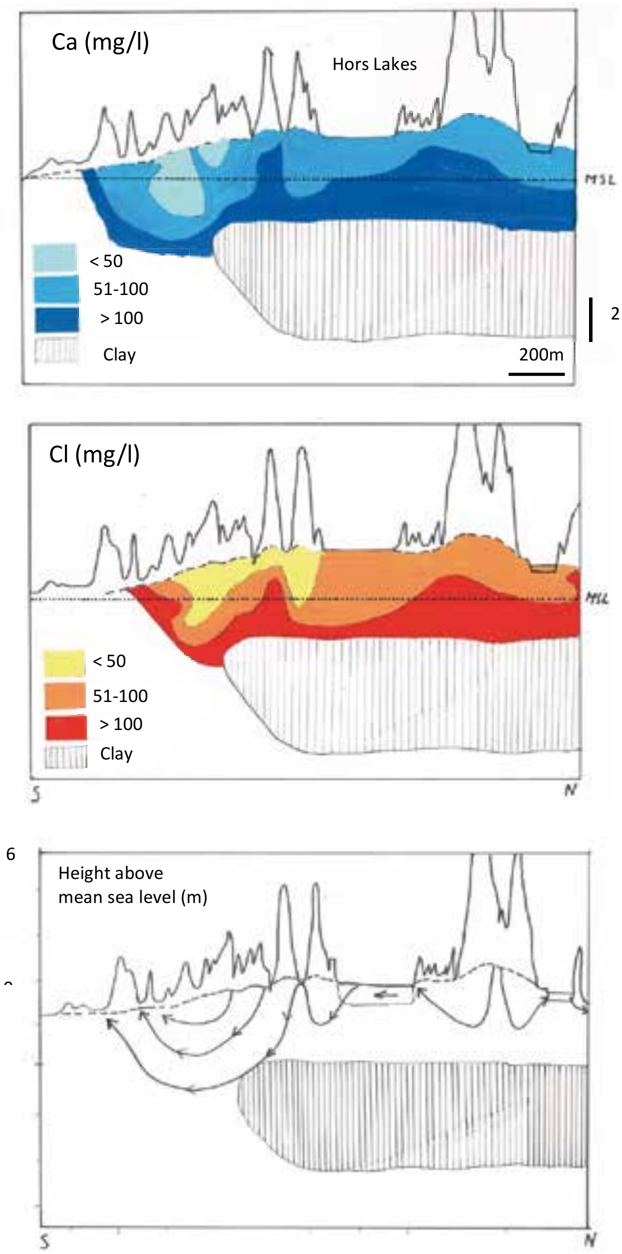


Figure 6. Isohypse map of the phreatic groundwater table August-September 2013) at the south-east part of Texel (the Hors). The yellow dotted line represents one of the transect studies in the hydrological research

Figure 7. Ca and Cl concentrations in the shallow groundwater in transect S-N on Texel, de Hors), measured in August 2013. MSL = Mean sea water level. Conceptual model of groundwater flow in the Hors area (Texel), based on the calcium and chloride concentrations in the shallow groundwater.



Hydrological systems analyses

The isohypse map of August 2013 for the southern part of Texel (Figure 6), indicates that the dune slacks in the Hors areas are supplied with groundwater from rather local hydrological systems, with rather thin groundwater lenses (5-10 m). This can be concluded from the chemical composition of the groundwater at different depths (Figure 7).

The chloride and calcium concentrations have a similar pattern. Low values were found in the young dunes and high values at greater depths and under the high dunes at the right of figure 7. The low values in the young dunes can be explained by the scarce vegetation cover of these dunes (see Figures 1 and 2).

Non-vegetated dunes trap less salt spray than vegetated ones. That could explain the low chloride concentrations. Also the production of CO_2 in the root zone is very low and therefore, little calcium can be dissolved in the calcareous dunes.

The hydrological system analysis also showed that several dune slacks in the Hors area functioned as 'flow-through lakes' (Stuyfzand & Moberts 1987; Figs. 7 and 9). The western Hors lake, for instance is permanently flooded, but is receiving groundwater from the northern and north-western dunes, while it supplies the eastern Hors lake and several southern dune slacks with groundwater for most of the year (Figure 7 and 8).

A flow-through lake is an open water wetland that receives groundwater from one side and loses (surface-) water at the other end (see also Stuyfzand 1993, Grootjans *et al.* 2014). Figure 9 illustrates the functioning of a through-flow dune slack.

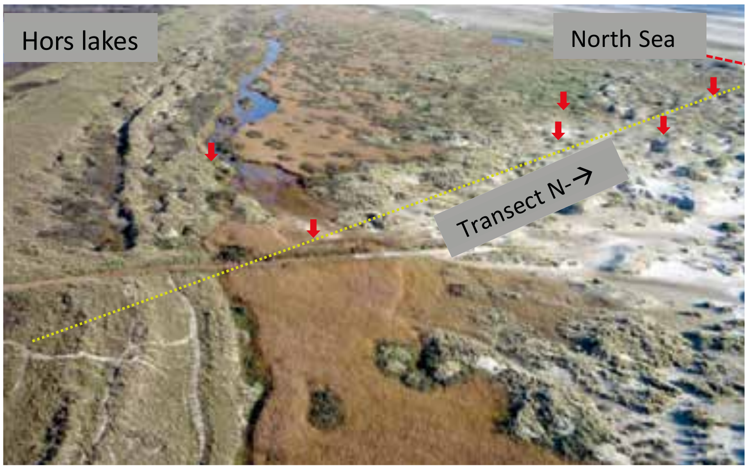


Figure 8. Photograph of a primary dune slack covered with common Reed (Phragmites australis). The yellow dotted line shows the sampling sites of the hydrological research (figure 6 and 7).

Figure 10. Photograph of a mini-dune slack (2 meters in diameter) of one year old showing iron precipitation on the left side, pointing to exfiltration of anoxic and iron rich groundwater.

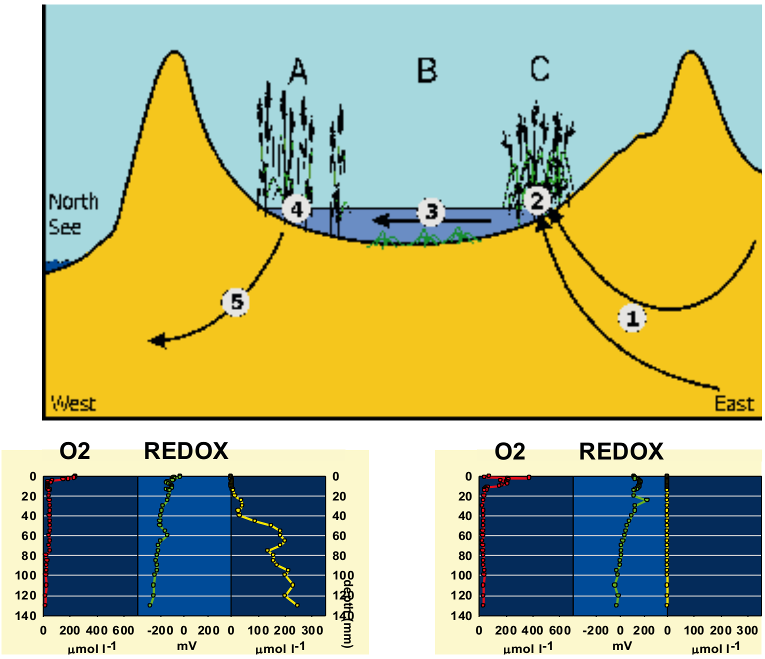


Figure 9. Conceptual model of a through- flow lake (changed after Stuyfzand & Moberts 1987). Groundwater, rather rich in iron and with low concentration of oxygen and sulphate (1) enters the dune slack on one site (2). When exposed to the air this water loses iron and phosphate and flows (only during wet periods) as surface water to the opposite site (closer to the sea). It infiltrates through organic layers and becomes deeply anoxic due to reduction of sulphates. In the absence of iron in the upper layers sulfide may accumulate in the topsoil (Adema et al. 2003a).The graphs in figure 9 illustrate these difference between the to sides of a dune slack. Measurements were done with micro-electrodes. Note that the depth is in millimeters below the soil surface.

Why is anoxic groundwater important for the stability of pioneer stages?

Anoxic groundwater in the root zone of plant can be very harmful for many plant species. Most species are not adapted to high concentrations of reduced iron, manganese and sulfide (Lamers *et al.* 2015). Several pioneer species in dune slacks have special adaptation for prolonged flooding in the wet period, which enable them to dominate for quite some time. *Schoenus nigricans* and *Littorella uniflora*, for instance have well-developed aerengyma, through which oxygen is actively transported to the tip of the roots, where leakage of oxygen occurs. This phenomenon is called 'radial oxygen loss' (ROL; Armstrong 1975, Adema *et al.* 2005). Anoxic condition thus can prevent the establishment of later successional species, such as grasses (*Calamagrostis epigeios* and *Phragmites australis*) and Salix shrubs and pioneer species with ROL can dominate the vegetation for a long time. Adema *et al.* (2003a,b, 2005) also discovered that *Littorella uniflora* and *Schoenus nigricans* can reduce the availability of nutrients for competitors, in particular nitrate. Dissolved ammonium that enters the slack via groundwater and precipitation water is oxidized in the root zone of the ROL species and changes into nitrate. The low productive pioneer species only take up a little of this nitrate, while most of it is passing the oxic rootzone and flows into an anoxic zone again, where denitrification occurs, which changes the nitrate in to nitrogen gas (N_2), which escapes into the atmosphere. Adema *et al.* (2005) hypothesized that this is a key mechanism to keep pioneer stages of dune slack stable for up to 80 years, but only if the dune slack is supplied with sufficient anoxic groundwater, to allow flooding for more than 6 month a year.

Studies on the accumulation rate of organic matter in the soil support this idea that pioneer species in groundwater fed dune slack can keep the soil organic matter (SOM) very low for a long time. Sharhudin *et al.* (2104) sampled successional stages in dune slacks of the Dutch Wadden islands and showed that in most dune slack SOM accumulations increased linearly during the first 50-60 years and then levelled off (Berendse *et al.*1998, Figure 11). However, slacks with low productive species, such as *Littorella uniflora*, showed low accumulation rates (0.02-0.08 kg/m^2/year), and persisted even over a period of more than 90 years (Sharuhdin *et al.* 2014). In contrast, slacks dominated by high productive species, such as Phragmites australis, showed ten times higher accumulation rates (0.17- 0.26 kg/m^2/year) over a similar time period and comparable annual inundation periods (176-240 days). So, once late successional species have invaded the slack, the pioneer species cannot keep the nutrient availability low for competitors and disappear within a decade.

The rate of SOM accumulation in wet dune slacks is, therefore primarily controlled by plant productivity. Both above-ground biomass and SOM accumulation can remain very low over a long period of time when dune slacks are flooded during most of the year and plants with adaptive traits are able to maintain vegetation succession in a pioneer stage.

How sustainable are *Liparis loeselii* populations on the Dutch Wadden Sea islands

On the Wadden Islands, decalcification of dunes once fixed by vegetation, is a relatively rapid process, because of the low primary $CaCO_3$ content of 0.5% (Texel) to 1.2% (Schiermonnikoog). With a simple mass balance Stuyfzand (in: Grootjans *et al.* 2014) calculated for Texel a decalcification rate of 0.56 m/century above the groundwater table and 0.15 m/century below it, for a bare dune lacking aeolian inputs of calcareous sand, and 0.73 m/century above the groundwater table and 0.26 m/century below it, for a dune fixed by dune grasses and mosses.

This means that fen orchid, with a rooting depth of about 0.1 m, will root in decalcified, acidified dune sand already after 14-18 years, provided that local groundwater is steadily replenished by rainfall (thus not exfiltrating). On Schiermonnikoog this would take a bit longer, namely 1,2/0,5x(14-18) = 34-43 years.

Acidification will rapidly follow after decalcification, because the acid front is moving downwards about 3-10 times faster than the decalcification front. The arrival of the acid front is manifested in soil moisture and groundwater by a sharp drop in pH, Ca and HCO_3, and a sharp increase for among others Al and SiO_2. We therefore conclude that decalcification and nearly simultaneous acidification form an excellent explanation of declining populations of fen orchid on older dunes without (sufficient) eolian inputs of calcareous sand and without exfiltration of calcareous groundwater.

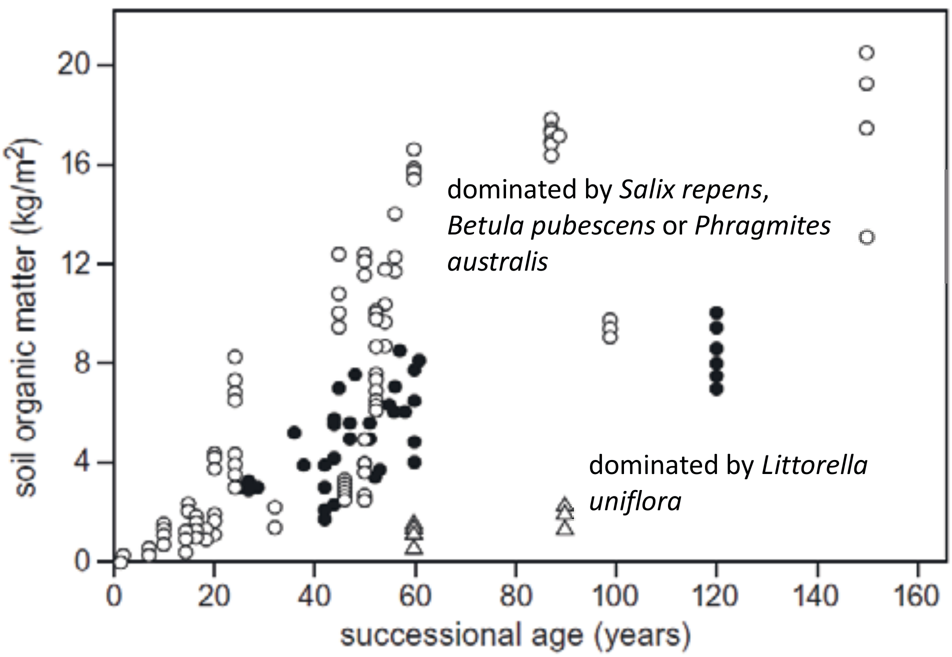
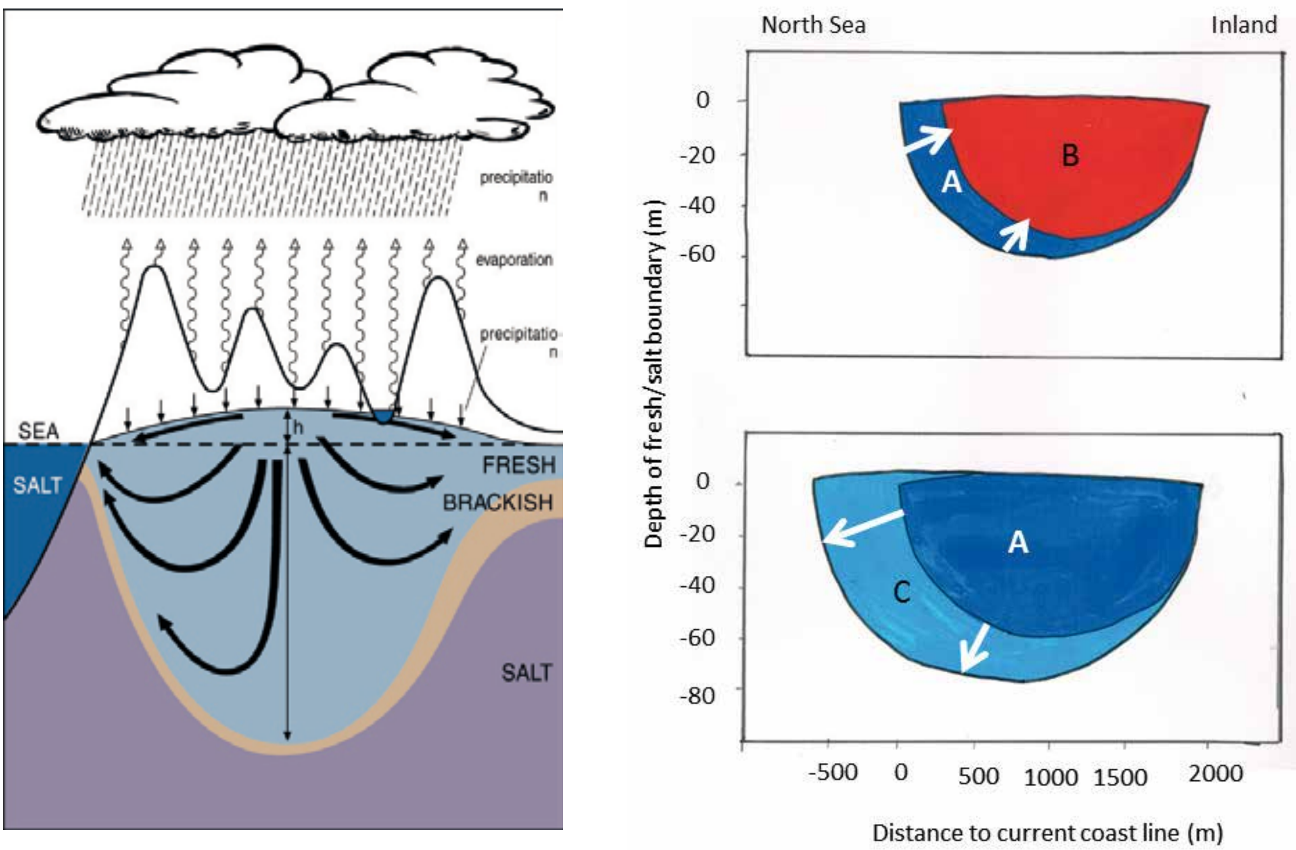


Figure 11. SOM accumulation data from dune slacks in the Netherlands (open symbols) and also the dunes in Wales (black filled circles). Older dune slack with high values of organic matter accumulation are dominated by shrubs or trees (Salix repens or Betula pubescence), while older dune slack with low accumulation values are dominated by Littorella uniflora (from: Sharhudin et al. 2014).

The situation in the United Kingdom demonstrates the importance of young dune slack habitats for the survival of Liparis loeselii. About 90% of the UK population is now only found in the coastal dunes of South Wales and these population are rapidly declining). Dune stabilization was one of the factors that caused this decline (Jones 1998). Recently principles of dynamic coastal management have been applied in Wales and new dune slack are being formed, allowing the orchid populations to move more easily between old sites and new sites. So, in existing fixed dune complexes, promotion of secondary dune slack formation through blow-outs is the most natural and cost-effective strategy to maintain viable metapopulations of early to mid-successional species. But when no or very few new slacks are formed, overlap in time may be lacking and local extinction might occur as was described by Jones (1998) for several sites at the coast of Wales. Under such conditions, new introductions from population of other islands might be helpful in sustaining the metapopulation.

Figure 12. Hydrological system of a Wadden Sea island (left) and simulation results of volume of freshwater lens (right) as influenced by sea level rise and sand nourishment on Texel, de Hors. Scenario A= present situation (dark blue), B= sea level rise of 1 meter without sand nourishment (red). C = sea level rise of 1 meter with sand nourishment (light blue; increase of coast line by sand nourishment is 800m).



Future impact of sea level rise

In natural dune systems with regular formation of dune slacks, management is not required to keep a metapopulation of *L. loeselii* viable over a long time span. However, metapopulation models have shown (Oostermeijer & Hartman 2014) that management to prolong the life span of individual populations, such as mowing to maintain an open vegetation structure, can increase the viability of a metapopulation to a modest extent, because seed sources remain available for several decades (Grootjans *et al.* 2014).

Our hydrological research on Texel revealed that most dune slacks with *Liparis* populations were fed by calcareous and anoxic groundwater from rather small hydrological systems.

These systems are vulnerable to sea level rise, which leads to a narrower beach plain, shrinking of the groundwater lenses and reducing the discharge of groundwater (Figure 12). Sand nourishment before the water line not only prevents erosion of the beach and dune areas, but may even temporary increase the discharge of groundwater to the newly-formed dune slack, when the groundwater lens of the island is expanding in reaction to sand nourishment.

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The Wyldlannen Friesland; an example of targets that cannot be reached any more

Ab Grootjans, Henk Everts

Thursday Aug 23rd 11.00-16.00

Polder 'Wyldlannen' near Eernewoude (Fr)

The polder 'Wyldlannen' in the province of Friesland (5"54"E; 53'13"N) consists of c. 60 ha of degenerated and species-poor Cirsio-Molinietum vegetation. In the past these mesotrophic fen meadows were very rich in species. They harboured many Red-List species that are currently endangered in most of Europe (figure 2). Examples are: *Cirsium dissectum, Carex dioica, Carex hostiana, Carex pulicaris, Dactylorhiza incarnata, and Parnassia palustris.* The polder is flooded during winter and spring with surface water during several months. This flooding practises has been done for centuries. Before the agricultural peat meadows were intensively drained (before World War II) these 'summer polders' were the lowest spots in the landscape and the floodwater originated from groundwater from the Drenthian Plateau (to the east). This groundwater was rich in iron and calcium, but poor in nutrients.

Human impact

The last 50 years the surface water that is used to flood the summer polders mainly originates from the large rivers Rhine and IJsel. This river water is polluted with nutrients, chloride and sulfate (Van Duren *et al.* 1998). Due to long term drainage practises in agricultural

Figure 1. A well-developed nutrient poor Cirsio-Molinietum meadow with sedges, sparse reed and many flowering individuals of Cirsium dissectum.

Figure 2. Impression of a lakes and 'summer polders', surrounded by agricultural peat meadows with very low water levels.

peatlands surrounding the lakes and adjoining summer polders, the peat surface have dropped several meter (subsidence) and the summer polders are now the highest spots in the landscape (Figure 2). Consequently the water levels in the summer polders have dropped a lot (up to one meter). Consequently grass species like *Agrostis canina and Phalaris arundinacea* gained dominance due to eutrophication of the flood water and increased fluctuations of the water table (Figure 3).

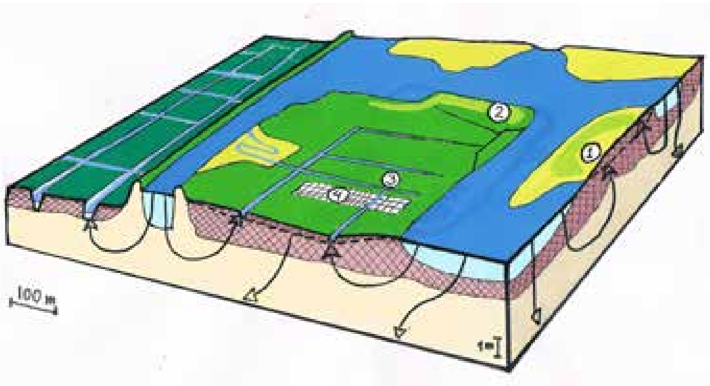

Figure 3. Position of the summer polder 'Wyldlannen' (light green) surrounded by open water and terrestrializing fens and reeds (yellow). To the left the low lying and heavily drained agricultural peat polders can be seen. 1 = reference are with well developed Cirsio-Molinietum vegetation, 2= degraded Cirsio-Molinietum stands near the open water, 3 = very degraded Cirsio-Molinietum stands next to a sod cut site where the acidified and degraded vegetation has been removed, 5 = helophyte filter to clean the polluted surface water.

Attempts to restore species rich fen meadows failed

In 1986 the Frisian nature protection agency ('It Fryske Gea' = The Frisian Landscape) initiated a project in order to restore the species-rich Cirsio-Molinietum meadows. They raised the water levels in the ditches, which resulted in some rewetting, but not in an increase of characteristic fen meadow species. In 1991 a small irrigated wetland (helophyte filter) was constructed to purify the polluted surface water before it would flood the meadows. Water analyses showed that the filter worked very well. The nutrient contents of nitrogen and phosphorous dropped by 90% after passing the helophyte filter. However the surface water that eventually reached the meadows was low in calcium and bicarbonate, due to dilution with precipitation water (Van Duren *et al.* 1998).

So, the flood water was cleaned, but remained base-poor. However, after 10 years of monitoring we

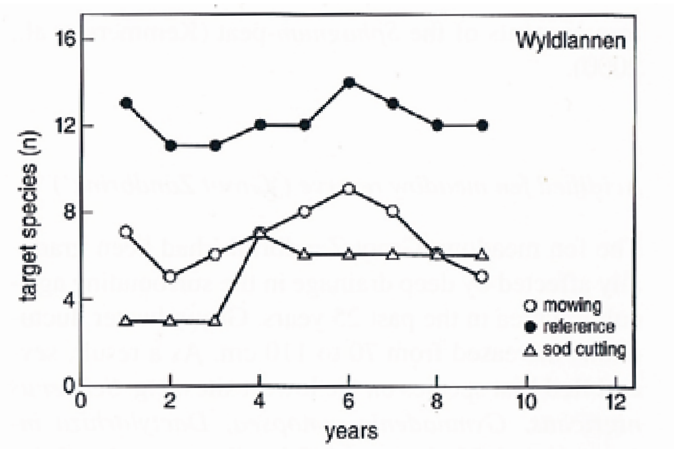

Figure 4. Regular mowing (site 3) nor sod cutting (site 4) resulted in the restoration of the original fen meadow in the Wyldlannen. Although some recovery was observed in the mown site during the first 6 years. However, none of the characteristic species of fen meadows returned.

found that neither continuous mowing nor sod cutting resulted in the restoration of the mesotrophic fen meadow vegetation (Figure 4).

Was is perhaps that the species could not reach the area anymore, because the species were not available any more in the local soil seed bank, or the remaining populations in the surroundings were too far away. Or the environment was not suitable anymore; iron, calcium and bicarbonate water in the surface water was too low to increase the base-saturation and the pH.

Analyses of the soil seed banks in the reference site, the sod cut site and the (degraded (mown) site showed that the reference site had viable seed of *Cirsium dissectum*, not of *Carex hostiana or Pedicularis palustris*, which were all present in the vegetation. In the degraded sits (both mown and sod cut, no viable seeds of characteristic species were found.

We decided to introduced juveniles of rare species to the experimental plots in 1994 *(Carex hostiana, Cirsium dissectum and Pedicularis palustris,* and also added lime ($CaCO_3$) to the sod cut and mown variants.

Pedicularis palustris died the same year. *Carex hostiana* and *Cirsium dissectum* survived one year and then died. Adding lime to *Carex hostiana* died have a significant positive effect on the growth of the species in 1995,but only in the sod cut plots. However none of the introduced individual survived the following winter.

So, something was wrong with the pH, which was not increasing after sod cutting, flooding with clean surface water and also not after liming the soil (only once in 1994).

We analyzed the base saturation of the soil 4 times within 10 years and found that in spring the base

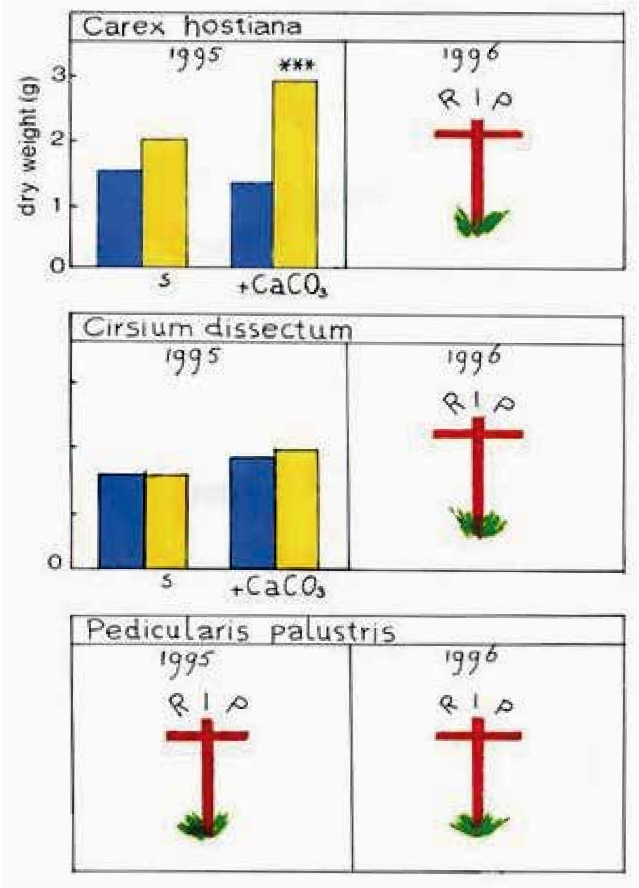

Figure 5. Dry weight and survival of three introduced species (Carex hostiana, Cirsium dissectum and Pedicularis palustris; 200 individuals per species)) in degraded mown plots, degraded sod cut plots and in plots that received additional lime. The results clearly show that the environmental conditions did not meet the requirements of the species, not even after liming.

saturation increased significantly, in both the sod cut area and the uncut, mown plots (Figure 6).

So, the restoration measures to increase the base saturation did work during flooding, but that was apparently not sufficient to restore the environment for Cirsio-Molinietum vegetation.

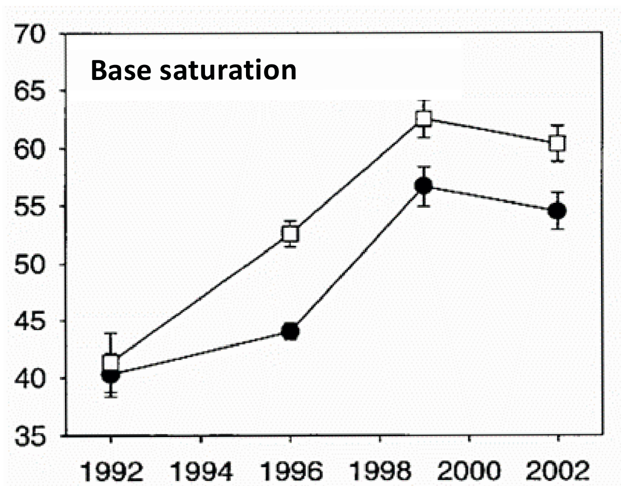

Figure 6. Increase in base saturation of the sod cut and not sod cut top soil in a degraded Cirsio-Molinietum in the nature reserve Wyldlannen (sites 3 and 4 in figure 3).

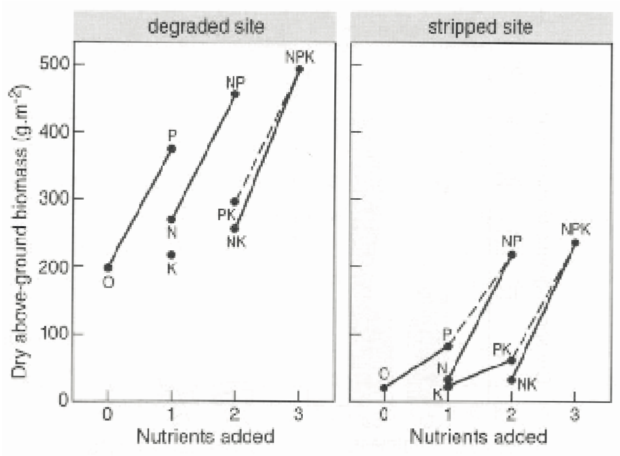

Figure 7. Results of a full factorial fertilization experiment in a degraded (mown) Cirsio-Molinietum meadow and in a neighboring site where the top soil has been removed (ca. 10 cm; stripped site).The results indicate clear phosphorus limitation, in particular in the sod cut site.

Perhaps the soil had become too eutrophic due to the longtime flooding with polluted surface water. Too test this we carried out a full factorial fertilization experiment in both the sod cut area and the uncut mown area. The results are shown in figure 7 and they clearly indicate that phosphorus was limiting plant growth, in particular in the sod cut site. Well developed Cirsio-Molinietum fen meadows usually are phosphorus limited (Egloff 1983, Wassen *et al.* 2005). So, a shift from phosphorus limitation to nitrogen or potassium limitation had not occurred.

In 1999 we measured the water composition of the top layer during most of the vegetation season. We compared the degraded (mown) site with a reference of a rather well developed Cirsio-Molinietum site (surface water fed) and also with a restored fen meadow in a groundwater fed site in a brook valley reserve ('Barten'). Then it became clear that the degraded (and also the reference site) in the Wyldlannen) showed very low pH values and high sulfate valuates in autumn when the groundwater levels were very low.

Increased sulfate concentration in autumn, combined with a strong drop in pH points to oxidation of iron sulfate (FeS) in the upper layers of the soil after oxidation during periods with low water levels. Low water levels occur usually in autumn. The oxidation of iron sulfate is more pronounced at 25 cm below the surface compared to the top 10 cm, where most of the FeS has already been oxidized.

But where do these high pyrite contents of the soil come from. It has been suggested that the pyrite has a marine origin and was formed when the sea regularly flooded the area several centuries ago. Other point to a more recent origin and relate it to increased

pH in soil water							
1999		Wyld	Wyld	Refer.	Refer.	Barten	Barten
	depth	*10*	*25*	*15*	*25*	*5*	*20*
Jan				**6,6**	**6,3**	**6,7**	**7,1**
Febr						**7,2**	**7**
April		**6,3**	**6,4**	**6,5**	**6,8**	**7**	**7,1**
May						**6,7**	**7**
June				**6,3**	**6,6**	**6,6**	**6,9**
July				**6,3**	**6,8**	**5,8**	**6,9**
Sept			**6,2**	**6,3**	**6,7**	**5,7**	**6,6**
Oct		**4,9**	**5,3**	**5,4**	**5,6**	**5,7**	**6,7**

Table 1. Changes in pH in soil water of the top soil of a degraded Cirsio-Molinietum site, a well-developed reference site area (both in the fen meadow reserve 'Wyldlannen' influenced by surface water, compared to another fen meadow reserve influenced by iron and calcium rich groundwater ('Barten').

SO_4^{2-} in soil water (mg/l)							
1999		Wyld	Wyld	Refer.	Refer.	Barten	Barten
	depth	*10*	*25*	*15*	*25*	*5*	*20*
Jan				**40,9**	**32,3**	**9,6**	**8,5**
Febr						**7,5**	**8,6**
April		**54,9**	**101,1**	**69,3**	**57,4**	**6,7**	**8,5**
May						**8,5**	**8**
June			**73,3**	**49,2**		**13,8**	**11,6**
July						**4,5**	**9,7**
Sept			**436**			**62,4**	
Oct		**294**	**501**	**173,5**	**271,1**	**14,3**	**20,1**

Table 2. Changes in sulfate concentrations during the season in the soil water of the top soil of a degraded Cirsio-Molinietum site, a well-developed reference site in the fen meadow reserve 'Wyldlannen', compared to a fen meadow reserve influenced by iron and calcium rich groundwater ('Barten').

atmospheric SO_2 deposition several decades ago (Kemmers *et al.* 2000). A very likely origin of pyrite is also the high loads of sulfate-rich groundwater during almost 50 years of pumping polluted river water into the low lying polders of Friesland. The iron has been brought in the past by groundwater discharge from the Drenthian Plateau. The sulfate (SO_4^{2-} from the large rivers is reduced to sulfite (S^{2-}) when the flood water stagnates on the surface of the polders and then binds with iron. Although the most important source of pyrite is not yet known, we may conclude that the water management of the past 50 years has made the problems for nature conservation worse. And when the subsidence of the surface in the agricultural peat polders accelerated a situation of no return occurred.

So the low water levels in autumn is responsible for the acidification of the profile and this overrides all restoration measures during the wet season. And low water levels during the end of the summer cannot be prevented anymore, because the nature reserve is now the highest point in the landscape; the groundwater in the reserve is flowing towards the low-lying agricultural areas at all times.

Finding new Targets

This means that acidification of the top soil cannot be prevented unless base-rich groundwater is pumped up from deeper layers during both dry and wet periods. It Fryske Gea, the owner of the reserve has rejected this option, because it too artificial and too expensive. Top soil removal is not an option, because it makes things worse. A new top soil is exposed with more iron sulfate, creating more problems during dry periods. Top soil removal should only be applied when strong discharge of anaerobic groundwater is present (Grootjans *et al.* 2002).

They have adopted new targets for the area and dropped the aim to restore species-rich meadows (Cirsio-Molinietum). Instead they try aim at maintaining small sedge vegetation (Caricion nigrae), which is slightly wetter and more acid then the Cirsio-Molinietum meadows. By pumping more clean surface water into the reserve during the summer or to prolong the flooding period in spring such a vegetation type can be maintained.

Further information/further reading

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The Drentsche Aa National Landscape Park; after 50 years of restoration

Ab Grootjans, Christian Hoetz, Henk Everts, Piet Schipper, and Enno Bregman

Friday Aug 24th 09.30-12.30

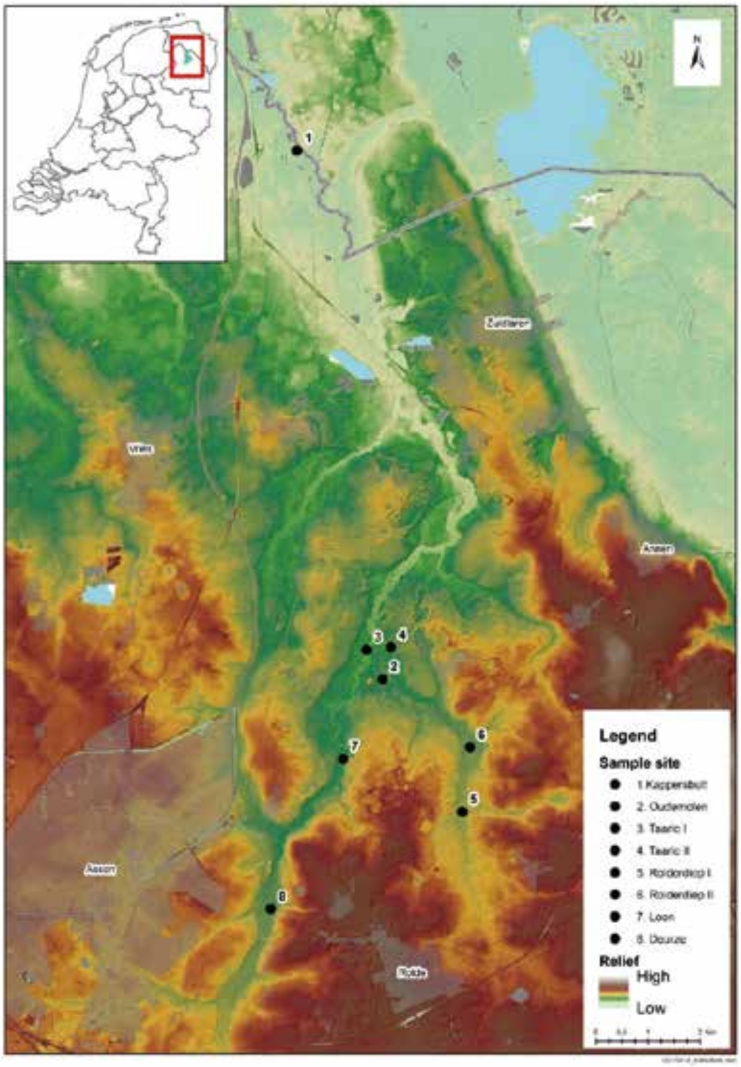

Figure 1. Relief of the Drentsche Aa catchment area with sites we will visit: 2 = Oude Molen, 3, 4 = Taarlo,5, 6 = Rolderdiep.

The Drentsche Aa National Landscape Park

The Drentsche Aa Reserve is a well preserved brook valley system in the north east of the Netherlands, named after the small river that dominates the area. It is located in the province of Drenthe and a plan to protect most of the catchment area was launched in 1965 after continuous destruction of almost all brook valley systems in the Netherlands due to agricultural improvement plans. At the end of the 1960-ties few brook valley systems with a more or less intact geomorphology and hydrological system had remained.

Human impact

Geomorphologically and hydrologically the Drentsche Aa landscape is relative to other brook valley systems in the Netherlands little disturbed, but the vegetation has changes very much, due to agricultural use during many centuries. These changes in time are illustrated in figure 2.

The natural mires in the Drentsche Aa area were formed in eroded melt water valleys since 10400 BP at the deepest parts. At 1800 BP the peat formation spread out over the valley shoulders. Peat formation stopped in early medieval times. In the beginning most of the peat was formed by alder forests and eutrophic sedge marshes. In a later stage, when the peat grew thicker, mesotrophic small sedges with no or little tree growth were the dominant vegetation types. During the early middle ages almost all of the natural fens changed into slightly drained fen meadows. Many

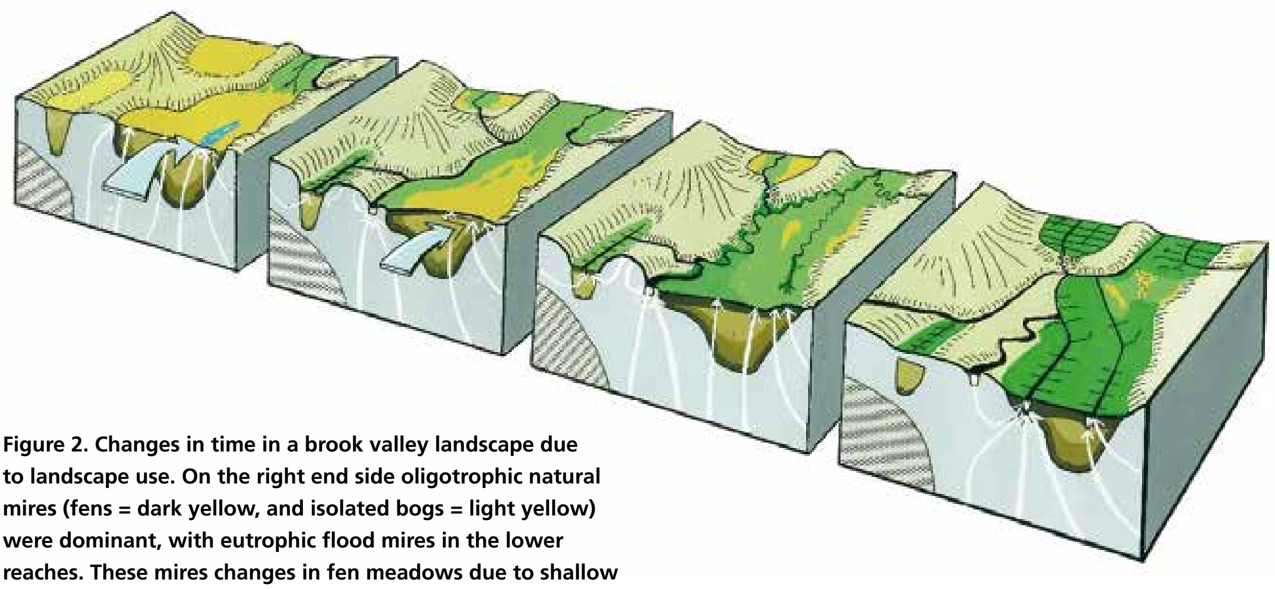

Figure 2. Changes in time in a brook valley landscape due to landscape use. On the right end side oligotrophic natural mires (fens = dark yellow, and isolated bogs = light yellow) were dominant, with eutrophic flood mires in the lower reaches. These mires changes in fen meadows due to shallow drainage and increased flooding. In a later stage modern agriculture left a landscape with deep drainage channels and heavy fertilized grasslands with a very low biodiversity (from: Grootjans & Van Diggelen 1995). White arrows represent groundwater flows. Brown colors represent peat soils, while grey colors represent sand or clay deposits (left).

small ditch systems were constructed, especially in areas with strong groundwater discharge. The large scale reclamation and fertilization if fen meadows and heathlands started around 1920 when more intensive agriculture started to develop and artificial fertilizers became available. In the 1960ties and 1970ties intensive agriculture and deep drainage practices destroyed most of the existing landscape and turned it into monotonous grasslands and croplands, with very little biodiversity. In the brook valleys the large scale drainage systems led to increased flooding events, which triggered the development of more infrastructure to regulate the surface water levels (Grootjans & Van Diggelen 1995, Van der Spek *et al.* 2015).

Restoring the species rich fen meadows (since 1965)

Between 1965 and 2006 the area that was bought by the state and protected nature areas steadily increased form a few hundred hectares to almost 5,000 hectares. Most of this area was managed by the State Forestry Commission, the state nature conservation agency. In 2006, around 32,000 hectares of the Drentsche Aa brook valley were designated as a National Landscape Park. The aim of this appointment was to maintain the characteristic landscape and its natural and recreational qualities. Nowadays the Drentsche Aa brook valley contains various valuable ecosystem types, harbouring many rare plant and animal species, such as the Northern sedge *(Carex aquatilis)* (Grootjans & Van Tooren 1984, Spek *et al.* 2015). Most brooks still meander freely and have maintained their natural course in the landscape (Figure 1). The area also has valuable cultural qualities such as a characteristic combination of historical villages and fields. There are also many archaeological sites, such as dolmens and burial mounds. National Landscape Parks in the Netherlands are different from nature reserves, where the focus lies on minimizing human impacts. In a National Landscape Park also cultural aspects are important (Spek *et al.* 2015). Within the landscape Park, for instance, many small villages and surrounding agricultural fields cover about 50% of the Park area. More natural areas occupy only 35 %. (Roelsma *et al.*, 2004).

After more than 50 year of restoration management in the Drentsche Aa catchment area, restoration outcomes have been very successful in most of the wet meadows.

Figure 3. Shows the vegetation changes after 20 years of restoration management (mowing without fertilization and additional rewetting). In 1982 most of the area consisted of intensely use agricultural grasslands with *Lolium perenne* and *Holcus lanatus* grasslands with small nature reserves with *Caltha palustris* meadows (Calthion palustris) and small areas of small sedge vegetation (Caricion nigrae). In 2012 the variation in vegetation types was much larger. Calthion palustris meadows and small sedge vegetation had expanded and new vegetations type of nutrient poor moist meadows (Junco-Molinion) had developed after 20 years of mowing, without fertilizing. In these new types *Juncus acutiflorus* had become the dominant species and many individuals of the orchid *Dactylorhiza majalis* appeared. Rewetting was achieved by closing small agricultural ditches (from: Bakker *et al.* 2015).

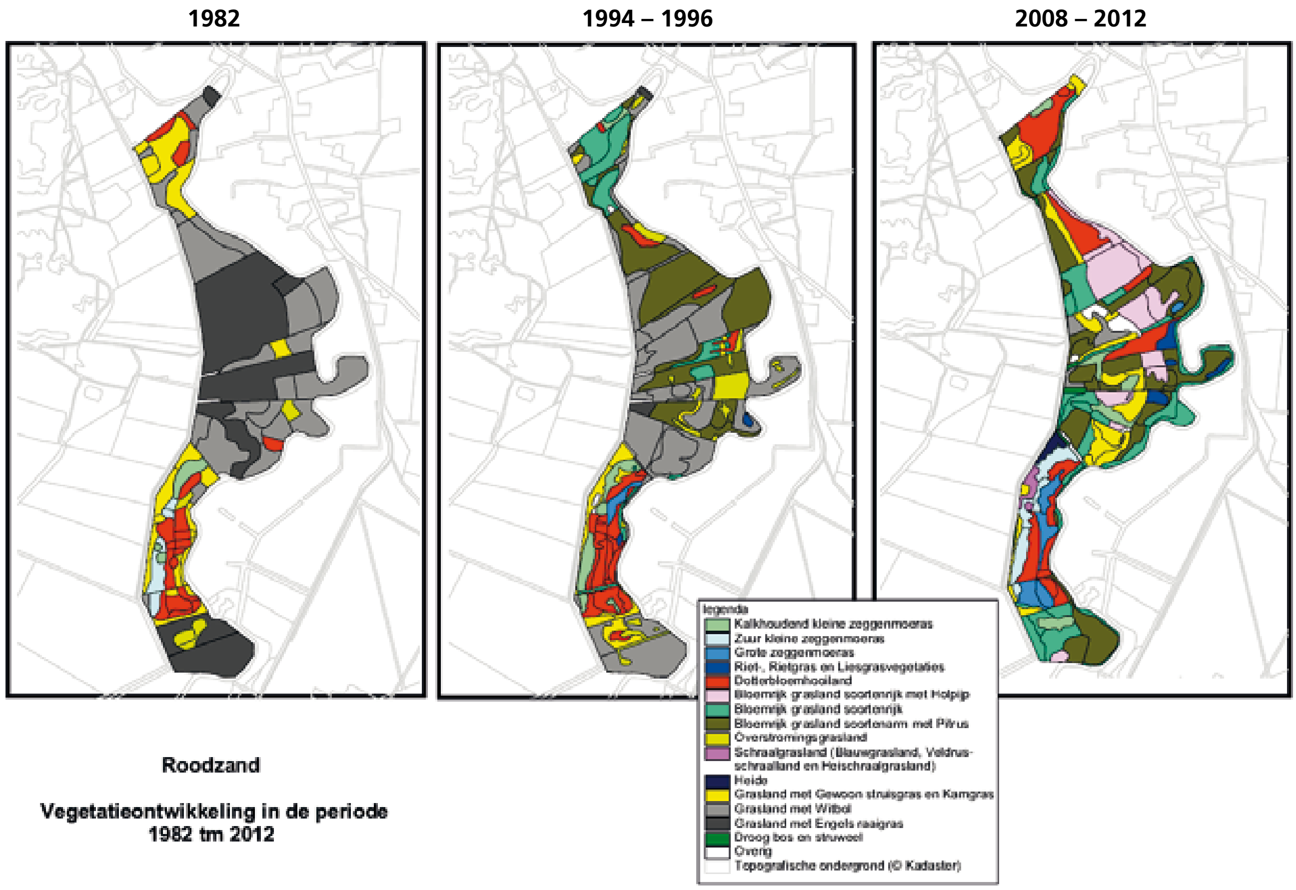

Figure 3. Vegetation development during 20 years in an area of 34.2 ha in the middle reaches of the Drentsche Aa National Landscape Park.

Hydrological systems analyses

The Drentsche Aa area is a basin where the water is drained towards the sea through the brook valley system. Its hydrology can be characterized as a Pleistocene groundwater system where the brook valleys are fed from a higher lying plateau along the southern edges (Engelen 1984, Oude Munninck 1985).

The hydrological system is quite complex, because there are many impermeable layers in the subsoil throughout the area. These layers block the flow of groundwater. Rainwater infiltrates the soil there, which flows north-easterly to the lower lying area. The maximum difference in height is 22 meters (Figure 4).

Where the stratigraphy of the subsoil is intact, two aquifers can be distinguished, divided by two poorly permeable layers. The first water layer in the subsoil is called phreatic groundwater. The second water layer is called the first aquifer and the third water layer is called the second or deep aquifer (Figure 3) (see also Magri & Bregman, 2011). Phreatic groundwater from the phreatic hydrological system has only travelled a short period through shallow decalcified soil formations before it exfiltrates. It is often eutrophic and oxygen rich, but acidic and mineral poor. Groundwater that originates from the first aquifer often comes from a local hydrological system. Its chemical composition is intermediate between phreatic and deep groundwater. Deep groundwater has been underground for long periods (Elshehawi *et al.* 2018). The water is alkaline, oxygen poor, mineral rich, has a high pH and is poor

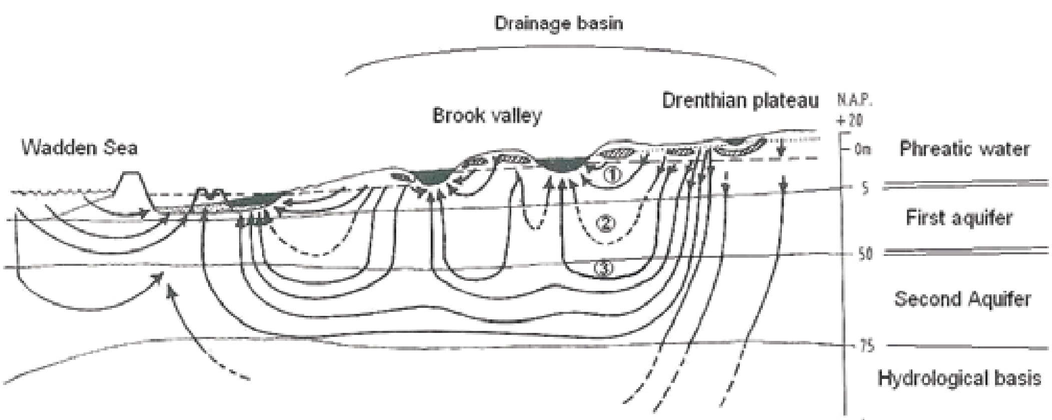

Figure 4: Hydrogeological sketch of the groundwater flows from the Drenthian plateau to the Wadden Sea, including the aquifers. 1 shows exfiltration of phreatic groundwater; 2 is local exfiltration of shallow groundwater; 3 is (sub) regional exfiltration of deep groundwater (figure modified from: Everts & De Vries, 1991).

in nutrients. In the brook valleys this water exfiltrates to the surface and enters the valleys. The exfiltration intensity is determined by the groundwater pressure and the presence of impermeable soil layers. The whole area of the Drentsche Aa used to be considered as one regional groundwater system. But later suggested that it actually consists of at least five hydrological subsystems. (Schipper & Streefkerk 1993). The relative shallow (up to 50 meter below the surface) and the surface systems itself have been very well studied and modelled in the past and the results are, up to now, the main base for nature/ and landscape planning. However, decreasing funds for nature conservation and increasing threats of agricultural pollution from higher grounds now require a better understanding of deeper groundwater flows and there interaction with the hydrological system of the Drentsche Aa as a whole. This would enable a more balanced long term nature and landscape policy.

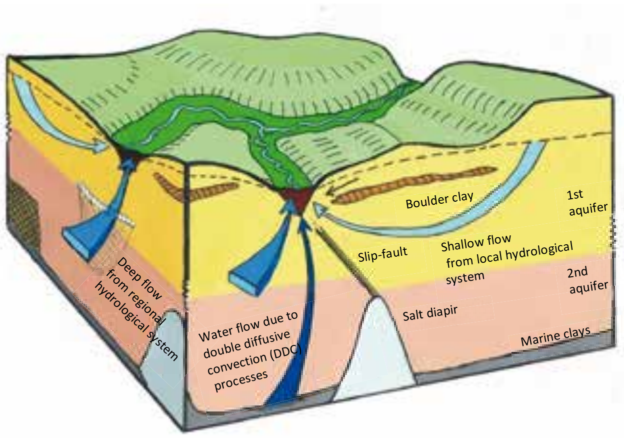

Figure 5. Hypothetical sketch of groundwater flows based on geological data, macro-ionic composition of groundwater and distribution patterns of plant species (After: Elshehawi et al. 2018).

Models of the genesis of the North Netherlands landscapes were based on geological data and hypothesis postulated in the 70ties- 90ties of the past century excluded pro- and postglacial differential Saalian and for sure Weichselian rebound and impact of subglacial formed deep eroded older Elsterian channel systems. Growing awareness and interest of the Drentsche Aa area at the South edge of a tectonic basin with up-coning (Permian) salt domes has initiated cooperation with Dutch-, Danish- and German universities (TU Kopenhagen, FU Berlin) and has generated a better insight of the deep (thermohaline) ground waterflow patterns.

To comprehend the hydrological system of the area, it is necessary to have a basic understanding of the geology of the area (Figure 5).

The subsoil of the brook valley is stratified and the characteristics of each layer influence the hydrological system. The area has a hydrological base which is largely impermeable to water due to its high fraction of clay, but broken near pro- and postglacial reactivated or induced slip faults which separated deep and shallow hydrological systems and disrupted the seal capacity of the hydrological base and overlaying clays. This disrupted hydrological base lies at a depth of about 50 to 150 meters (Magri & Bregman 2011). At locations where impermeable layers have been eroded by the subglacial channels or weak fault zones, water can flow from one aquifer to another or exfiltrate to the surface. Large local differences occur within the basin concerning thickness, composition and even presence of the formations. At certain locations the formations have been pushed to the surface and eroded because of the movement of underlying salt domes or other glacio-induced or older tectonic processes (Roelsma *et al.* 2004, Bregman & Magri 2011, Bregman *et al.* 2015). Recent detailed 3D studies, based on seismic and geological and geomorphologic data showed that the present Holocene river patterns and initial erosion of salt domes, (re-)activated faults consequently influenced deep groundwater flow. ^{14}C dating indicate a start of peat formation at 10400 BP in a lake with brine water influence; downstream the valley base at 1.5 m peat formation started at 1800 BP in the uplifted areas. The presence of brine water in deeper layers is caused by discharge of deep groundwater in the surroundings of (Permian) salt domes. Salt has a higher temperature because of a better heat conductivity. This leads to double diffuse convection (DDC): because of the warmer environment the groundwater has a higher density and flows to surface. The seepage of this (bicarbonate rich) groundwater from the regional systems results in a different vegetation in seepage areas compared to areas only influence by local groundwater systems. (figure 5).

To summarize: the brook valleys can be fed by exfiltrating phreatic groundwater, groundwater from the first and from the second aquifer, or even by the brine groundwater from below the clay layers (Magri & Bregman 2011) that was in former times considered to be the ‘hydrological basis’. In case the river or the old glacial erosion channelshave cut through the various clay layers, wet meadows in the valleys can even be fed by 2-4 different groundwater flows (Figure 6). Near area’s

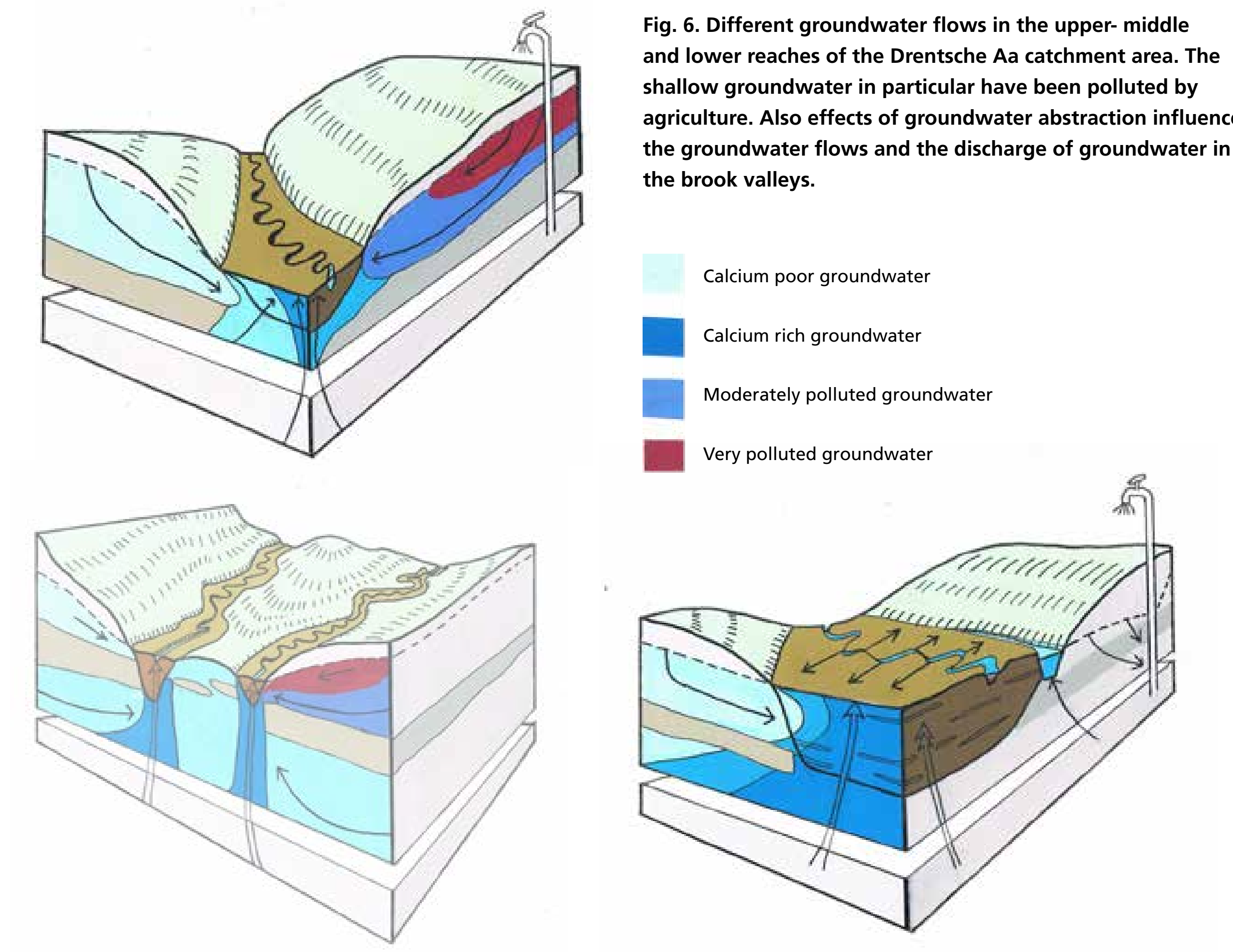

Fig. 6. Different groundwater flows in the upper- middle and lower reaches of the Drentsche Aa catchment area. The shallow groundwater in particular have been polluted by agriculture. Also effects of groundwater abstraction influence the groundwater flows and the discharge of groundwater in the brook valleys.

with faults structures the deep groundwater pressure and salinity is higher, as well as the groundwater temperature (0.8 – 1.5 degrees).

Groundwater extraction for drinking water production

At present there are 6 groundwater extraction facilities within the border of the National Landscape Park or very close to it. One of the facilities (Loon) have been reduced from 6 to 3 million cubic meter in 2013 already. Groundwater is usually extracted from the second aquifer. Only one (De Punt, in the lower course) used mostly surface water from the river to produce drinking water, but will be closed in the near future. Groundwater extraction from the second aquifer causes a drop in water pressure in this aquifer, which leads to less exfiltration of nutrient-poor and base-rich groundwater in the brook valleys. This leads to lower water levels in the wet meadows and causes the replacement of groundwater by acidic rainwater in the topsoil (Grootjans *et al.* 1988, Van Diggelen *et al.*, 1998). One of the areas that are most affected by groundwater abstraction is the Kappersbult (c. 25 ha.), situated in the lower course of the Drentse A. This nature reserve was originally established in 1965 (first initiatives) to protect typical flood mire vegetation with *Carex acuta*, *Carex aquatlis* and *Carex elata* and the cultural heritage of the landscape elements.

Repeated vegetation mapping of the area (over 37 years) showed that between 1975 and 1996 showed that there were few changes in wetness and trophy indication of the vegetation between 1974 and 1996 (Figure 7). Eutrophic vegetation types were dominant and relatively stable for almost 22 years. Mesotrophic species showed a small increase at the expense of oligotrophic types in 1982. This effect partly disappeared again in 1994-96. As can be seen in figure 6, there was a large drop in nutrient availability in 2011. Mesotrophic vegetation types became dominant at the expense of eutrophic types. Figure 7 also showed that the flood meadows acidified between 1996 and 2011; the intermediate alkaline types showed a large decline in cover from 74% to 35 %. They are mostly replaced by neural types, but also by intermediate acidic and acidic vegetation types. The vegetation types that declined were the four communities of *Carex aquatilis*, *Carex acuta* and *Glyceria maxima*. They were mainly replaced by four

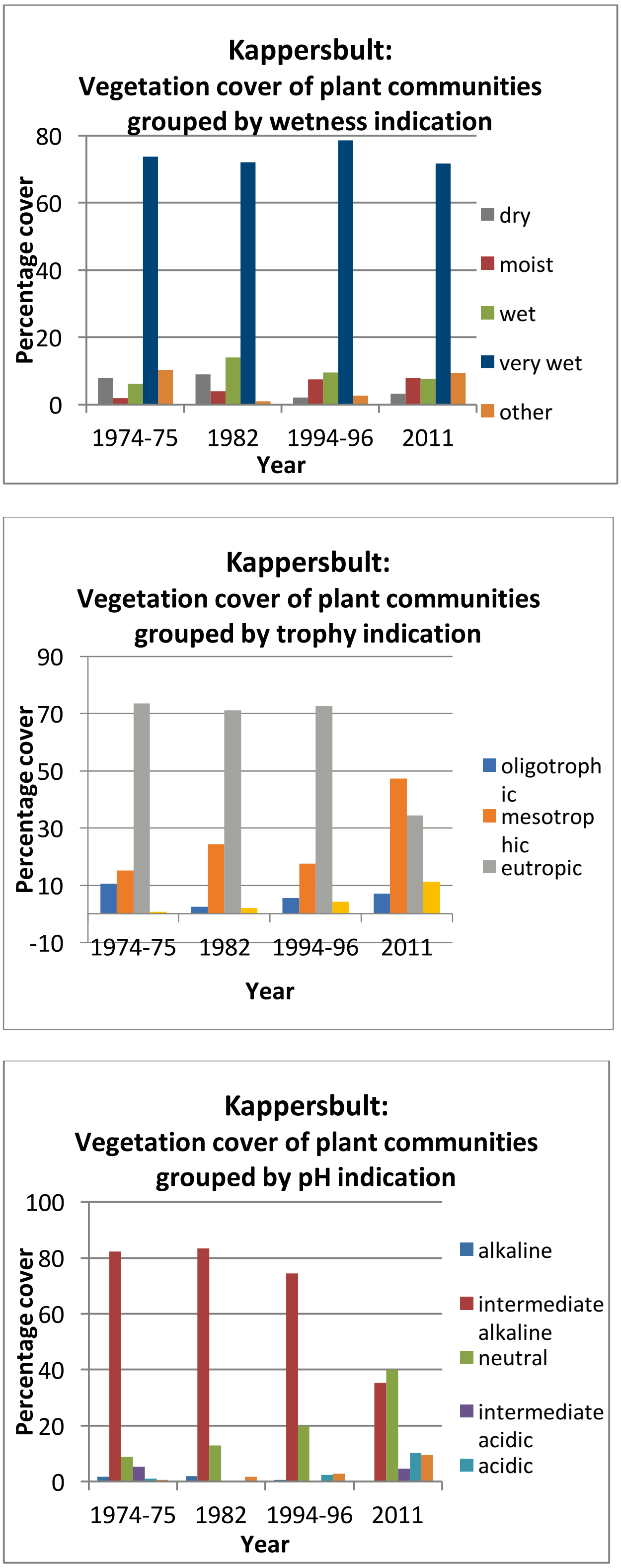

Figure 7: Vegetation cover of plant communities grouped by their indication of wetness, nutrient availability and pH in the Kappersbult (Drentsche Aa).

communities of *Carex nigra, Carex aquatilis, Equisetum fluviatile*, and partly *Pedicularis palustris*.

The causes of this decrease in nutrient availability and acidification is not only due to groundwater extraction that triggered increased infiltration of rain water, but also a decrease in flooding frequency by the river. Therefore, the meadows would only receive nutrient-poor rainwater and became oligotrophic (Van Diggelen *et al*.., 1990). The possible improvements to the hydrological system because of the reduction of GWE by the pumping station of De Punt are not noticeable from these results. This development is in line with the prediction of both van Diggelen *et al*. (1990) and Schipper & Streefkerk (1993) that the hydrological system of the Kappersbult is strongly affected by several factors, therefore solving only one problem will not lead to hydrological improvements.

Since the Kappersbult used to be a eutrophic and alkaline marsh, the current shift to neutral and mesotrophic conditions is detrimental to the native vegetation. Although the environmental value of the Kappersbult is still very high, this is likely to decrease as the degradation of the nature reserve progresses.

External and internal drainage of wet meadows

In 1995 about half of the vegetation on peat soils were considered to be affected by desiccation (figure 8a). Groundwater extraction for drinking water production is partly responsible for this environmental problem, especially in the areas near the pumping stations (Hoetz, 2013). The intensive drainage that is required for agriculture is the other main cause.

But also internal drainage had a negative impact on restoration. During the last century mowing of meadows on peat soils occurred with small tractors, which would get stuck in the peat when the drainage

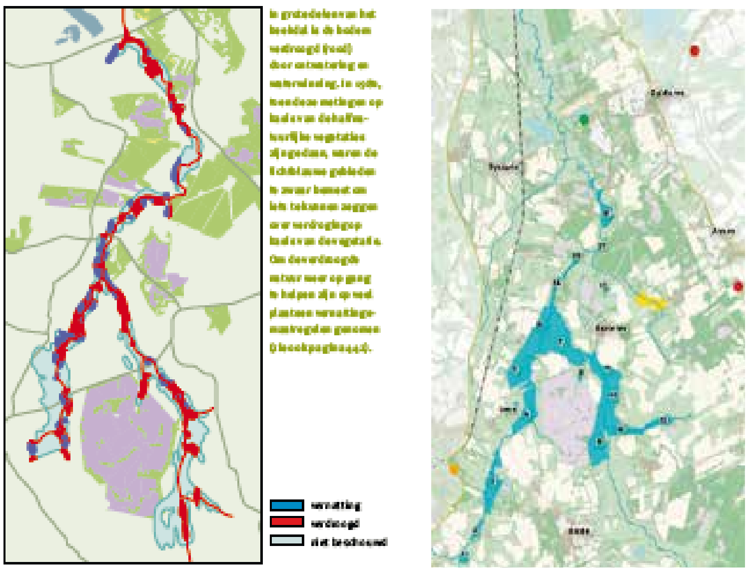

Figure 8. The left figure (8a) shows areas that from a vegetation composition point of few are influence negatively by internal of eternal drainage (survey carried out in 1995?). The right figure (8b) shows the areas (in blue) where since 1996 large scale rewetting occurred by removing all (former) agricultural ditches.

ditches were not functioning. Since 1996, most of the mowing is carried out using large mowing machines with very broad tracks that exerts little pressure per cm^2 of soil. Since the use of this equipment, more than 600 ha of wet meadows have been rewetted by removing all the former ditches (Figure 8b). In 2008 the area with desiccated meadows on peat soils was reduced to nearly 10 % of the peatland areas.

Figure 9. Some impressions of the rewetten hay meadows in the Drentsche Aa National Landscape Park, with Caltha palustris (top) and iron deposition along former ditches.

Avoiding greenhouse gas emissions by rewetting

A secondary benefit of rewetting areas with peat soils is that this reduces peat mineralization. A high water table prevents oxygen to penetrate the soil and thus reduces aerobic decomposition of the organic components of the peat. Peat mineralization causes eutrophication and land subsidence (De Vries *et al.*, 2008). The peat also releases all of its carbon and part of its nitrogen as greenhouse gas (GHG) emissions to the atmosphere. In contrast, methane emissions increase with a higher water table, as less oxygen is available for decomposition. Therefore the decomposition becomes anaerobic. This partially offsets the emission reduction of CO_2 and N_2O after the rewetting (Couwenberg, 2009). Nonetheless, there is usually a net reduction of the total GHG emissions (Augustin *et al.* 2011).

The rewetting measures of SBB (Figure 9) have therefore inadvertently led to a secondary benefit. Not only did they increase biodiversity, but they have also reduced GHG emissions in the rewetted areas. Rewetting measures are costly. To counter desiccation within the National Landscape Park Drentsche Aa, over 5 million euros have been allocated for the period of 2007 to 2013 (Thije & Folkertsma, 2009). Hoetz (2013) has tried to assess how much GHG emission had been avoided by rewetting 634 ha of peat soils in the Drentsche Aa and how much could have been sold on the voluntary carbon market, when the rewetting had been carefully monitored. Hoetz (2013) even expected that this could even become a new business model to fund restoration management in peat areas (see also: Joosten, 2010, 2011). Hoetz (2013) calculated that the increased groundwater levels in 635 hectares of peat soil has led to a reduction of ca. 2,000 tonnes of CO_2 emissions per year, due to reduced peat mineralization. Methane emissions were estimated to increase with ca. 1600 tonnes of CO_2-equivalent per year, due to increased anaerobic decomposition. The rewetting measures thus led to a net emissions reduction of ca. 400 tonnes of CO_2-equivalent per year. Selling that on the voluntary carbon market would yield a sum of ca 150,000 for the coming 50 years at the current price of 7€ /ton. Higher prices are sometimes paid, up to 35€ / ton (Joosten 2011?), which would amount to 700,000 € / ton over a 50 years period, or 140,000 a year. That would not cover the cost of the rewetting measures (more than 700,000 per year (period 2007-2013), but could be a helpful in carrying out the mowing efforts).

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The Dwingelderveld; the largest wet heathland complex in Western Europe

Ab Grootjans, Gert Jan Baaijens

Friday Aug 24th 13.30-17.00

Small heathland bogs in the National Park Dwingelderveld

The Dwingelderveld is a nature reserve in the south-west of the province of Drenthe. It is the largest uninterrupted wet heathland in Western Europe. The area contains extensive wet and dry heath, small heathland bogs, remnants of small raised bogs, drift sands and juniper shrubs. Both the nature values and the location of the area within a virtually intact farming-village landscape are unique. Therefore, the Dwingelderveld was proclaimed as a National Park in 1991.

The area of ca. 3800 hectares (Figure 1) is not only designated as a protected nature reserve as part of the national ecological network and is additionally both a Birds Directive and a Habitats Directive area. It harbors 126 bird species (90 breeding birds), including the Crane, Woodlark, Black woodpecker, Whinchat,

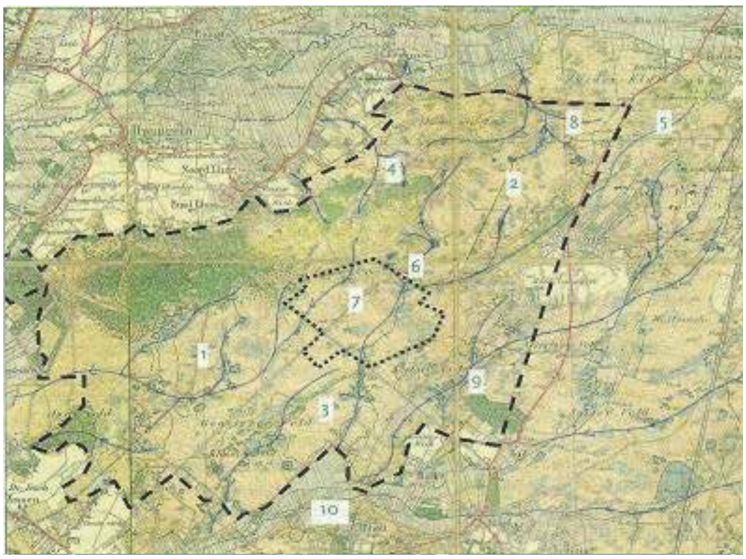

Figure 1: Map of ca. 1900 of the Dwingelderveld. Most of the area consisted of Heathland, with in the North and North-East areas of sand blown dunes and afforestation with pins to stop the sand blowing. Blue lines represent old erosion gullies.

Map of 1995 showing that the pine plantations have expanded a lot at the cost of the heath. The agricultural enclaves in the Dwingelderveld are indicated in yellow and originate from the 1930ties.

Stonechat, Shoveler, and Common teal. The area has also been designated for the rare Northern crested newt. The Province of Drenthe is the competent authority and has the ultimate responsibility for setting up the Natura 2000 Dwingelderveld management plan.

The Province is ensuring that the objectives for the area are achieved. Staatsbosbeheer (Dutch Forestry Service) and Natuurmonumenten (Dutch Society for the Preservation of Nature) own and manage the majority of the Dwingelderveld.

With 822 mm annual precipitation the Dwingelderveld is one of the wettest parts of the Netherlands and the rain water cannot easily infiltrate into the soil. During the last glacial period a thick layer of boulder clay was deposited, which was later partly or totally eroded by old river systems (Figure 2).

pines was carried out to stop the sand blowing. In 1936 about 50 ha of agricultural land was created in the center of the heathland area, which expanded to circa 200 ha in 1950; this is the Noordenveld. Deep drainage ditches were dug, lowering the water table till 70cm below the surface. The drainage water from the agricultural flooded the some of the remaining oligotrophic heath pools, resulting in severe eutrophication. Another problem was the lowering of the water tables of the brook valleys situated on both sides of the Dwingelderveld. The combination of agricultural drainage, pine afforestation with higher evapotranspiration and lowering water tables in the brook valleys led to severe desiccation of the Dwingelderveld.

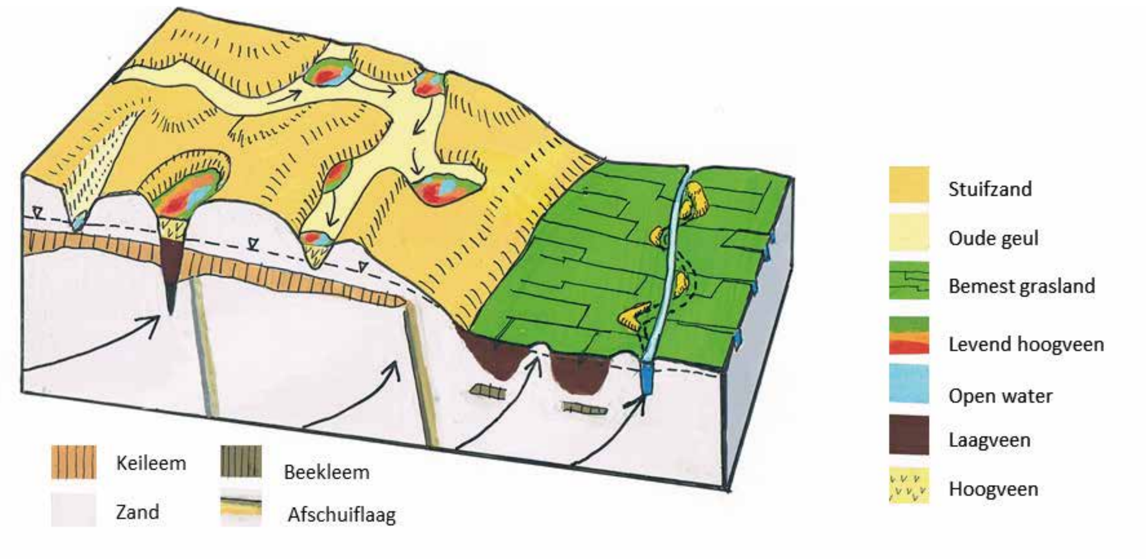

Figure 2. Simplified geology and geomorphology of the Dwingelderveld area (from Grootjans et al. 1998) (top) and heath pool types in the Dwingelderveld bottom). The small bogs along the valley slopes and in the pingo remnants were once influenced by groundwater, but are now fed by precipitation water. The pools above the boulder clay have always been fed by precipitation water, and may have been formed relatively recently (after Bakker et al., 1986; Baaijens et al., 2018).

This widespread occurrence of boulder clay in the upper soil layers has led to much variation in hydrological conditions and thus a varied heathland landscape with *Erica tetralix* dominating the wet parts, and occurrence of numerous small bogs. In the dryer parts *Calluna vulgaris* is co-dominant. In the past (some hundred years ago), drift sands were extensive in the dry parts of the Dwingelderveld due to extensive sheep grazing. Since the beginning of the 1920's afforestation with

Atmospheric Nitrogen deposition

As in most areas in the Netherlands atmospheric nitrogen deposition is a serious problem for nutrient poor ecosystems, leading to grass encroachment and soil acidification. In the 1960-1970 acidification of precipitation water (due to SO2-emissions) had severely damaged many heathland areas and bogs. In the 1990 ties the emission of SO2 had been reduced considerably, but the atmospheric nitrogen deposition still increased. The effects of increased nitrogen deposition has been recorded well in the Dwingelderveld. In 1967/1968 Baaijens measured the water composition of ca 30 bogs in the Dwingelderveld and estimated met that the annual nitrogen deposition was about 22 kg N per ha/year (Baaijens, 1982). In 2002 this research was repeated (Verschoor *et al.* 2003) and it was found that the pH, the calcium-, ammonium- and nitrate concentration had all increased: so acidification had dropped, while nutrients had increased. The increased concentrations of calcium were explained by the rewetting measures since 1987 supplying the bogs with more groundwater.

A detailed overview of changes in environmental conditions in small bogs in the area during almost 50 years was presented by Van Dam *et al.* (2013). They studied water chemistry, water levels, and the composition of vegetation, algae, and macrofauna in the bogs. Data from 2010/2011 and compared the data with similar research in 1990, 1994, 2003, and also older data. The found that during the last 10-20 years the quality of most parameters had improved, mostly due to a steep decrease in SO2 (acidification) combined with large scale restoration measures. The pH, for instance rose from 4.0 in 1990 to 5.5 in 2010. But the macrofauna did not recover. The explanation of the authors was that mineralization of organic matter in the bogs could be responsible. The last decades the temperature in summer had increased by 1.6 degrees, while the sulphate concentration in the water had decreased. This could point to increased sulphate reduction in the peat, which together with higher pH conditions, could have increased mineralization of organic matter and associated availability of nutrients (see also Smolders et *et al.* 2006). So, the legacy of acidification and increased sulphate concentrations in the bog system, still had a negative impact on the macrofauna, even after the input atmospheric input of SO2 had stopped decades ago.

Interactions between different hydrological systems

Figure 3 shows a conceptual model of possible groundwater flow in and around the heathland bogs in the Dwingelderveld. The bogs itself are mainly found in old gullies, which are remnants of past (erosive) surface water systems.

These gullies have been filled with much larger bogs in the past. Most of these bogs have disappeared, partly by exploitation by man, but possible also due to desiccation of the whole area as a result due to hydrological changes in wider surrounding plateaus and river valleys. But these old bogs left a mark in the form of impervious organic layers in the subsoil (gyttja and podzolic layers).

The present bogs are in fact regenerating *Sphagnum* mats that are floating on the water after farmers had taken away most of the peat during the past centuries.

A cross-section through the erosion gulley (from north to south; figure 4) shows that during the winter period all heath bogs are in contact with the groundwater (light blue), but still the water level of the bog itself is higher than the local groundwater level. In autumn the local groundwater table is lower (dark blue) and several bogs have lost contact with the local groundwater, especially in the right side of the transect. Groundwater has been lost in areas where boulder clay has been eroded away or where the clay layer is very thin. If the local groundwater drops below the bottom of the bog the infiltration of bog water increases (Dekker *et al.*, 1986); the bog losses water to the groundwater. And the local groundwater level is drained by the low levels in the central agricultural area and the low water level in the small valleys on both sides of the Dwingelderveld. During most of the year almost no water flow occurs between the small bogs in the erosion gully. In dry periods the bog loose water due to evaporation and they lose (small amounts of water due to leakage through the organic layers. But in wet periods the situation is different. After prolonged rains and decreasing evapotranspiration the bogs are filled with precipitation water and start to overflow, loosing

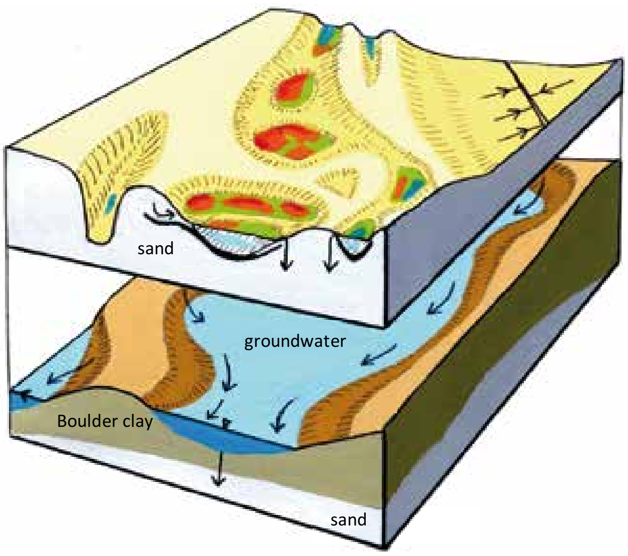

Figure 3. Position of small heathland bogs (orange) in former gullies (yellow), which are underlain by impervious podzolic layers (B-horizons; black) and organic deposits (gyttja). The arrows indicate groundwater flows. The top segment shows the groundwater flows within the shallow sand layer (up to 5 meters). The bottom segment (5-10 meter below surface) indicates groundwater flow above the boulder clay deposit, which have a high resistance to downward water flow if the layer is more than 2 meters thick. When the boulder clay layer is less than 50 cm thick groundwater infiltrates to lower sandy layers and flows to the small (drained) river valleys situated on both sides of the Dwingelderveld.

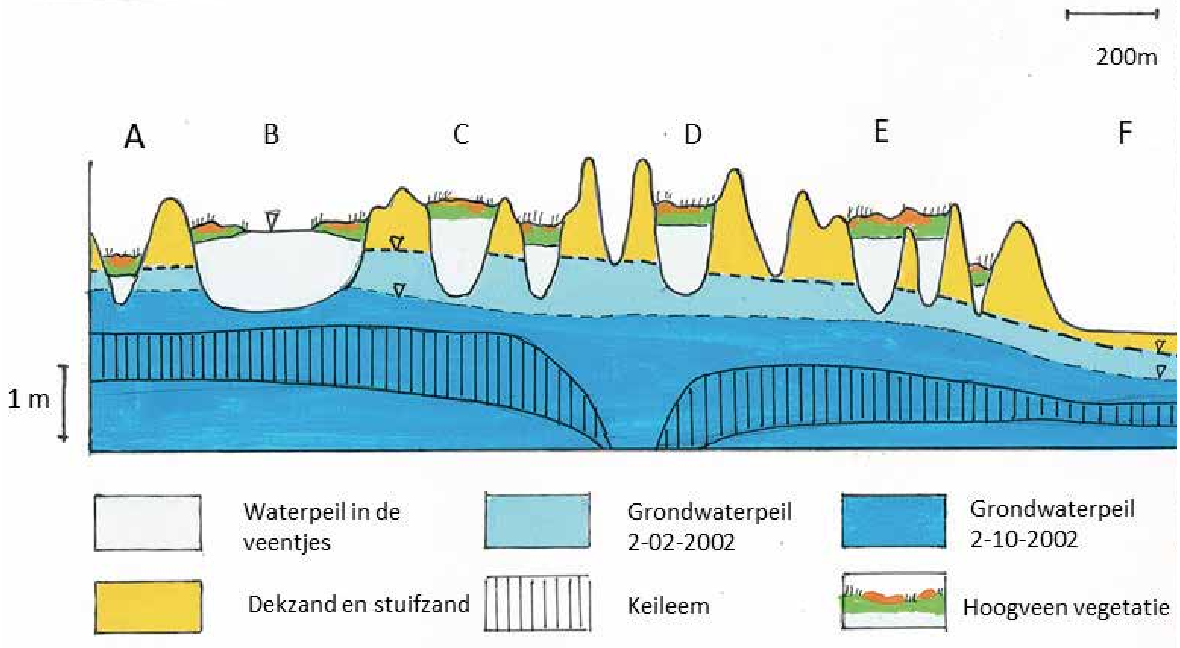

Figure 4: Cross-section through the length of an erosion gully showing the position of 8 small bogs. The groundwater level of winter 2002 and autumn 2002 is indicated in blue colors. Water levels drop to the right due to leakage through a thin layer of boulder clay in the Groot Koelevaartsveen, which in turn loses groundwater towards drainage ditches in a large agricultural enclave (changed after Verschoor et al. 2003). A= Wolfsklauw Veen, B = Zandveen, C = Barkman's veentje, D = Groote Veen, E = Lange Veen, F = Groot Koelevaartsveen.

water to the groundwater in the gullies. Some bogs also receive local groundwater from surrounding dunes and the Bog Asphodel *(Narthecium ossifragum)* is often abundant in such bogs (Van Dijk *et al.* 2009; see also Figure 5)

Rooke (2002) studied the relationships between the occurrence of *Narthecium ossifragum* and possible flow of local groundwater. As a tracer for local groundwater flow he used temperature profile in the bogs (Fig. 6).

The measurements were carried out in spring 2001 during a period of rathe high temperatures. Groundwater from neighboring hills was still relatively cold, while shallow surface water in the bog itself was warmed up. One bog (called 'Poort 2') shows inflowing cold groundwater from the neighboring sand hill at the right`.

In the bog itself the water is heated up and infiltrates again to the opposite side. In another bog (called peatbog nr 4076) no incoming groundwater can be detected. Temperature profiles are stratified.; warm in the upper layers (very recent warming) and in the lower layers as well, (warming from last summer).

The importance of additional inflow of ground- or surface water to a growing bog has been researched by Patberg *et al.*, 2013). Between 2007 and 2009 they

Figure 5. Overview of two small bogs with active growing Sphagnum carpets (left: 'Barkmansveen' with flowering Rhynchospera alba, and right 'Poort 2' with an abundance of Bog Asphodel (Narthecium ossifragum) (fruit setting). Photos: André Jansen.

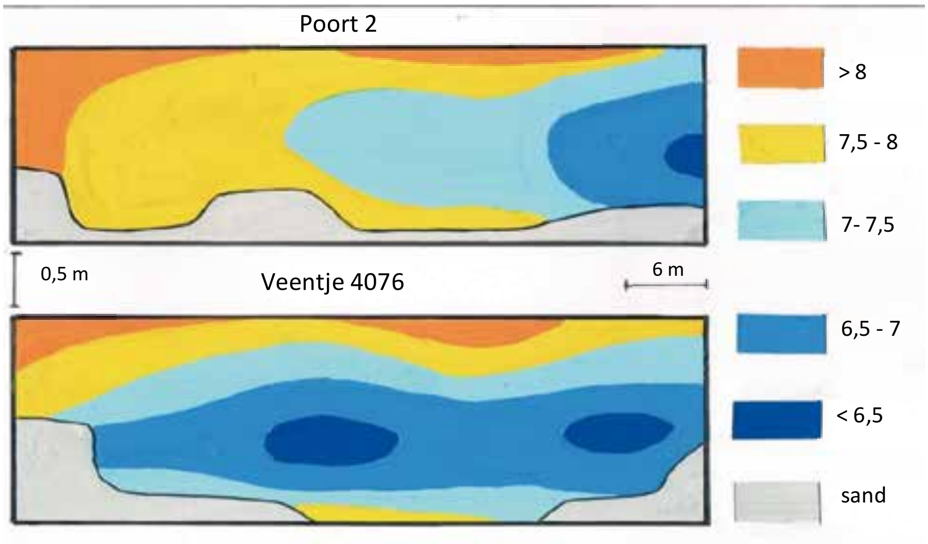

Figure 6: Temperature profiles in two small bogs in the Dwingelderveld. In the upper bog with Narthecium ossifragum, cold groundwater is flowing into the bog from the right. In the small bog without Narthecium ossifragum ('4076') the temperature profile shows only horizontal stratification indicating that no water movement is (after: Rooke 2002).

analyzed the composition of bog water during the season to investigate what could be limiting factors for *Sphagnum* growth in the field. Patberg wanted to know that successful restoration of *Sphagnum* growth was indeed depended on the position of the bog in the landscape as was suggested by Verschoor *et al.*, (2003). In his research Patberg distinguished two categories of bogs; well developing bog vegetation after rewetting ('good') and not well developing bog vegetation after rewetting ('bad'). 'Good' and 'bad' vegetation

	Bog surface water		
	good	bad	significant
HCO_3^-	15 ± 18	25 ± 51	n.s.
CO_2	1215 ± 730	743 ± 626	*
pH	4 ± 0.3	5 ± 1	*
NH_4	77 ± 70	72 ± 80	n.s.
NO_3	8 ± 14	9 ± 15	n.s.
K	26 ± 19	34 ± 28	n.s.
P	5 ± 8	4 ± 7	n.s.
Al	10 ± 8	8 ± 9	n.s.
Ca	31 ± 35	34 ± 32	n.s.
Cl	256 ± 80	290 ± 152	n.s.
Fe	42 ± 107	12 ± 14	*
Mg	26 ± 14	30 ± 13	n.s.
Na	192 ± 48	227 ± 95	*
S	22 ± 16	28 ± 22	n.s.
Si	36 ± 22	19 ± 22	*

Table 1 Chemical composition of surface water in well developing and badly developing bogs after restoration measures in the Dwingelderveld (in µmol/l).The last column indicates if difference between the two bog types are significantly different (*) or not (n.s).

development were based on the growth of *Sphagna* that could be seen on aerial photographs of 1982 and 2006. From this analyses Patberg concluded that *Sphagnum* growth was mainly determined by differences in CO_2, iron and silica concentrations of the surface water (table 1).

Differences in nutrient concentrations were not significant, indicating input of groundwater with high concentrations of CO_2, iron and silica were more important for abundant *Sphagnum* growth than nutrient concentrations in the water.

The research of Patberg *et al.* (2013) confirmed experimental research on limiting factors of *Sphagnum* species carried out by Smolders *et al.* (2003). But where does this CO_2 and iron rich water come from? There are two main sources of CO_2 : (i) from local groundwater that picked it up from the root zone in surrounding infiltration areas, and (ii) from peat decomposition in remnant peat in the bog itself. Farmers left a shallow layer of peat in the past and that appeared to be an important source of CO_2- for the growing *Sphagnum* species at the surface (Smolders *et al.*, 2001, Tomassen *et al.* 2011).

Flow of water in the actively growing *Sphagnum* layer (acrotelm); Buoyency driven water flow

Water flow on the microscale can occur in the living *Shpagnum* layer of small bogs (acrotelm). The mat of growing *Sphagnum* plant is floating on the water. During the day the temperature in the top layer can increase considerably in the top 10-15 cm, while during the night the top layer is cooled down. Especially in spring and autumn relatively large differences in temperatures can occur between day and night. Around midnight a cold layer of surface water is covering a warm layer of water that was warmed op the previous day. Cold water is denser than warm water and tends to drop to lower layers, while warm water tends to move upwards. The shallow peat layers is preventing such water flow if the differences between day and night temperatures are small. But when the differences are larger than 10 degrees and the resistance to water flow in the upper peat layer is low, then water flow occurs in the top layer during the night.

This phenomenon is called buoyency- driven flow of water. This mechanism in which water from deeper parts of the acrotelm mixes with precipitation water in the top has been described in bogs by Rappoldt *et al.* (2003). This mechanism has been described in various types of soils and in lakes, but was not known in bogs. But in the 1970-ties G.J. Baaijens already mentioned the possible importance of 'warm water pumps' for the availability of nutrients in bogs. He formulated this hypothesis based on day and night measurements of the pH in the topsoil of bogs.

Figure 7 illustrates the occurrence of buoyency driven flow of water in an experimental *Sphagnum recurvum* bog in the laboratory (Rappoldt *et al.*, 2003; Adema *et al.*, 2006). The authors point to the possible importance of buoyency driven flow of water for the availability of nutrients and CO_2 for *Sphagnum* growth in the top layer. This was later confirmed experimentally by Patberg (2012).

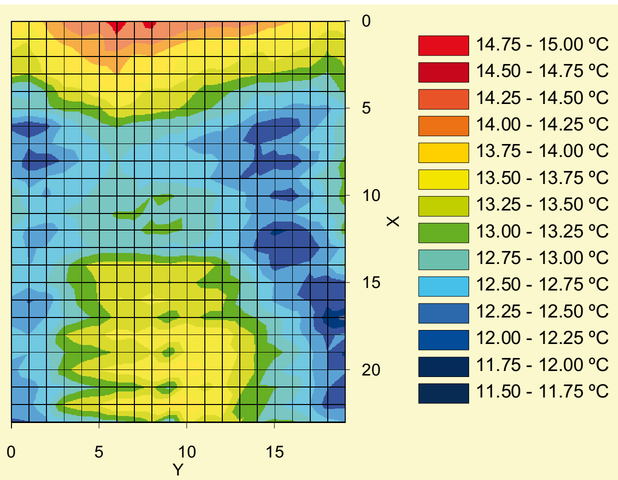

Figure 7: Spatial differentiation in temperature in an experimental desighn where difference in day and night temperatures were imposed on a floating mat of Sphagnum recurvum. The differentiation in temperature at a scale of 20 by 20 cm occurred at midnight when warm water from deeper layer was raising to the surface, while parts the cold water was still present (from: Baaijens et al. 2018).

Restoration measures to restart *Sphagnum* growth

After the establishment of the National Park in 1991 measures were taken to reduce the effects of drainage, both inside the park and also outside. Inside the Park drainage ditches that had been dug in the wet erosion gullies to improve the productivity of the pine plantations, were eliminated and pines were cut in the immediate surroundings of the bogs. In some areas with larger bog remnants pine forest was cut. Outside the reserve agricultural drainage ditches at the borders of the Park were also removed and weirs were placed in the agricultural channels in order to keep more water in the area and to have a more stable fluctuation pattern in the ditches. This also reduce the groundwater fluctuation in the heathlands of the Park.

In 2010/2011 the agricultural enclaves within the Park were finally bought by the government and large scale restoration measures were carried out. The largest enclave was the 'Noordenveld' that had been a big obstacle to create a more natural hydrological system in the Dwingelderveld (Figures 8 and 9). The agricultural ditches were removed and in a large area

Figure 8. Former drainage ditch in the Noordenveld.

Figure 9. Aerial photograph of the experimental site in February 2012. (dry site in purple and wet site in blue). Clearly visible are the at that time still unexcavated agricultural soils surrounding the Experimental plots and the mounds of removed topsoil next to the dry site.

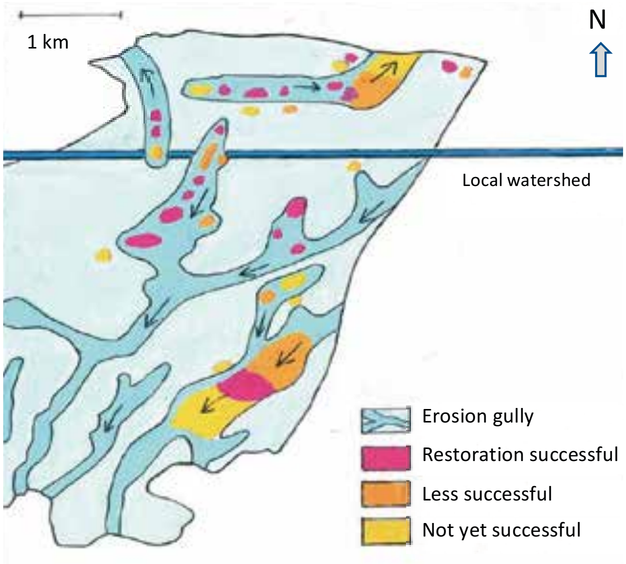

Figure 10. Evaluation of restoration success of 35 small bogs ten years after implementation of hydrological measures to rewet the bogs (after: Verschoor et al. 2003). The arrow indicate the flow direction of surface water within the former erosion gullies.

also the fertile top soil was removed. By doing this also the eutrophication of surrounding wet heathlands by polluted surface water came to an end.

Evaluation of restoration measures

Ten years after the start of (hydrological) restoration measures, the success of 35 rewetted bogs was assessed (Everts *et al.*, 2002; Baaijens *et al.*, 2005). The presence of a well-developed and characteristic bog vegetation was the main criterium for restoration success. Three categories of success were distinguished (Fig. 10): (i) successful, (ii) less successful, but promising and (iii) not yet successful. An interesting pattern was found on the landscape scale; bogs within the former erosion gullies were more successfully restored compared to bogs situated outside the gully or at the beginning of a gully. Apparently the position within the gullies was important for successful restoration, because water losses were small within the gullies.

After 40 years Natuurmonumenten and Staatsbosbeheer have succeeded in procuring the last agricultural enclaves within the Dwingelderveld, which has greatly increased restoration prospects of the National Park. However the focus is now on reducing the atmospheric nitrogen deposition reaching the area from intensively used agricultural areas in the surrounding. Also the deep drainage of such areas remains worrying.

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The National Park Weerribben-Wieden; developing fens in an infiltration area

Annemieke Kooijman, Casper Cusell & Iwan Mettrop

Saterday Aug 25th 09.00-16.00

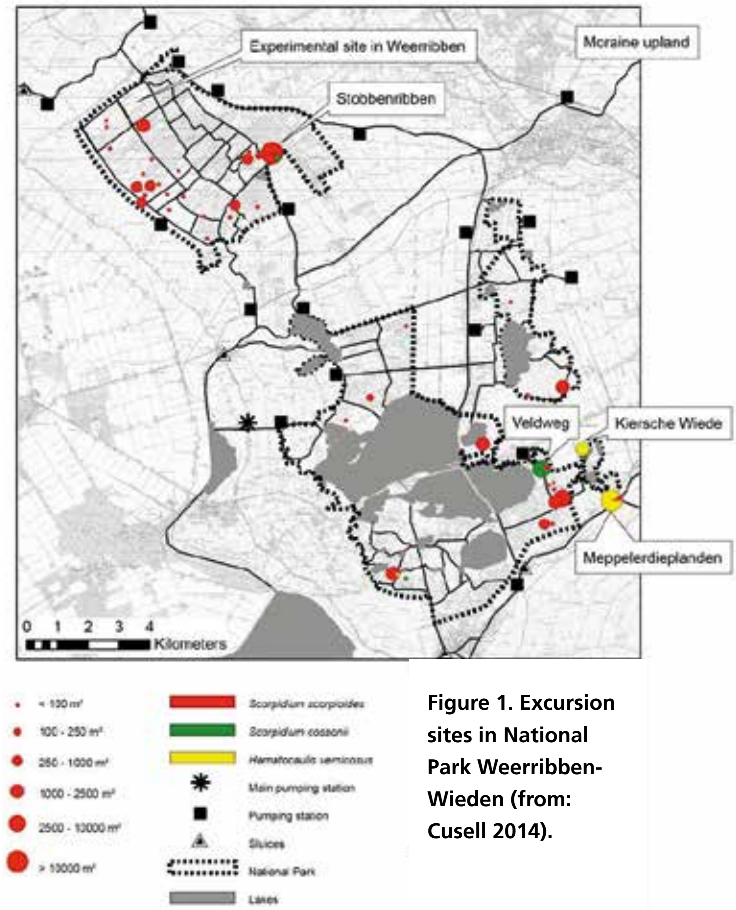


Figure 1. Excursion sites in National Park Weerribben-Wieden (from: Cusell 2014).

The National Park Weerribben-Wieden

The National Park Weerribben-Wieden is one of the largest RAMSAR and Natura 2000 wetland areas in NW-Europe, and located in NW-Overijssel. The area originally consisted of peat bog, which was drained and converted to agriculture in the 15th-16th Century. Besides lakes, the area has several complexes of turf ponds, which have terrestrialized in the past 100 years. Turf pond complexes in The Netherlands have mostly been excavated below the water table in the 18th and early 19th century. They are now characterized by very species-rich fen vegetation. The plant communities in the terrestrializing fens in turf ponds are undergoing succession from aquatic to semi-terrestrial vegetation under mesotrophic and slightly eutrophic conditions (Van Wirdum *et al.* 1992, Verhoeven & Bobbink, 2001). These conditions were quite common in The Netherlands until the 1950s and occurred in groundwater discharge areas and floodplain areas of streams and small rivers. Complexes of turf ponds with these terrestrializing fen systems can be found in The Netherlands where the Holocenic low fen areas border the higher sandy areas of Pleistocenic origin, e.g. De Wieden, De Weerribben and the Vechtplassen area.

The National park is a hotspot for wetland diversity, including characteristic brownmosses of mineral-rich fens, and the only place in the Netherlands where this habitat type (H4170A) is still relatively common. The area is also home to habitat directive plants such as *Liparis loeselii* and *Hamatocaulis vernicosus*, and many birds, butterflies and dragonflies. This excursion takes

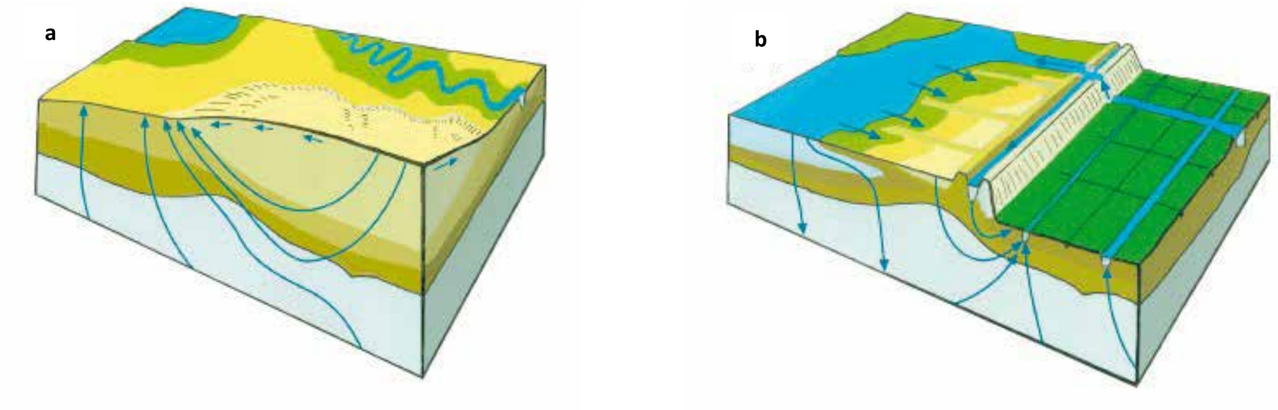


Figure 2. (a) NW-Overijssel as a pristine landscape with growing bogs surrounded by fens. (b) After the mires had dried out and were later reclaimed for peat digging, open water bodies were left in which where terrestrializing mires developed. Intensive agriculture initiated severe peat subsidence, which turned a the former exfiltration area into a infiltration area. These hydrological changes were accelerated by the reclamation of the Noord-Oost Polder in part of the former Zuider Zee. This cause also a severe drop in groundwater levels in NW-Overijssel (right figure after Van Wirdum et al. 1992).

us to four different rich-fen complexes, in which several management problems and solutions have been studied (Cusell 2014, Mettrop 2015): Stobbenribben, Veldweg, Kiersche Wiede and Meppelerdieplanden (Figure 1).

Human impact on hydrology and water composition

Before humans impacted the area, this part of NW-Overijssel was covered with mires, first fens and later also large bogs. The bog dried out by natural causes. From the 15th century onwards, peat was cut on an ever increasing scale. Most of the drained peat lands were converted into agricultural meadows. In the 1940-ties part of the former Zuiderzee was diked and drained. The new low water levels in this polder, called the Noordoostpolder (North-East Polder), causes a severe drop in water levels in the surrounding part of NW-Overijssel. Together with intensification of agricultural and associated deep drainage of the peatlands severe soil subsidence in the agricultural areas was initiated. This led to the situation that the remaining wetlands and fens were the highest areas in the landscape and were surrounded by low lying polders; seepage areas had become infiltration areas and this was irreversible (Figures 2 and 3).

Nowadays, the remaining wetland of about 9500 ha has an average surface level of 0.3 – 0.6 m below mean sea level (BMSL).

The most species-rich succession stage is the floating rich fen, which belongs to the base-rich transition fens (H4170A) in the EU-habitat directive. NP Weerribben-Wieden is the only area in the Netherlands in which this habitat type is still relatively common. Unfortunately, these base-rich fens are also the most threatened. One problem is that formation of new ones has not yet been observed, not even in the Weerribben-Wieden, where the terrestrialization process is more advanced than in other Dutch wetland areas. The other problem is that succession towards *Sphagnum* peatlands is going unnecessarily fast, due to high atmospheric N-deposition, P-eutrophication of surface water and insufficient buffer capacity. However, in the Weerribben-Wieden area, we can see that rich fens can be preserved much longer than expected, if sufficient base-rich and nutrient-poor (surface) water is supplied.

Surface water levels are allowed to fluctuate between 0.73 – 0.83 m BMSL throughout the year. The surrounding polders have one to two meter lower surface levels, and are drained by about 30 pumping

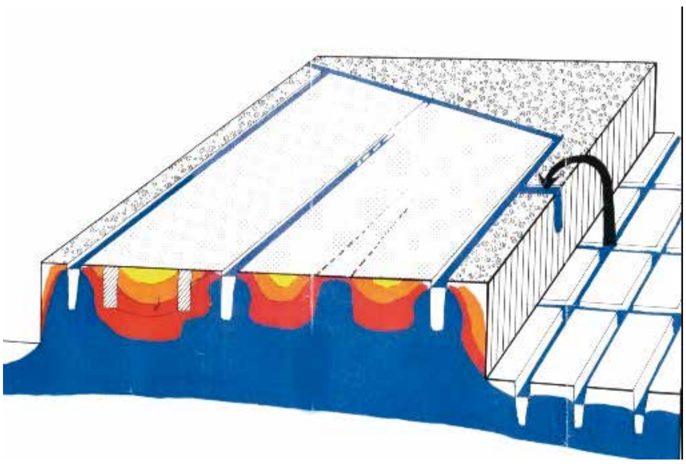


Figure 3. Impression of the hydrological system of the Weerribben in NW-Overijssel with low lying polder areas. Surface water is pumped from these agricultural areas into the lakes and terrestrializing fens. In most of the area the precipitation water is forming rain water lenses in the floating mats which rapidly causes acidification of the top layers (after Van Diggelen et al. 1996).

stations which pump excess water into the higher lying wetland. As a result, there is almost no direct discharge of groundwater anymore in National Park Weerribben-Wieden, and the remaining wetland is losing water to the surrounding polders by groundwater recharge. In the wetland reserve itself, surface water levels are regulated by one main pumping station at the western border of the nature reserve, which removes water during wet periods, and sporadically pumps water in during pronounced dry periods. However, water is coming in from the surrounding agricultural polders in wet periods.

Water balance studies for National Park Weerribben-Wieden (Cusell 2014) show that the water input of the present wetland consists of rainwater (about 35%), drainage water from the adjacent upland (about 20%), and water pumped in from lower lying agricultural polders (about 45%). Mean annual precipitation is about 800 mm. The discharge of polder water is about 50% smaller in summer than in winter, due to the precipitation surplus in winter and the evapotranspiration surplus during large parts of the summer.

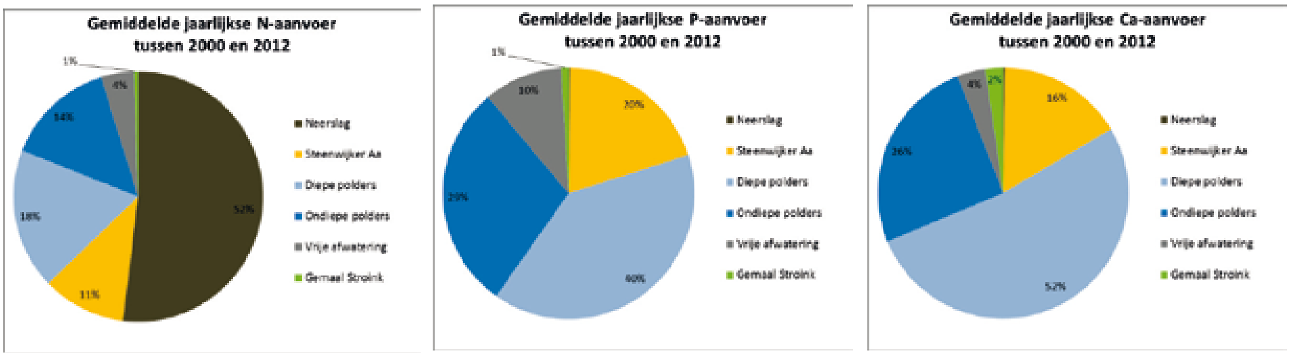
The water composition in the present wetland is thus largely determined by season and especially the land use of the surrounding polders. During the second half of the 20th century, when new polders were created and manure was being used excessively, which led to severely increased N-and P-inputs into the National Park. For N, atmospheric deposition was an important additional input.

Although the present estimated deposition of about 19 kg N ha-1 year-1 is lower than in many other Dutch areas, it is still above the critical N-deposition of about 10 kg ha-1 year-1 for *Sphagnum*-dominated poor fens (H7140B) and 17 kg N ha-1 year-1 for *Scorpidium*-dominated rich fens (H7140A). Almost all P comes from the low-lying agricultural polders (Figure 4), which may lead to eutrophication of ponds and fens. An additional problem is that almost all Ca comes from these polders as well. As groundwater seepage is non-existent in the National Park, supply of base-rich surface water with high concentrations of calcium and bicarbonate is the only way to keep the buffer capacity in base-rich fens, the most diverse but also most vulnerable habitat type, high enough.

More natural water levels: discussion and experiments

In the Netherlands, hydrology of most wetlands is highly artificial. Most areas have fixed water levels, which are artificially kept at a particular height, required by law. Water is pumped in from other sources in dry periods, and pumped out in wet periods. This water is often polluted, and many wetland areas have problems with surface water quality. One of the potential solutions may be more natural water levels, or larger fluctuations in the actual level. The idea is that when water levels are allowed to fluctuate, it is possible to keep surplus water inside the system in winter, so that there is less need to pump in polluted water from elsewhere in summer. More fluctuating water levels may have a number of positive effects, such as (i) lower input of polluted water in general, (ii) lower water levels in summer which could promote germination of shoreline species, (iii) higher water levels in winter which could improve breeding grounds for fishes and (iv) flooding of the rich fens in winter, which could increase buffer and reduce acidification potential. For some isolated wetland areas this may work to some degree. However, for Weerribben-Wieden in particular, there may also be a number of negative effects, such as (i) larger accumulation of rain water inside the area which leads to lower buffer capacity and increased

Figure 4. Mean annual input of N, P and Ca in NP Weerribben-Wieden. About half of N comes from atmospheric deposition, but almost all P from the surrounding low-lying agricultural polders. However, almost all Ca, needed to maintain high buffer capacity in base-rich fens, comes from the agricultural polders as well. Data are from Cusell (2014).



acidification, (ii) severe drought in summer in the base-rich fens which may lead to acidification and increased mineralization of C, N and P, and (iii) input of N and P from the agricultural surroundings especially in winter, which means that flooding of the rich fens may occur with highly polluted water. We were able to study some of these questions (Cusell 2014, Mettrop 2015), and will discuss some of the results in the four field sites.

De Stobbenribben: reference site with occasional ditch flooding

The Drentsche Aa The Stobbenribben is located in the Weerribben and consists of four adjacent rectangular ponds of approximately 20-40 m width and 200 m length; depth of the ponds to the Pleistocene sandy underground is approximately 2.5-3 m (Van Wirdum 1991). The complex is one of the best example of floating fens, with many characteristic rich-fen species, such as *S. scorpioides* and the EU Habitat directive species *Liparis loeselii.* The fens are annually mown to prevent establishment of shrubs and trees. In the southeast, the complex borders an agricultural polder, which has been drained in the 1950s and is situated several meters lower than the fens themselves. As a result, the fens are subject to a downward water movement (infiltration) of approximately 1-2 m year^{-1}. The water loss is far greater than the precipitation surplus, and compensated by lateral inflow of surface water from a ditch at the northeastern side of the fens. This water flows underneath and through the floating root mat. Towards the southwestern end, the fens are hydrologically isolated by peat baulks, and mineral-rich ditch water becomes increasingly mixed with rain water. As a result, the fens generally show a vegetation gradient from brownmoss communities with *S. scorpioides* closer to the ditch to *Sphagnum*-dominated vegetation in the more isolated parts.

Although water quality was better than in many other parts of the Netherlands, various measures have been applied to improve water quality since the 1970s, including major changes in the regional water flows. The inlet has been shifted from relatively eutrophic rivers to the much cleaner lake Vollenhoven. Also, water purification plants have been constructed, and P-input from urban areas has strongly decreased (Cusell 2014). Local measures to improve water quality and increase supply of base-rich ditch water were taken in 1992. The flow of water to the ditch in the Stobbenribben fen complex was redirected, leading to a longer pathway, hence increased uptake of nutrients along the way. Also, the local ditch at the northeastern side of the fen complex was cleaned and enlarged.

Year	Phanerogam biomass (g m^{-2})	N:P ratio (g g^{-1})	Number of replicates
1984	1123 (241)	16.0 (1.8)	n = 3 (with 10 subplots)
1990	512 (73)	19.1 (3.1)	n = 5
2005	212 (136)	22.4 (2.2)	n = 5
2010	187 (110)	.	n = 5
2011	229 (96)	23.7 (1.5)	n = 3
2012	287 (74)	22.1 (1.1)	n = 5

Table 1. Changes in aboveground biomass and foliar N:P ratio of vascular plants in the Stobbenribben fens between 1984 and 2012 (Kooijman et al. 2016).

In 1988, the Stobbenribben belonged to the best rich fens of the Netherlands in 1988 (Kooijman & Paulissen 2006; Kooijman *et al.* 2016). Brownmosses such as *S. scorpioides* were present almost everywhere, except for the most isolated end dominated by *Sphagnum* and the area adjacent to the ditch, dominated by eutrophic mosses. In the past decades, the fens both deteriorated and improved. In 2013, large parts of the fens had become dominated by *Sphagnum spp.*, first by *S. subnitens*, then *S. fallax* and now *S. palustre*, probably due to increased isolation from base-rich ditch water and high atmospheric N-deposition (Kooijman *et al.* 2016).

However, the zone with more eutrophic mosses adjacent to the ditch had become much smaller through time. Also, aboveground biomass in the rich-fen zone showed a fourfold decrease (Table 1), probably due to improved surface water quality. The fens were already P-limited in the past (Kooijman 1993), but P-limitation has become stronger (Cusell *et al.* 2014; Kooijman *et al.* 2016). As a result, characteristic brownmosses and other rich-fen species not only persisted, but also expanded in the area up to 100 m distance from the ditch. This is due to occasional flooding of the fen with ditch water during wet periods, when a lot of water is pumped in the wetland area from the agricultural surroundings. Inundation from time to time leads to increased buffer capacity, and prevents the establishment of and acidification by *Sphagnum* spp.

De Veldweg: reference site with occasional flooding from small ditches

This fen complex is located in the Wieden, and consists of approximately one meter of peat on top of Pleistocene cover sand. The fens partly consist of rich fen, dominated by the brownmosses *S. scorpioides* and especially *S. cossoni.* Base-rich water is supplied to interior parts of the fen by small ditches. This particular fen was used as control site in the water level manipulation experiment, which was conducted from summer 2008 to summer 2014 (Cusell *et al.* 2015; Mettrop *et al.* 2015a). In this particular fen area, water levels were not experimentally manipulated, in contrast to the real test area, because it served as control site. Different vegetation types were included in the study, such as mesotrophic base-rich fens with *Scorpidium* spp. (H4170A); slightly eutrophic base-rich fens with the brownmoss *Calliergonella cuspidata* (H4170A) and *Sphagnum*-dominated transition fens (H4170B). In summer 2009, which was supposed to be a dry period in which the effect of lower water levels should be tested in the experimental area, rainfall suddenly became rather large. This led to increased water levels in the control area, and the lower lying rich fens even flooded with water from the small ditches. During the measurement period, buffer capacity in the two rich fen plots did not remain the same, but instead increased due to the unexpected flooding. In the *Sphagnum*-dominated fens, however, buffer capacity remained the same. Throughout the Wieden, small ditches have been created to supply base-rich surface water to the interior of the fens, and they almost always have a positive effect on the rich fen habitats.

De Kiersche Wiede: experimental site with manipulation of water level

This fen complex is also located in the Wieden, and also consists of approximately one meter of peat on top of Pleistocene cover sand. The fens partly consist of rich fen, dominated by the brownmoss *Hamatocaulis vernicosus.* This particular fen was used as experimental site in the water level manipulation experiment, which was conducted from summer 2008 to summer 2014 (Cusell *et al.* 2015; Mettrop *et al.* 2015a).

Different vegetation types were included in the study, such as mesotrophic base-rich fens with *Scorpidium* spp. (H4170A); slightly eutrophic base-rich fens with the brownmoss *Calliergonella cuspidata* (H4170A) and *Sphagnum*-dominated transition fens (H4170B). In this particular fen area, water levels were experimentally manipulated with large pumping stations.

In winter, water levels were 17 cm higher than normal for a period of ten days in winter. During these periods, large parts of the area were actually flooded (Figure 5).

Figure 5. Experimental flooding in winter in de Kiersche Wiede.

However, flooding in winter did not lead to increased buffer capacity at all, as was expected from mesocosm experiments (Cusell *et al.* 2013, Mettrop *et al.* 2015b). In winter, the water levels inside the fen was already very high, and evapotranspiration very low, so the water could flow over the fen, but did not infiltrate. From the control experiment, we learned that (unexpected) summer flooding can lead to increase in buffer capacity, so the flooding experiment was also applied in summer 2013 and 2014 (Mettrop *et al.* 2015a). This indeed led to increase in buffer capacity in especially the two rich fens, which further supports that flooding with base-rich, clean surface water can be a serious management option, if the water contains enough calcium and bicarbonate. This is further studied in ongoing OBN-experiments in other wetland areas in the Netherlands, such as Wieden, Naardermeer, Nieuwkoop and Rottige Meente.

In de Kiersche Wiede, we also tried to simulate summer drought. In summer, water levels in the ditches of the entire area were 8 cm lower than normal for a period of ten days. However, during the measurement periods, rainfall was usually so high that water levels inside the fens were not lowered at all. This made it impossible to test the effect of summer drought in the field. However, drought manipulation measurements in the laboratory learned that drought can have very rapid effects through the immediate access of oxygen when water tables drop (Mettrop *et al.* 2014). Mineralization of C and N strongly increase under oxygen-rich conditions, especially in base-rich fens. With more fluctuating water levels, lower water tables in summer may thus reduce the intake of polluted water in the wetland area from elsewhere, but for rich fens, lower water levels are not at all a good idea. Moreover, in the Weerribben-Wieden area, the water which would be supplied in dry periods is relatively clean. The contribution of lake Vollenhove to the annual P-input is not more than 1% (Figure 3. This is much less than the amount of P coming in from the agricultural polders, and not at all worth the risk of increased mineralization of C and N from large peatland areas. This also means that the discussion about more fluctuating water levels is more complicated than generally thought.

Meppelerdieplanden: flooding with Fe-rich water

The Meppelerdieplanden are clayey peatlands located along the Meppelerdiep river, with rich-fens dominated by the brownmoss *Hamatocaulis vernicosus.* The fens are regularly flooded with Fe-rich water from a nearby ditch with local seepage water, which keeps the buffer capacity and pH high enough to prevent acidification. However, the fens are also relatively rich in P (Cusell *et al.* 2014, Mettrop 2015). There is still (or again) a lot of discussion about the relation between Fe and P, and whether high Fe levels are reducing P-availability to the vegetation, or not. Very likely, high Fe levels can catch P from the water, which leads to low phosphate concentrations and relatively clear water. However, in peatlands, a lot of P is probably weakly sorbed to complexes of Fe and organic matter, rather than precipitated as iron phosphates, and plant roots probably take this up rather easily (Mettrop *et al.* 2018). However, high P-levels in the plant of Fe-rich soils may not necessarily lead to high biomass production, but may also act as protection against Fe-toxicity. This needs to be further studied.

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Restoration of bog relics in the Netherlands; Restoration at what costs?

Ab Grootjans, André Jansen & Gert Jan van Duinen

Sunday 26th - Monday 27th August

The former distribution of Bogs in the Netherlands

Since the end of the last glacial period huge areas of fens and bogs have developed in the Netherlands. The peat reached its largest distribution around 100 AD. Then, almost two-thirds of the Netherlands was covered with peat. By sea level rise, peatlands disappeared due to drowning and erosion, or became covered by marine or riverine clays (Figure 1, 800 AD). These deterioration processes continued for centuries. Therefore, at the end of the Middle Ages (Figure 1, 1500 AD), the acreage had shrunk further. Since the Middle Ages also human activities, mainly salt extraction ('moernering' in Dutch) and turf extraction in the southwestern bogs, resulted in a further decrease of the vast peatland area. Starting from the eighth century, the extensive mires of the western and northern part of the Netherlands (Holland and Friesland) were colonised and used as meadow, pasture and arable land. An important driving force for reclamation of the marshes, fens and bogs during the Middle Ages was the church, especially the monasteries.

Since the shift of the economic centre from Flanders to Holland around 1600, peat was extracted by dredging on a large scale for fuel, both for industry and households. This large-scale peat dredging started in the western part of the Netherlands and in the peatlands surrounding the former Zuiderzee. When these peat stocks had been depleted and an increasing area of land disappeared under water, the excavation of the vast bogs in the northern part of the Netherlands started.

Around 1850 the peat had already been excavated in large parts of the northern Netherlands, especially in Friesland, Groningen and the northern part of Drenthe (Figure 1). During the 19th century and the beginning of the 20th century the excavation continued at an enormous scale, not only in the northern part of the country, but also in the south-east (Figure 2), until coal became the most important fuel for industry and households. In 1939, peat supplied only 3% of the national energy demand (Gerding 1995). Afterwards, almost all of the remaining bogs were mined for agricultural and horticultural use, i.e. for soil improvement and horticultural crop production, and to produce active coal for water purification purposes (Joosten 2009).

In addition to the extraction of peat in a large-scale and industrial manner, peat was also cut in small peat pits by residents of villages and hamlets. This happened not only at the edges of the very large bog complexes, but also in the smaller bogs along the German-Dutch border, as we will see in the Wierdense Veld. In the eastern part of the country several remnants of these smaller peat bogs have not been reclaimed. They are almost all designated as nature reserves and Natura 2000 sites. The Aamsveen is a characteristic example of this. In the south, almost all of these smaller bogs have

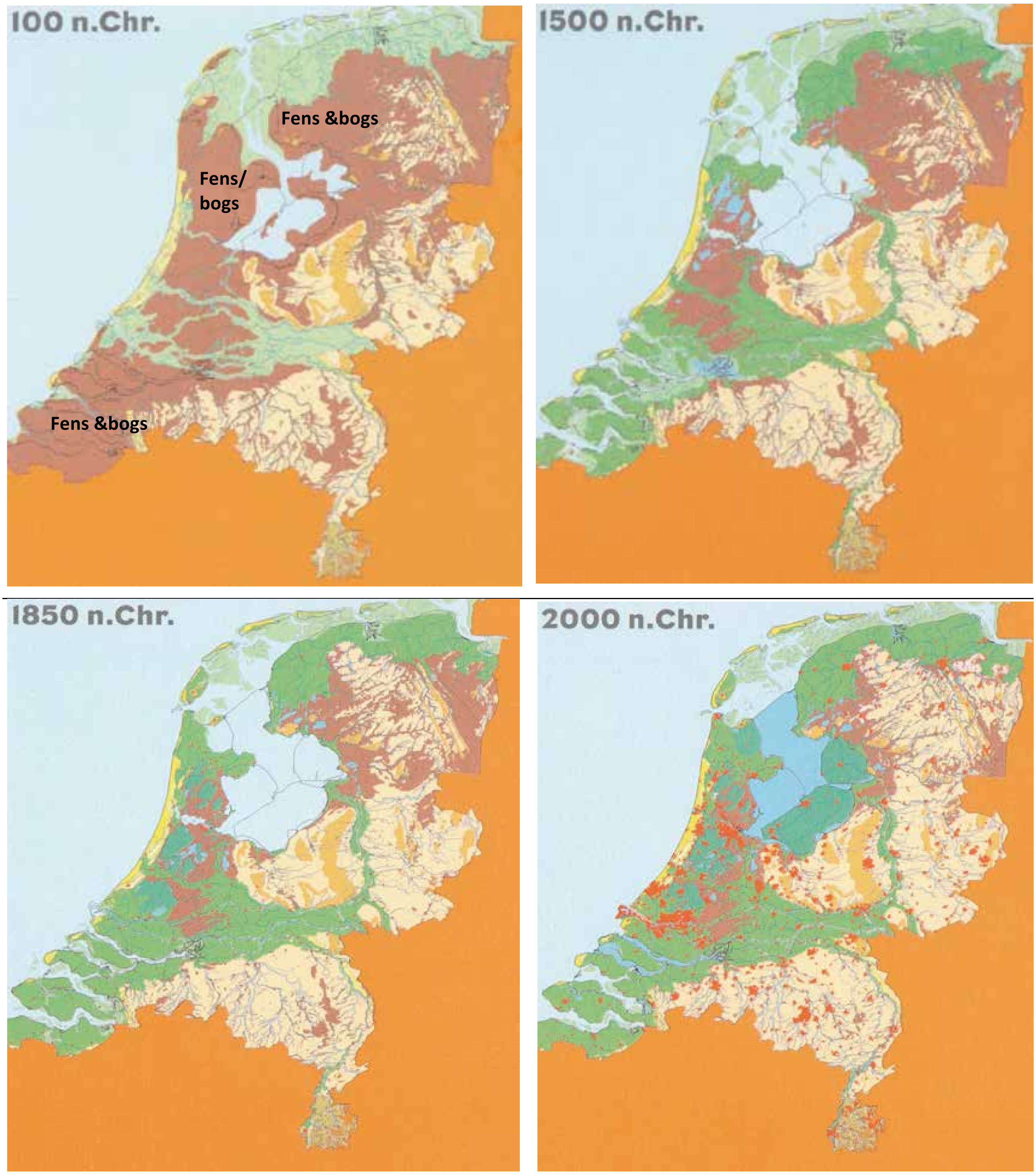


Figure 1: Former distribution of fens and bogs in the Netherlands. The map of AD 2000 depicts the distribution of peat soils. Nature reserves with fens and bogs are being (a minor) part of it. After: Bazelmans et al. (2011).

been completely excavated and subsequently cultivated into agricultural land. The large bogs in the north and south were also mined to agricultural land, where a very distinctive allotment was created (Figure 3). The former bogs in the north have long been used for large-scale cultivation of grain and potatoes, now livestock farming is gaining ground, which in the south have developed into the stronghold of intensive livestock farming.

Nowadays, only little remains of the former vast area of marshes, fens and bogs (Figure 1). Almost no traces of the former mires can be found anymore in the Netherlands (Borger 1992). Not one bog or fen has been left untouched. In 2005 ca. 290,000 ha. of peat soils had remained. About 40,000 ha of degenerated mire relics and lakes remained, of which 30,000 ha is 'fen' (Vermeer & Joosten 1992) and about 12,000 'bog' largely covered with dominance of *Molinia caerulea* and *Betula pubescens.*

The area of actively growing bog vegetation dominated by *Sphagnum* (hummock) species did not

Figure 2 Distribution of raised bogs in the Netherland (c. 1500 AD). The largest bog complexes could be found in the northern provinces. And in the south-eastern part. In the north the huge transboundary bog complex of the Bourtanger Moor (B) was situated, of which the present nature reserve Bargerveen is one of the last remnants, whereas in the south the Peel bogs(P) were situated. The Wierdense Veld (W) and the Aamsveen (A) are examples of smaller bogs in the eastern part of the country. After: Casparie & Streefkerk (1992).

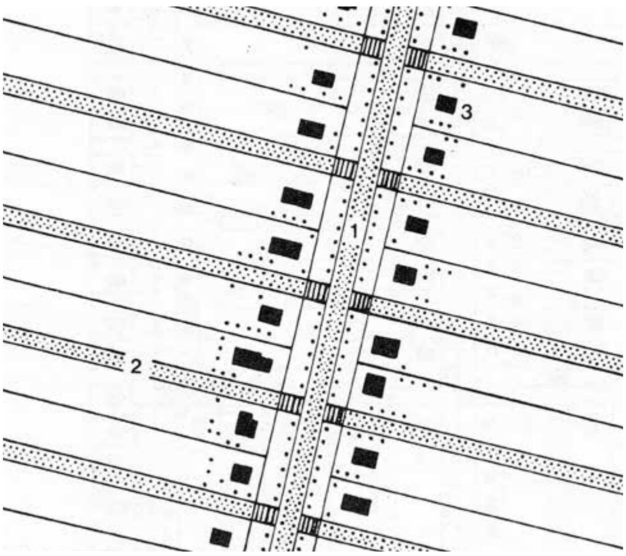


Figure 3: Characteristic allotment after peat excavation in the northern part of the Netherlands. 1 = canal; 2 = side channel ('wijk') and 3 = farm. After: Visscher (1975).

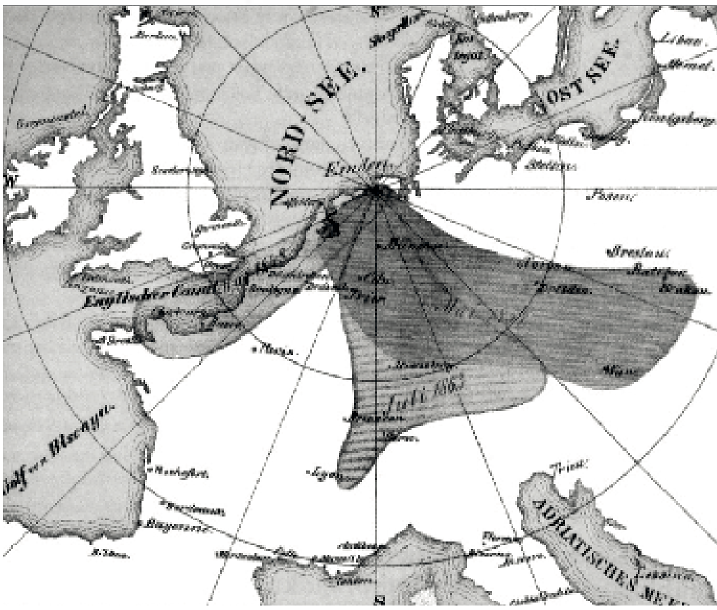


Figure 4: Map of the distribution of moor haze stemming from buckwheat fi re cultivation in north-western Germany in the years 1848, 1857 and 1863. (After Prestel 1903, in: Joosten 2009).

exceed a few hectares before 1994 (Joosten 1994), but has now increased to 7.6 ha (Jansen *et al.* 2013). The area of well-developed rich fin covers also only a few hectares (Cusell 2014).

Before their reclamation the bogs themselves were also agriculturally used. Grazing by sheep was wide-spread, as is indicated by the large amount of pollen Calluna vulgaris in peat bodies since the Middle Ages, as was found in the Aamsveen. Later, small farms ('boetes') were built on the bog, where shepherds lived during the summer. Next to the 'boetes' they reclaimed grasslands in long and narrow lots, so-called 'bovenveengraslanden' which were superficially drained. Subsequently, the vegetation was completely removed, after which the lots were excavated up to 90 cm deep. Then manure was applied. These grasslands were grazed or mown. A few of these grasslands have remained in the Bargerveen nature reserve, where they have developed into species-rich grasslands with also a rich fauna.

In the reclaimed bogs, the technique of buckwheat fire cultivation was wide-spread, especially from the 18th century up until the 1930s. For this cultivation, part of the bog was superficially drained, after which the surface was set on fire. After the fire was (finally) extinguished, the crop was sown on ash-rich peat surface. In this way, mainly buckwheat was grown. Occasionally rape, potatoes, rye, and oats were grown (Van der Linden 2018). This burning of the peat caused an enormous air pollution, that even reached Southern France and Hungary (Joosten 2009; Figure 4). At the end of the 19th century this burning practise was forbidden by law.

Restoring remnants of oligotrophic bogs

In the Netherlands the Korenburgerveen was the first bog that was purchased as a nature reserve. That happened in 1918 by the 'Vereniging Natuurmonumenten', a Dutch NGO, which currently owns and manages almost 110,000 hectares of nature reserves. In 1938, Natuurmonumenten purchased part of the Fochteloërveen. It was only after the Second World War that the remnants of the other Dutch bogs were purchased or designated as nature reserves, most of them in the 1950s and 1960s, the Wierdense Veld last in 1975. In almost all of these remnants the peat had been almost entirely excavated; in no more than four reserves, including the Bargerveen, small areas remained unexcavated. The management of the bog reserves consisted primarily of the removal of young trees. Large parts, however, were not managed and became forested. In some areas ditches were closed to rewet the peat. In the 1980s, the first dams were constructed to retain water and to slow down its superficial drainage, after which large-scale dams were laid out in the 1990s or plastic foils were placed in the subsoil. Although, progressive desiccation had been delayed with these measures, it almost did not lead to the development of actively growing bog vegetation with dominance of hummock species. However, swards of hollows and lawns did develop over large sections in compartments separated by dams. The development towards hummock species stagnated; *Sphagnum fallax* formed monotonous and species-poor vegetation, with still abundant *Molinia caerulea.* At the same time these bog remnants became very important for many water birds and waders, and for birds of semi-open landscapes and heathlands. After millions of euros were spent on restoration measures, in the first decade of the 21st century research was done in the framework of the OBN, the Dutch nature restoration programme, on the determining processes in bogs, on landscape as well as on site level, to learn the factors that the recovery of bogs could favour. The research showed that the development of the lawns stagnated due to excessive nitrogen deposition and lack of CO_2-and methane rich groundwater. The Irish-Dutch exchange program of the State Foresty Commission (Staatsbosbeheer) also generated a lot of knowledge, especially about the hydrological functioning of pristine Atlantic bogs. This new knowledge resulted in an improved hydrological designs of many reserves, including the construction of buffer zones.

Bargerveen

Within the Netherlands, the Bargerveen Reserve is one of the largest bog remnants and also the one where restoration is the most promising. The reserve is managed by Dutch State Forestry service.

The Bargerveen Reserve is a very small remnant

Figure 5. Left: The location of the former Boertanger Moor bog complex (yellow) and the present Bargerveen (green) on the border of Netherlands and Germany. Centre: The former extent of the Boertanger Moor with the Bargerveen (red). Right: the present Bargerveen Reserve with the Meerstalblok (red).

(23 km^2) of the former Boertanger Moor (3,000 km^2), which once formed the border between Germany and the Netherlands (Fig. 5). The development of the bog complex was studied in detail by Casparie (1972).

Figure 6A shows an impression of the southern part of the former Boertanger Moor, where several raised bog domes had merged to form one large bog complex. A small river (Runde) was exporting excess surface water towards the river Hunze. Between the domes a large dystrophic lake (Zwarte Meer = 'Black Lake') was present. Because the bogs were dome-shaped, precipitation water flew from the top of the bog through the acrotelm (=living top layer of *Sphagnum*) to lower areas. Infiltration into the mineral underground was almost totally prevented by the presence of boulder clay layers in the subsoil and the almost impervious lake sediments and other organic layers with a high resistance to water flow. The bog complex was not only fed by precipitation water: locally groundwater from surrounding sandy ridges could enter the complex through so-called 'hydrological windows' where the boulder clay layers had eroded away (Casparie & Streefkerk 1992).

Only a very small part of the Dutch side of the Boertanger Moor has not been subject to peat extraction. This area, part of the Meerstalblok, was the only place where typical bog vegetation and a small bog lake (in Dutch 'meerstal') had remained before the area was declared a nature reserve in 1968 (Figure 6B). Although drainage and burning of the top layer for growing Buckwheat was practiced here, typical plant and invertebrate species persist in the area (Van Duinen 2013). The bog remnant is situated 4 meter above the surrounding area, where large scale peat extraction in the 19th and 20th century has left some small strongly desiccated bog remnants amidst areas with shallow remaining peat layers that were transformed into pastures and arable fields.

Management and management challenges

Since 1971 a network of smaller peat dams and more recently large dikes has been built in order to raise the water levels in the reserve (Figure 6C). Because of the very large height differences between the areas with thick remaining peat layers and the cut-over areas, nearly all low lying areas became almost permanently flooded. In the central part of the reserve the regrowth of *Sphagnum* and *Eriophorum* species was good.

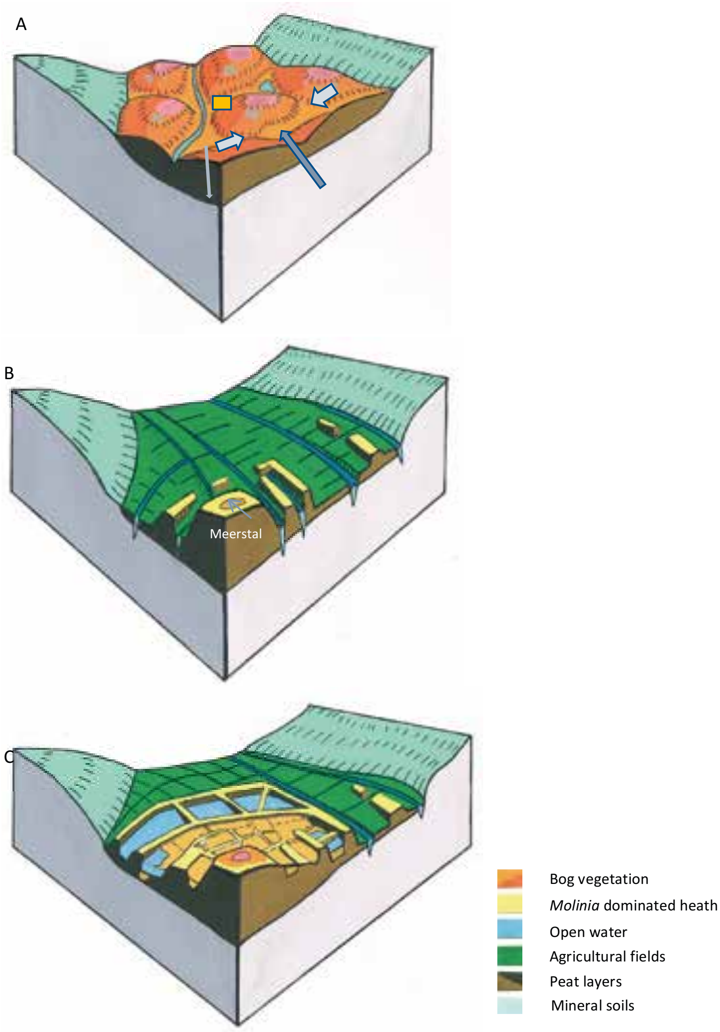


Figure 6. A: Impression of the southern part of the former Boertanger Moor consisting of various large bogs that had merged to one large bog complex. The yellow square represents the present extension of the bog relict Bargerveen. B: Impression of the cutover and largely reclaimed peatland with in the lower corner the small bog remnant Meerstalblok before the start of restoration. C: Impression of the present bog reserve Bargerveen showing restored bog vegetation around the core reserve (Meerstalblok in the foreground) and large flooded buffer zones on former agricultural land (Figure drawn by Ab Grootjans).

Currently, several hectares are now classified as active raised bog (H7110A). In case of open water *Sphagnum* starts floating when sufficient methane and carbon dioxide is produced by the underlying substrate (Lamers *et al.* 2002), which may consist of peat or litter formed by grasses or trees. *Sphagnum* mats keep floating for a long time in case little decomposed *Sphagnum* peat is present (Tomassen *et al.* 2004) or when slightly calcareous groundwater enters the peat from below and stimulates decomposition (Smolders *et al.* 2003). In the low-lying areas with shallow peat layers and permanent flooding, *Sphagnum* growth is limited by lack of CO_2.

Figure 7. The central part of the bog reserve Bargerveen showing the restored bog vegetation growing at almost the same height as the peat dikes that have been built to raise the water level with several meters. (Photo: André Jansen, December 2014).

Only diffusion of CO_2 from the atmosphere is not sufficient to support *Sphagnum* growth under water (Smolders *et al.* 2001, Patberg *et al.* 2012).

The grass species *Molinia caerulea* expanded massively after rewetting. Experimental research in the field and in the laboratory revealed that the vigorous growth of Molinia was caused by the high nitrogen deposition from the air (Limpens *et al.* 2003, Tomassen *et al.* 2003). In the Bargerveen area the atmospheric N-deposition is 20-40 kg N $ha^{-1}yr^{-1}$. Critical loads for bogs are 5–10 kg N $ha^{-1}yr^{-1}$, above which the *Sphagnum* species are unable to absorb the nitrogen (Lamers *et al.* 2000) and nitrogen becomes available for vascular plants such as *Molinia caerulea* and *Betula pubescens.* Above 18 kg of N $ha^{-1}yr^{-1}$ the vascular plants start to shade the *Sphagnum* plants to the extent that their growth is reduced considerably (Limpens *et al.* 2003). In the Bargerveen Reserve the rapid growth of grasses and shrubs has been suppressed by introducing sheep and cattle grazing in the area. This has stimulated the growth of *Sphagnum* to the extent that in the best rewetted areas in the Meerstalblok *Sphagnum* has become dominant and grazing is no longer necessary. The final touch to rewetting of the central parts of the reserve was given by the establishment of large buffer zones on agricultural land around the reserve, where very high water levels were installed. The farmland was bought, mostly by the government.

Figure 7 shows that as a result the high peat dikes in the central parts of the bog remnant are almost overgrown by bog vegetation.

The total budget scheduled for the period 2013-2026 for further measures to restore the Bargerveen bog amounts to about 34 million Euro, including 30 million for restoration measures and hydrological buffer zones and c. 4 million for continued management of the reserve. These funds come from the Provincial government, the national government, and the European Union.

The hydrological buffer zones surrounding the bog relic are 500-800m wide on the Dutch side (Figure 8). The German authorities are planning a hydrological buffer zone of 300m wide at the eastern border of the reserve.

The hydrological buffer zones are largely established and planned on cut-over peatlands with shallow layers of (black) peat that have been intensively fertilized and are extremely rich in nutrients, in particular phosphate. After rewetting these former agricultural lands are highly productive and species like Reed *(Phragmites australis)* and Common Cattail *(Typha latifolia)*, or Willow *(Salix)* dominate the vegetation within a few years. Harvesting these crops is possible with machines that are adapted to driving in marshes and shallow water. Currently, a pilot project is starting to explore the productive use of rewetted agricultural fields on peat (Paludiculture.com; Wichtmann *et al.* 2016).

Figure 8. Left: deeply drained agricultural fields; right: peripheral hydrological buffer zone to keep the water levels in the Bargerveen bog reserve high. (Photo: André Jansen).

Excursion programme

Sunday 26th august 9.30-15.30

The excursion starts at the office of State Forestry Services (Staatsbosbeheer; Figure 9).

We will walk to the remaining small bog lake 'Meerstal' and pass the buffer area and water retention basins. We will also see the differences between the older peat dams and the more recent large dikes constructed to raise the water table in the bog remnant (Figure 10). The vegetation succession following rewetting of poorly humified peat and the effects of sheep grazing can be observed during our walk in the Meerstalblok. A last stop will be on one of the remaining pieces of 'bovenveengraslanden', which consists of grasslands that have been used for agriculture in the past (Figure 11). These grasslands can be rich in plant and invertebrate species, but their preservation is difficult with the raised bog being restored around them.

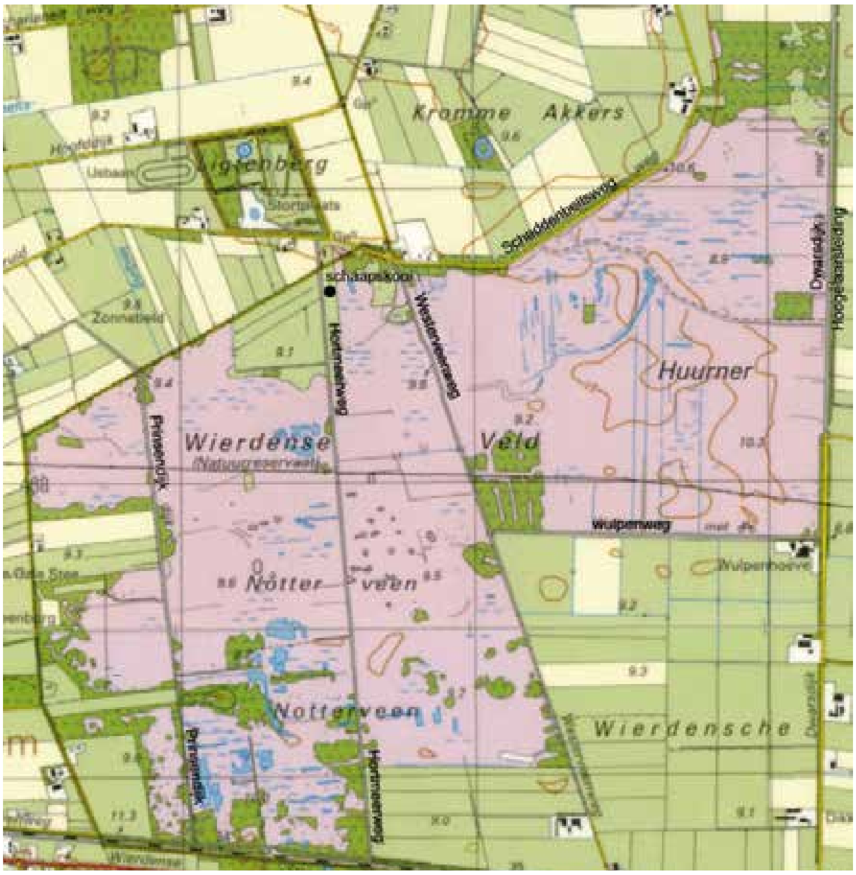
Figure 10. Large dam along the German-Dutch border under construction.

Figure 11. Traditional grassland on decomposed peat soil, which are now very rich in flora and fauna.

Figure 9. Excursion route in the Bog relic Bargerveen.

Excursion programme

Monday 27th august 9.30-12.00
Wierdense Veld



Topographic map of (1:25.000) of the Wierdense Veld.

We leave by bus from the sheep cage. A group crosses the Huurnerveld (in the northeast) where the vegetation and fauna of the peat pits will be examined and explanations are given on the restoration measures. The other group goes by bus to the Prinsendijk in the south, where attention will be payed to the vegetation development since the installation of a foil screen in the late 1980s.

Wierdense Veld

The Wierdense Veld is located between Wierden and Nijverdal in the province of Overijssel (Figure 1?) and is an approximately 450 ha large remnant of an extensive bog landscape (Figure 2?). The area is owned by the Dutch state and since 1975 in leasehold and management by Landschap Overijssel. It is predominantly vegetated by dry and wet heathlands, mostly dominated by Purple moorgrass *(Molinia caerulea)*, in alternation with an often poorly-developed peat moss vegetation of hummocks, hollows and pools. The Wierdense Veld is a collective name for Westerveen (in the southeast), Huurnerveld (in the northeast) and Notterveen (in the west). The reserve has been designated as Natura 2000 area.

Originally, the bog complex of the Wierdense Veld was limited to the east by a moraine and in the west by the Regge, a brook (Figure 2?). It covered a vast cover sand plain bordered by ridges in the west and south, which retarded the superficial flow of ground- and surface water. In the north the plain had just a narrow outlet, which also hampered drainage. Nowadays, the bog (remnant) is limited to a small part of this sand plain. The first permeable layer is shallow due to the occurrence of a glacial loam deposit at a depth of approximately 6 meters. In the west this layer is absent. Peat development started presumably in the groundwater seepage areas at the western edge of the moraine Wierden-Hooge Hexel (Figure 3). The groundwater discharged with its highest intensity at the base of this moraine, where the slope of the ground level changes fairly abruptly from fairly steep to flat. Moreover, the phreatic aquifer is thin (15 meters or less), which further promotes upward discharge. Therefore, peat development in the western part of the plain where the first aquifer is thicker, and the poorly permeable loam layer lacks, started later.

Figure 12: 17th century map of the Wierdense Veld. Detail of the map of Ten Have (end 17th century (source: Atlas van der Hagen, Royal Library, The Hague. The position of the Wierdense Veld is indicated with a black circle.

Mire development in this part was a consequence of the poor superficial lateral drainage, promoted by bog development in the east and in the north. Due to increasing wetness of the plain, in which infiltration was the predominant hydrological process, poorly permeable layers, especially podzol B-horizons, could develop, which caused even wetter conditions, which eventually allowed bog development.

Around 1850 a vast bog complex does still exists, although it is already strongly influenced by people: the area is intersected by roads and quays, there are here and there watercourses and vast fields with peat pits. In the second half of the 1930s, considerable parts of the Westerveld and Notterveen have been excavated. Later, after the Second World War, large-scale peat excavation, started in the south-east and west of the current Wierdense Veld. After the second half of the 1960s the reclamation activities stopped and the Wierdense Veld reached its current size.

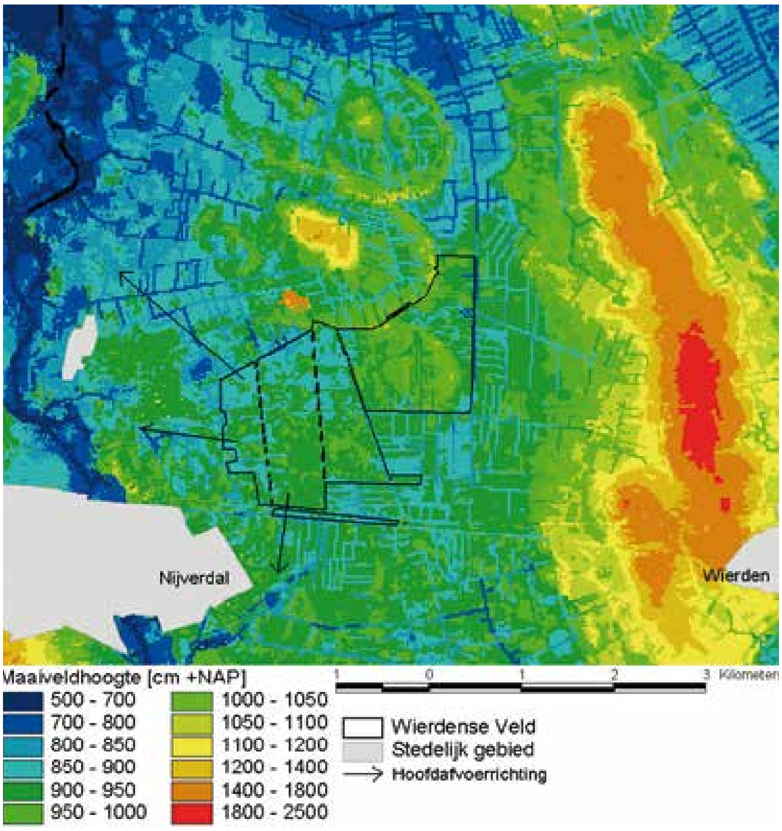


Figure 13: Height map of the Wierdense Veld and surroundings.

Desiccation is the main bottleneck for bog recovery in the Wierdense Veld, especially the enormous amount of infiltration. In an undisturbed bog circa 40 mm water infiltrates to the mineral subsoil during a year. Hydrological modelling suggested a much higher infiltration rate, varying from circa 125 mm to circa 200 mm per year. The desiccation is reflected in the wide-spread monotonous vegetation of *Molinia caerulea*, indicating a deep drop of the groundwater table as a consequence of too low hydraulic heads in the sand subsoil. The impact of these too low heads is being amplified by the locally intersected poorly permeable peat base. The main causes of desiccation are nevertheless outside the reserve. In the area, the water levels have been reduced on a large scale by excavating the peat and the subsequent construction of an extensive drainage system with many deep water courses. Two drinking water extractions have also lead to a lowering of the hydraulic head Drinking water extractions and drainage system contribute to a similar extent to the lowering of the groundwater tables in the Wierdense Veld.

Due to the severe desiccation well-developed plant communities of hummocks are rare, despite the internal hydrological measures which have been taken in the late 1980s and the first decade of the 21th century. Nevertheless, since then the vegetation develops in a positive way. In the beginning of the 1990s hardly any *Sphagnum magellanicum* and *S. papillosum* were found. A recent vegetation survey shows a remarkable increase of these species, especially at and nearby the sites where rewetting measures have been taken. Despite these recent positive developments, the development of a functioning bog system on landscape level requires many more rewetting measures, especially outside the reserve. In the southeast and west of the area such measures are foreseen in the framework of Natura 2000.

Fauna

In the Wierdense Veld various old peat cutting pits are still present. Research in other Dutch bog remnants showed that (1) such peat cutting pits harbour many rare and characteristic species of aquatic invertebrates, and (2) rewetting had been beneficial to only a limited part of the species spectrum of raised bogs. The aquatic microinvertebrate fauna seems to recover quickly after rewetting of drained and cut-over bogs, but this is not the case for macroinvertebrates, like aquatic beetles and caddisflies (Van Duinen *et al.* 2003, 2006). To define a proper restoration strategy for the Wierdense Veld in the years 2003-2005 the situation (chemistry, vegetation, aquatic invertebrates; Tomassen *et al.* 2005) at that time was investigated and compared to other bog areas. In total, 163 aquatic macroinvertebrates were found, including 39 species characteristic of bogs. Although relatively many characteristic invertebrate species were found in the area, the number of species and individuals per sampling site was low. This might indicate small population sizes. A large number of characteristic species showed a preference for temporary water bodies (Figure 14). The presence of

Figure 14. Preference of the 21 characteristic aquatic beetle species found in the Wierdense Veld for temporary (hatched part of the bars) or permanent water bodies (black part of the bars). The preference was calculated as the frequency of occurrence in permanent and temporary sites, with the sum of these two frequencies converted to 100%. The numbers of sampling sites in which the species were found are given between brackets. 1. Dytiscus lapponicus (4); 2. Hydroporus scalesianus (7); 3. Graphoderus zonatus (11); 4. Hygrotus decoratus (22); 5. Acilius canaliculatus (12); 6. Hydroporus umbrosus (29); 7. Bidessus spec. (10); 8. Enochrus affinis (18); 9. Enochrus ochropterus (11); 10. Berosus luridus (4); 11. Hydroporus obscurus (8); 12. Hydroporus melanarius (4); 13. Hydroporus tristis (18); 14. Agabus melanocornis (5); 15. Hydroporus pubescens (15); 16. Hydroporus gyllenhalii (23); 17. Agabus labiatus (12); 18. Rhantus suturellus (7); 19. Hydroporus neglectus (3); 20. Agabus congener (3); 21. Ilybius aenescens (1). (From: Van Duinen et al. 2004).

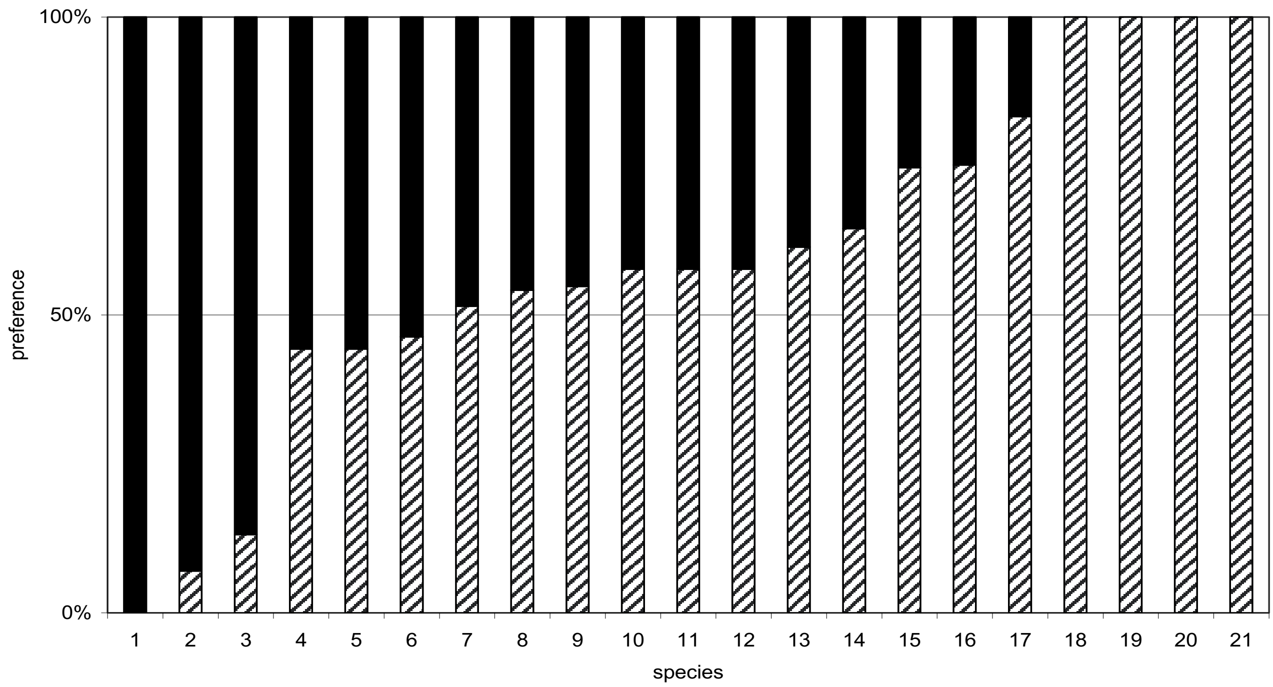


Figure 15. Bund with plastic sheet inside and weir shortly after their construction in 2011 at the eastern edge of the Wierdense Veld reserve.

both temporary and permanent water bodies offers opportunities for many species to survive in the area, e.g. in case of extreme drought, like in 2018. Especially the small populations of characteristic species might be sensitive to sudden changes in water table fluctuations. In order reduce the risk of extinction of characteristic species, a step-wise approach was recommended for the restoration measures in the Wierdense Veld.

Pyrgus malvae (Aardbeivlinder).

Restoration measures

End of the 1980's a plastic sheet was placed in the southern part of the road called Prinsendijk. After the year 2000 plans were made for a partial removal of the drinking water extraction Wierden. This would probably result in suitable conditions for restoration of raised bog in parts of the Wierdense Veld. In 2011 several restoration measures were carried out (Figure 15).

Excursion programme

Monday 27th august 9.30-17.30 Aamsveen (13.00-16.30)

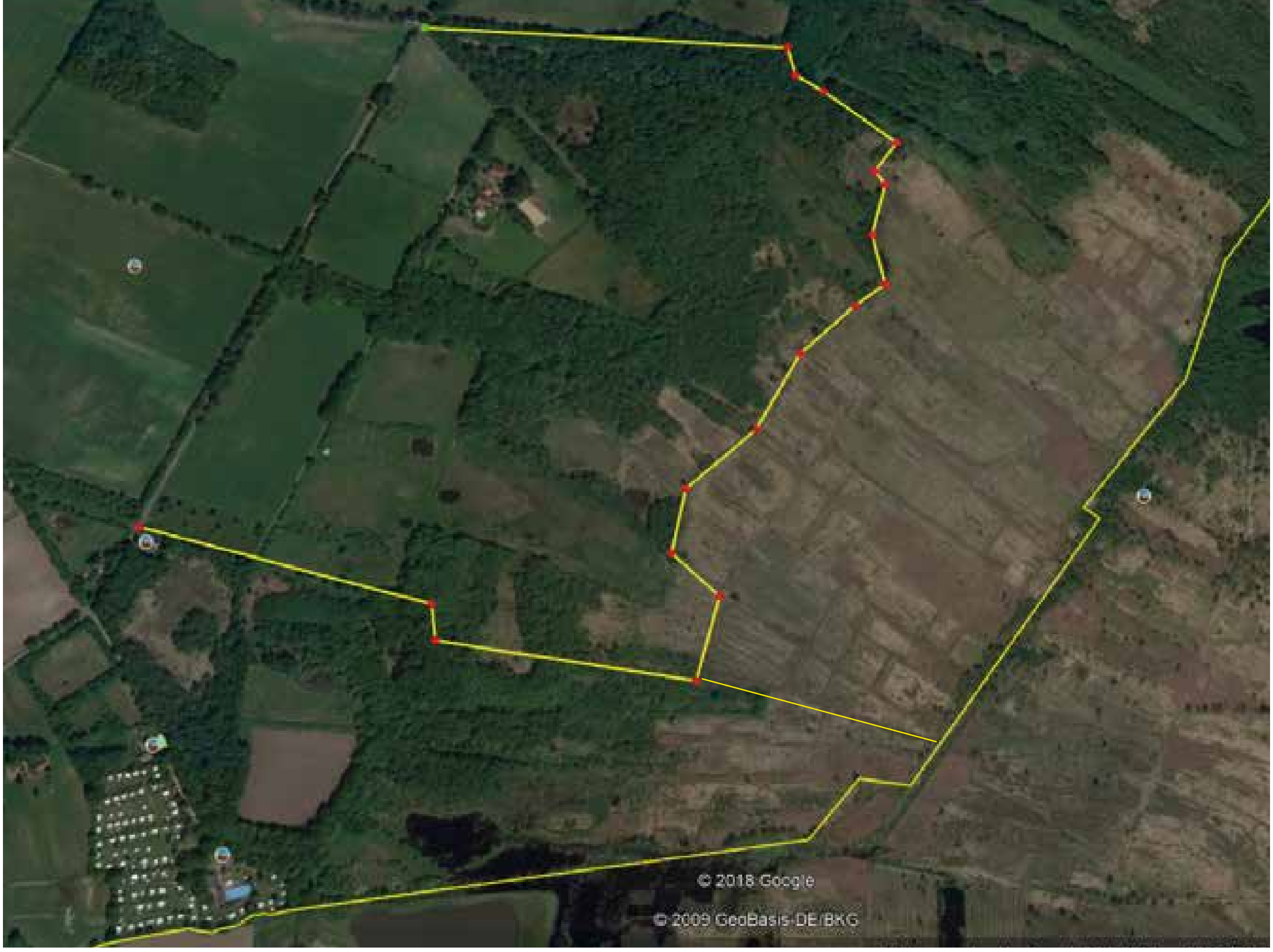
After leaving the bus, we will walk into two groups, in opposite direction. One group starts in the north, the other in the south. During our walk the vegetation and fauna of the lagg and some compartments will be examined and the hydro-ecological functioning will be explained. Moreover, some soil profiles will be examined in order to discuss the historical development of the bog.

Aamsveen

The Aamsveen (Figure 16) is the north-western Dutch remnant of an originally circa 2000 ha large cross-border bog complex of which the major part (circa 1800 ha) lay on German territory (Fig. 17). The remaining German part consists of the Hündfelder Moor, Alstätter Venn, the Amtsvenn and Graeser Venn. The Aamsveen, with an area of about 140 hectares, is located about three kilometres south-east of Enschede, and consist for about 40 hectares of the habitat type Regenerating bogs (H7120), whereas as the remainder probably belonged largely to the lagg, which today is covered by grasslands and forests. The reserve was acquired by the Dutch state at the end of the years 1940. Nowadays he NGO 'Landscape Overijssel' is owner and manager of the reserve and aims at restoration of a complete, transboundary bog landscape, including a well-developed lagg.

The entire bog complex is situated in a glacial basin of which the subsoil consists of Tertiary clays with a total depth of several tens of meters on which a thin package boulder clay is deposited.

In the West the bog is bounded by a moraine of



ice-pushed Tertiary clays. This hydrological base is covered with a thin layer of cover sands that nowhere is thicker than about 5 meters. This sand layer wedges out against the Tertiary clays of the moraine. In this shallow and thin sand layer several depressions occur. The deepest is located just across the border in Germany.

Figure 16: Topographical map (1:25.000) of the Aamsveen and the neighbouring part of the German Hündfdelder Moor.

Here, peat formation started as a consequence of rising groundwater tables. Therefore, the origin of the Aamsveen bog is a water rise mire, which constituted the peat base of the later Aamsveen bog.

Starting from the Middle-Atlanticum (circa 6000 BC). the vegetation became gradually more base- and nutrient-poor. The proportion of Black alder *(Alnus glutinosa)* then decreased and that of birch (*Betula* spec.) increased (Van der Linden, 2018). Gradually, birch carrs

Figure 17: The transboundary bog complex 'Aemsveen' with a central pool on a 17th century map of N. te Have. Private collection.

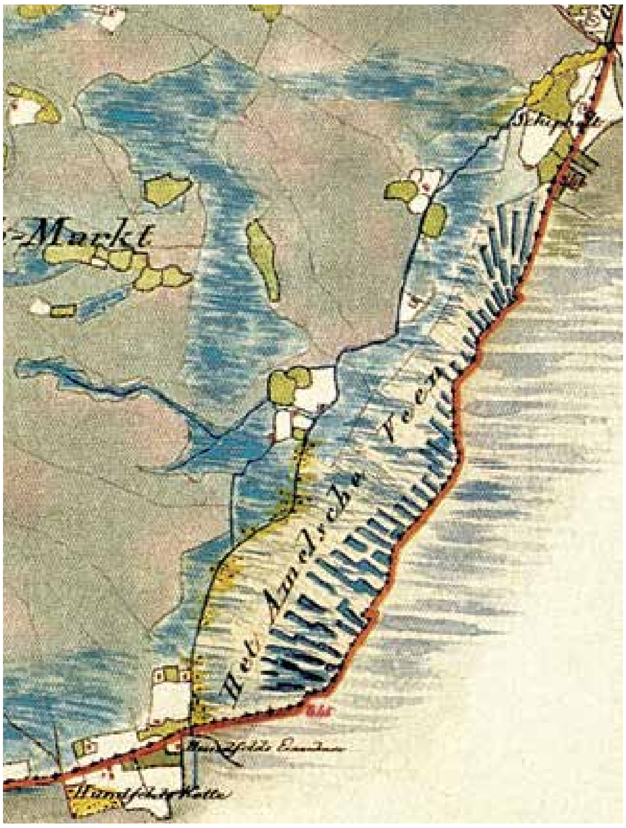


Figure 18: The Huegenin-map of 1819-1829 of the Aamsveen clearly shows peat cutting by pits. In pink bog and heathlands, in blue fens and fen meadows. In the middle the Glanerbeek has two courses, pointing to a watermill ('Roodmolen', Red mill). Along the excavated, southern course of the Glanerbeek forests (yellow) are depicted, which cover sand ridges, intersected by the brook. In white arable fields and in green meadows.

developed, in which beside peat mosses (*Sphagnum* spec.) ground water fed species occurred. In the late-Atlanticum (ca. 5000 BC) these carrs were fully acidified and characterised by acidiphilous species as *Eriophorum vaginatum.* From around 4500 BC hummock forming peat mosses from the section *Acutifolia*, presumably *Sphagnum rubellum* came to dominance. The mire became completely rainwater fed and eventually a thick player of old peat moss peat was formed. Due to the growth of the bog, the water level in the area increased, which caused the emergence of fens in other, formerly higher elevated depressions. Later, these fens also developed into bogs, which eventually fused into one large dome. During the Subatlanticum (ca. 400 BC) it became even wetter, which gave rise to the formation of young peat moss peat. The hummocks now consisted mainly of *Sphagnum imbricatum (S. austini).* Also, the first signs of human influence became apparent by pollen of species, such as *Plantago lanceolata* and cereals *(Secales).*

Although, active bog development still occurred in the Middle Ages, the human impact became larger. The number of tree pollen, also that of Black Alder, decreased, pointing to deforestation. Man cultivated the surroundings of the bog and an open landscape did arise. In the peat pollen are present of field weeds, rye and buckwheat. Rye is grown on the fields in the surroundings, buckwheat in the peat itself. Further, the amount of pollen of heather *(Calluna vulgaris)* had increased, pointing to grazing of the bog itself.

Peat was cut in numerous pits (Figure 18). After the Second World War a small part has been cut off in an industrial way.

Desiccation is the main problem, indicated by the abundant occurrence of *Molina caerulea.* Since the beginning of the 20th century in the lagg all characteristic species of alkaline fens have disappeared by desiccation. The same appears for species of fen meadows, but this happened later. From the beginning of the 21th century the last remaining species of weakly buffered conditions are seriously threatened. They still occur in low numbers in humid *(Nardus stricta)* swards, the plant community that has developed in a degradation series from alkaline fens. In alder carrs in the lagg locally species of base-rich conditions still occur (Figure 19).

In the 1990s the first measures have been taken to reduce the impact of the desiccation and improve the hydrology. Small dams were built, resulting into a chain of small compartments. Within 20 years these measures have locally resulted in the abundant growth of peat-mosses again. Especially, in the transition zone from the former bog to the former lagg. where weakly buffered and carbon dioxide-rich groundwater discharges, the development of a well-developed hummock-hollow pattern shows the possibilities for further restoration. In this vegetation Reed *(Phragmites australis)* accompanies peat mosses as *Sphagnum magellanicum* (which was extincted in the reserve), *S. papillosum, S. palustre, S. fimbriatum, S. fallax, Oxycoccus palustis* and *Andromeda polifolia.* Further, several ditches and a deep water course on the Dutch-German border have been filled in.

Besides the excavation of the larger part of the bog, the presence of many ditches and trenches and the deep watercourse of the Glanerbeek are responsible for desiccation. Moreover, large peat excavations in Germany have an negative influence on the water tables in the bog and the mineral subsoil. The decline in water tables has resulted in a wide-spread encroachment and gradual afforestation, which in turn, provides for a

Figure 19: Locally in the lagg species of base-rich conditions still occur, such as Hottonia palustris.

further decline in groundwater tables due to increased evaporation. Hydro-ecological research revealed that high water tables in the bog itself are the driving force for upward discharge of groundwater form the shallow aquifer into the lagg. This discharging groundwater is very base-rich due to the lime-rich character of the Tertiary clays. Therefore, measures to raise the water table are required in the bog as well as in the lagg. The prospects for re-activation of abundant *Sphagnum*-growth in the bog remnant and restoration of a lagg with wide-spread and well-developed basiphilous vegetation are promising due to the favourable hydrological conditions, and because measures in and along the edges of the reserve will be sufficient. The latter will contribute to a larger social and political support.

Further information/further reading

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The Polder Westbroek

Jos Verhoeven & Boudewijn Beltman

Wednesday Aug 29th 10.00 – 16.30

Historical setting and succession in turf ponds

Turf pond complexes in The Netherlands have mostly been excavated below the water table in the 18th and early 19th century. They are now characterized by very species-rich fen vegetation. As many as 35 different vegetation types have been described for such habitats in The Netherlands (Van Wirdum *et al.* 1992). There are three different succession series, which each characterize a specific water chemistry in the open-water stage, i.e. brackish, fresh mesotrophic and fresh eutrophic. The succession goes through 7 stages (aquatic, floating raft, helophyte, brown moss, transitional fen and carr) and has been described by space-for-time substitution of an extensive database of vegetation relevées, see Figure 1, (Van Wirdum 1992, Verhoeven & Bobbink 2001).

Figure 1. Succession seres in terrestrializing ponds in The Netherlands. Names of plant communities according to the Zürich-Montpellier school of vegetation science (after Verhoeven & Bobbink (2001) and Van Wirdum et al. (1992)).

carr and forest *absence of mowing*	Salicetum auritae	Carici curtae-Betuletum pubescentis	Thelypterido-Alnetum
transitional fen, fen heath *prolonged mowing, atmotrophiation*		Pallavicinio-Sphagnetum	Sphagno palustris-Ericetum
brownmoss fen *summer mowing*			Scorpidio-Caricetum diandrae
helophyte-dominated fen *winter mowing*	Scirpetum tabernaemontani	Typho-Phragmitetum Cladietum marisci	Caricetum paniculatae Caricetum elatae
floating rafts		Scirpetum lacustris Cicuto-Caricetum pseudocyperi	Cicuto-Calletum
submerged and floating-leaved plants	Najadetum marinae Nitellopsidetum obtusae	Myriophyllo-Nupharetum Utricularietum vulgaris Charetum vulgaris	Potametum lucentis Stratiotetum Myriophyllo verticillati-Hottonietum
Succession Initial water quality	Bulrush sere *oligohaline*	Reed sere *fresh-eutrophic*	Quagfen sere *fresh-mesotrophic*

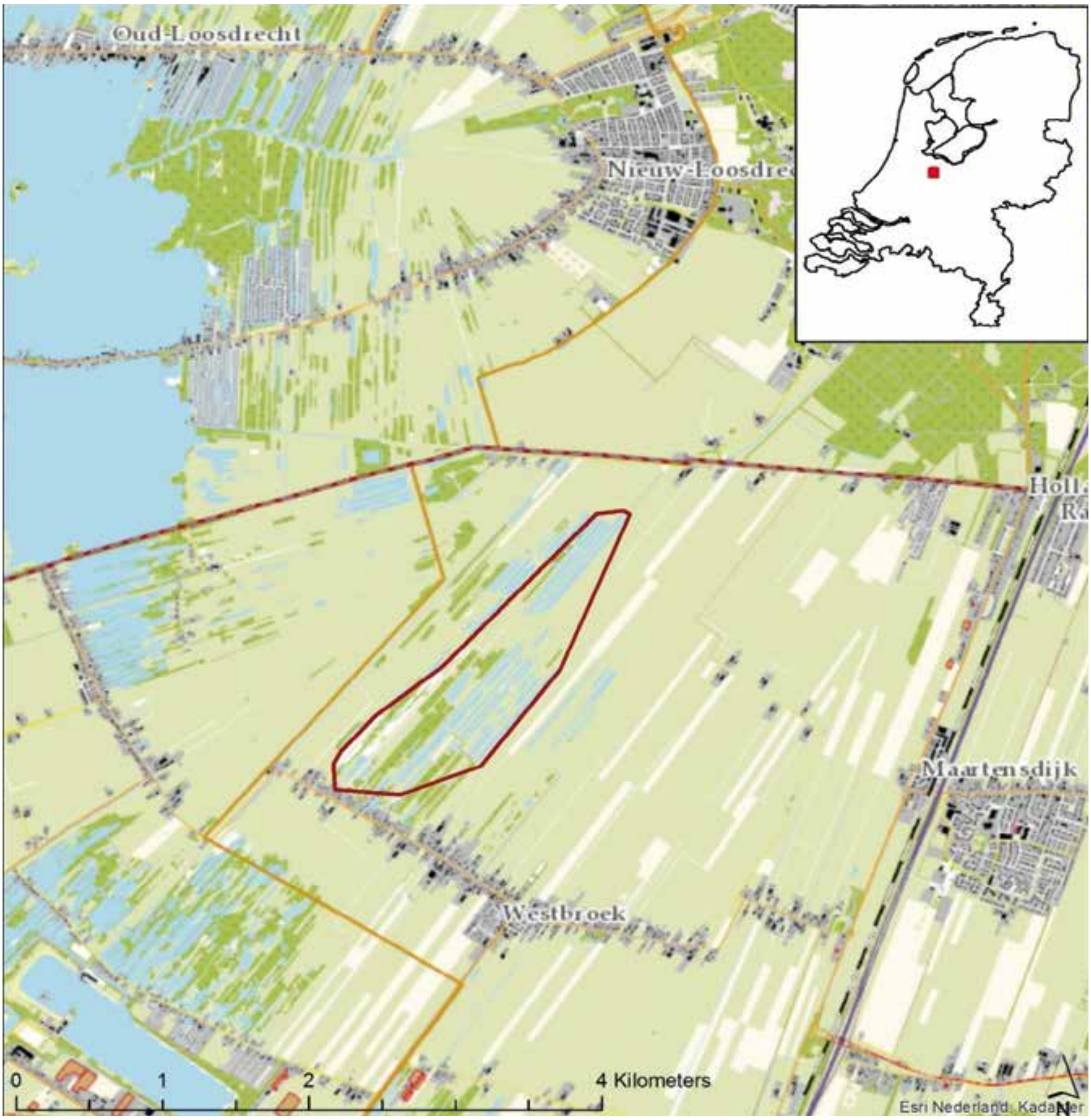

Fig. 2. Location of the polder Westbroek/Tienhoven.

The Polder Westbroek/Tienhoven

The polder Westbroek/Tienhoven is located 10 km North of Utrecht. Originally this area has been a peat bog, which was drained and converted to agriculture in the 15th-16th century. The area has several complexes of turf ponds, which have terrestrialized in the past 100 years. A number of late-succession ponds covered with Alder forest have been re-excavated in the 1990s and some extra turf ponds have been created at the time. This excursion takes us on a 5-km walk across the Bert Bos-path and shows the various succession stages and the current status of the ponds that had been restored/created 25 years ago.

The eastern Vechtplassen area is situated north of the city of Utrecht and contains many turbaries in the polder Westbroek/Tienhoven (Figure 2). This is an example of at least 6 major complexes of long, rectilinear ponds located in a zone between the upper sandy areas and the low coastal plain in The Netherlands (Beltman *et al.* 2011a).

The ponds have been created by peat dredging in the 18th-19th centuries, and have filled up again with vegetation and peat since then. They occur in a peat-meadow landscape that had been reclaimed in the 14th-16th centuries (Borger 1992). The turf ponds are still embedded in a landscape of peat meadows used for cattle grazing. The vegetation in such turf pond complexes is quite varied and species-rich. The species-rich plant communities in the terrestrializing fens in turf ponds are undergoing succession and can be attributed to the Phragmites and the brownmoss succession series, which are typically associated with mesotrophic and slightly eutrophic conditions (Van

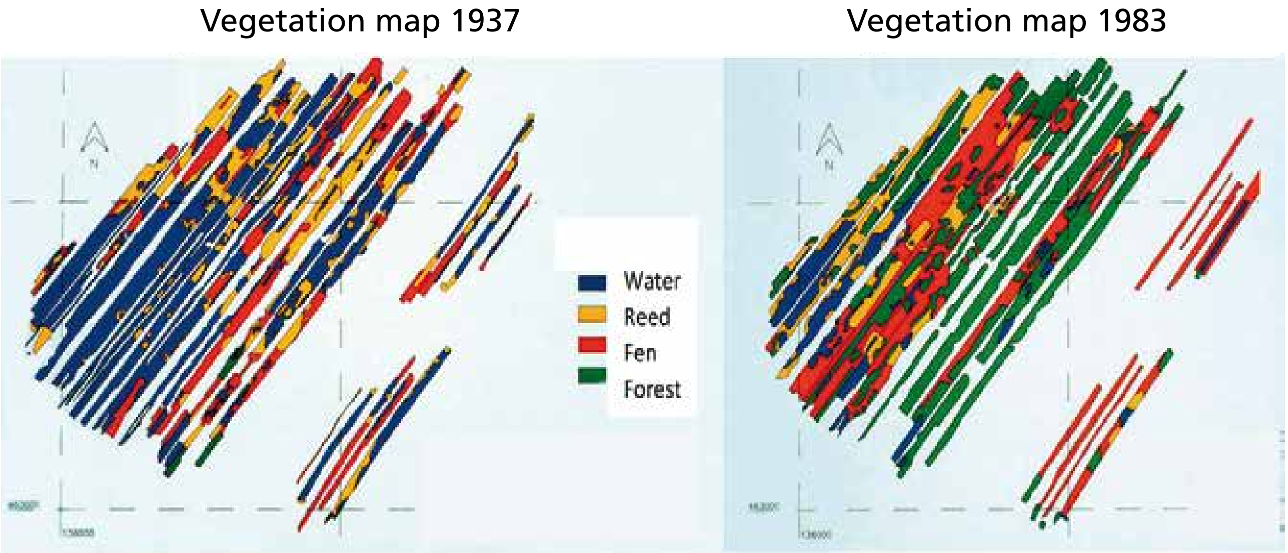

Fig. 3. Vegetation structure in the turf ponds of Westbroek in 1937 and 1983, based on digitized aerial photographs (Bakker et al. 1994). Water: open water with submerged vegetation; Reed: helophyte-dominated vegetation; Fen: brown moss; Forest: carr.

Wirdum *et al.* 1992, Verhoeven & Bobbink 2001).

These conditions were quite common in The Netherlands until the 1950s and occurred in groundwater discharge areas and floodplain areas of streams and small rivers. Complexes of turf ponds with these terrestrializing fen systems can be found in The Netherlands where the Holocenic low fen areas border the higher sandy areas of Pleistocenic origin, e.g. Rottige Meente, De Wieden, De Weerribben and the Vechtplassen area.

In a study of historic aerial photographs of the 52-ha study area in the eastern Vechtplassen area spanning a 50-year time period (1937-1987), four successional stages were identified, i.e. open water, tall reed, short fen meadow and carr forest (Bakker *et al.* 1994). Many ponds in the Westbroek/Tienhoven polder were still open water in 1937, but terrestrialized rather readily in a period of 20-40 years, with the share of open water decreasing and that of carr forest strongly increasing over time. By the end of the 1980s, the area had lost most of its early-succession stages, while some mid-succession species-rich fens were maintained by a mowing regime (Figure 3). These systems did, however, show signs of acidification, which is an indication of moving forward in succession to transitional fen. This process was probably enhanced because of atmospheric deposition of NH_y and NO_x (Paulissen *et al.* 2014), but particularly by surface water pollution and eutrophication with P, which led to increased growth of fast-growing *Sphagnum* species such as *S. squarrosum* and acidification of its surroundings (Kooijman and Paulissen 2006). At the end of the 1990s, brownmoss fens had become overgrown by *Sphagnum* within a few years' time. Also, the characteristic brownmoss *Scorpidium scorpioides*, which was probably very common in the 16th century but had already become rare in the 1980s (Faber *et al.* 2017), has now disappeared altogether. The State Forest Service, who owned and managed this fen area, decided to re-excavate a number of ponds to restore the early-succession vegetation types, so that the complete successional series would be safeguarded on the long term (Beltman *et al.* 1996). In the course of 30 years (1985-2015), at least 45 ponds were restored or created, strongly increasing the share of open-water ponds in the area. Initial monitoring activities indicated that recolonization of the ponds was slow and differed quite substantially between different ponds, which was hypothetically attributed to dispersal issues, to changes in the water chemistry and to herbivory by invasive musk rats (Beltman *et al.* 2011b, Sarneel *et al.* 2011).

Water flow and water chemistry

The Westbroek polder is a flat area with drained fenlands, situated close to a hill ridge of sandy moraines. The drainage occurs through parallel ditches about 50 m apart, which date back from the era of peatland reclamation in the 14th-15th centuries (Borger 1992). The general direction of surface water flow, fed by rain water and groundwater discharge, is towards the south-west. Groundwater discharge from the sandy ridge toward the polder used to result in a water chemistry in the drainage ditches and the turf ponds which was favourable for the mesotrophic plant communities mentioned. The water discharging in the polder Westbroek from this aquifer is relatively low in

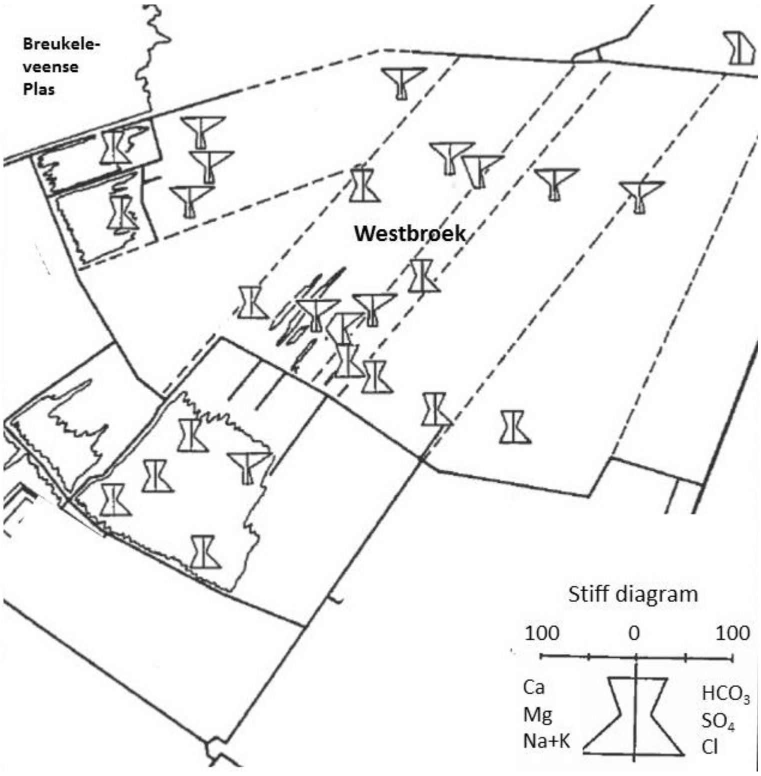

Figure 4. Water chemistry in the Westbroek polde ditches in summer 1983. The Stiff diagrams give the proportional concentrations as % of total electrical postive and negative charge. Water types dominated by Na, K and Cl occur in the southern part of the polder, while in the northern part the water is relatively rich in Ca and HCO_3.

nutrients, chloride and sulphate, but rich in calcium and bicarbonate ions.

However, these mesotrophic to moderately eutrophic systems became disturbed by polluted surface water since the 1960s. As groundwater resources in the hill ridge were increasingly used for drinking water abstraction, the amount of groundwater discharged in the polder decreased and more surface water supply was needed to keep water levels sufficiently high during dry periods in summer. This surface water originated from the Vecht river and, ultimately, from the Rhine and was polluted with nitrogen and phosphorus. It also had high concentrations of potassium, chloride and sulphate (Beltman *et al.* 1988, Beltman & Verhoeven 1988, Beltman & Rouwenhorst 1991).

As a result of the surface water supply, the water chemistry in the polder Westbroek/Tienhoven changed considerably in a non-favorable direction, as can be seen in the composition of the supply water in the 1980s. As the direction of surface water flow during such dry periods was reversed, i.e. towards the north-east, ditches in the southern parts of both polders showed a strongly modified water chemistry with high sodium, potassium and chloride and low calcium and bicarbonate (Figure 4, Beltman & Rouwenhorst, 1991) As a consequence, signs of deterioration of the quality of the submerged vegetation in ditches were observed in the early 1980s and there was increasing concern that the species-rich turf ponds would become negatively affected as well.

The observed effects of the polluted river water in dry summer periods led to a decision by the water board to change the surface water source to feed the polder Westbroek/Tienhoven in the early 1990s; the new source was the Breukeleveense Plas, a shallow lake just 1 km west of the polder (Figure 4).

This lake has a good water quality which is chemically rather similar to the groundwater in the aquifer. The regional water regime controlled by pumping stations and weirs was modified in such a way that the water from the Breukeleveense Plas was directed towards Westbroek in dry summer periods. This has improved the situation in the polder to the point that no signs of negative impacts on the submerged vegetation in the ditches are visible any longer.

This major change in the water management of the polder has prevented the precious plant communities in the turf ponds to be affected by the polluted river water. The water chemistry in the turf ponds remained favorable even in the 1980s, when the polluted water was penetrating the ditch system in dry summers. The slow flow rates in the exchange between turf ponds and ditches, as well as the timely measure of changing the surface water source to the polder have played a positive role. The current water chemistry of the Westbroek turf ponds is characterized by low ammonium, phosphate and sulphate concentrations, which is favorable for the development of initial, submerged stages of the brown moss succession series (Geurts *et al.* 2008), although this has not yet happened.

Restoration: digging of existing and new ponds

As indicated above, the terrestrialization process associated with the succession from open-water plant communities to floating fens and finally Alder and Willow forest, had resulted in a situation in which the species-rich phases became under threat by progressive acidification and forest expansion (Figure 5).

Helped by the National Nature Policy Plan (1990), the major nature conservation agencies in Westbroek/Tienhoven, Staatsbosbeheer (SBB) and Natuurmonumenten (NM), started to make plans for:

(1) Enhancing the management of high-quality species-rich floating fens by consistent annual mowing in the summer and by removing young trees and tree seedlings;
(2) Removing the top soil in pastures and abandoned agricultural fields to restore species-rich wet grassland vegetation;
(3) Excavating part of the turf ponds that had terrestrialized into late-succession Alder forests, while another part remained untouched to protect the final successional stages as well.

These long-term restoration activities were planned and overseen by a team of experts from the Nature conservation agencies (SBB and NM), scientists (in particular Boudewijn Beltman from Utrecht University) and land management contractors. This team has worked from 1990 until 2010 and the resulting landscape now shows a drastic increase of the number of open-water turf ponds, while all other stages of the succession are also well-represented. During the 20 years of carrying out this work, a lot of experience had to be built up regarding the technical aspects of the excavations with modern, heavy equipment, instead of the hand labor in former centuries, in a peaty environment.

Figure 6 shows a schematic overview of the restoration actions that were designed in the 1990s; this figure worked as an initial framework for the activities. Along the way, variations of the exact width, bank shape (90° with ground level or less steep) and depth (standard 1 m) were tried out, resulting in a number of ponds with different specifications, in particular in the area with 'new' ponds in the northern section of the ponds shown in Figure 5.

As will be shown during the excursion, these restoration activities have resulted in a very promising vegetation development, with difference in plant community structure and speed of succession in ponds with different morphometry.

These developments are being monitored and will add to the knowledge base for maintaining the actions needed for conservation of the complete succession of these terrestrializing fen communities. Some illustrative examples:

- Species-rich floating mats *(Carex rostrata, Potentilla palustris, Calla palustris)* have established in small patches locally and slowly expand from the banks
- Some ponds are fully overgrown with emergents *(Typha latifolia, T. angustifolia)* after 25 years, while others (mostly deep and with steep banks) have not shown much vegetation development yet.

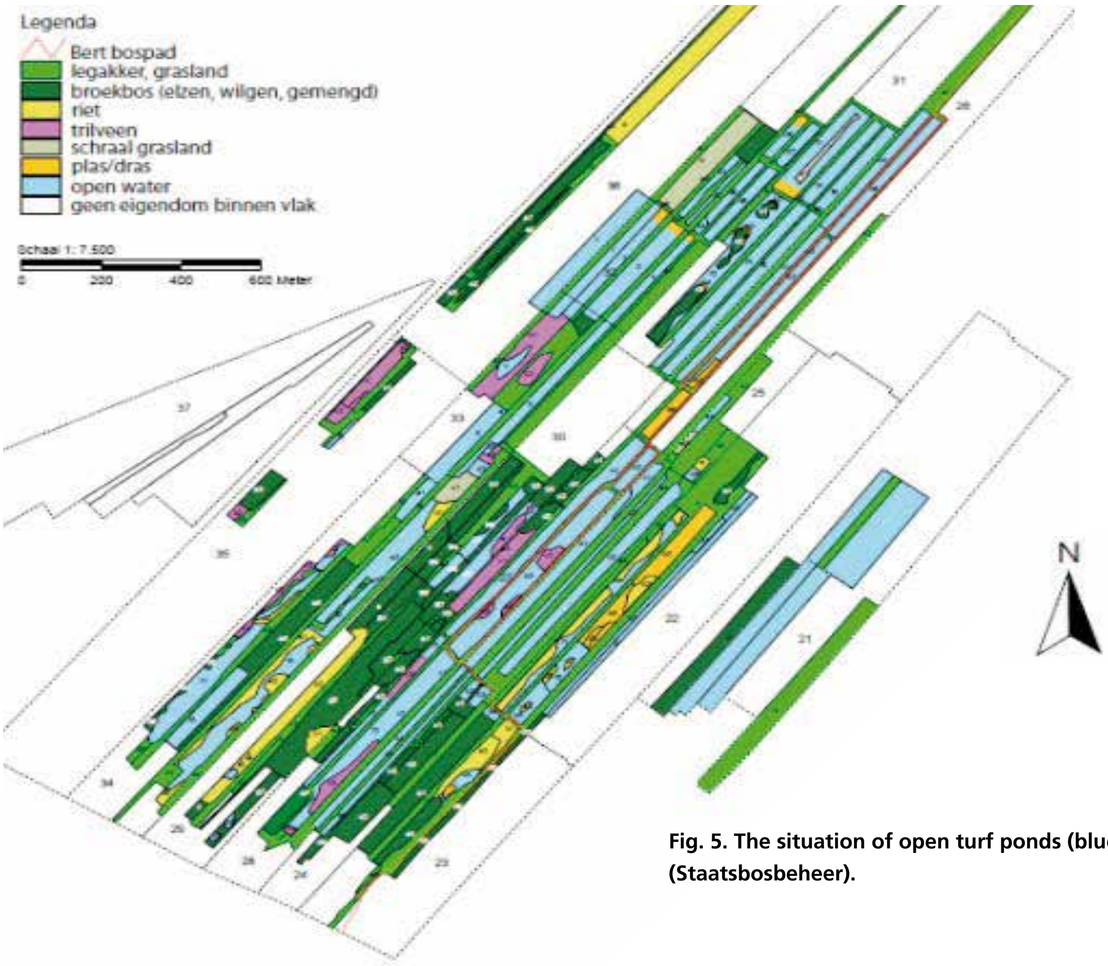

Fig. 5. The situation of open turf ponds (blue) in 2005. (Staatsbosbeheer).

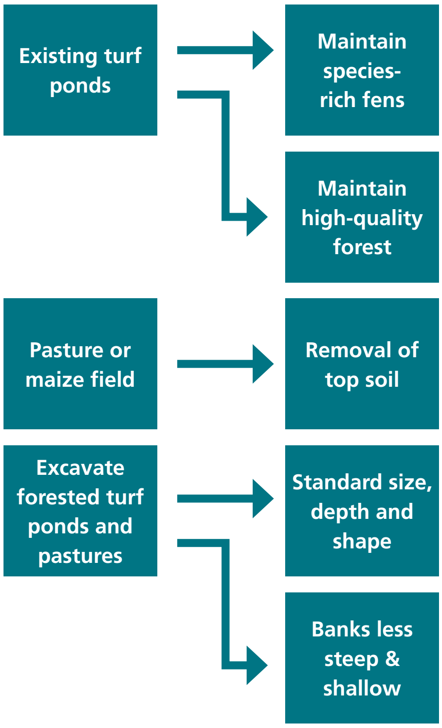

Figure 6. Schematic overview of activities in the restoration of turf-pond vegetation in Westbroek/Tienhoven (Beltman 2016).

- The restoration works have not resulted in adverse eutrophication and water quality has only improved.
- Mat formation is locally hampered by grazing by non-native species (Muskrat, Red American crayfish).
- Generally, invertebrate communities and birds have improved strongly in the past 20 years.

Plant dispersal

At The large number of plant species associated with the succession from open water to carr forest and the rapid turnover of these species during succession imply that dispersal to new or restored ponds is essential. In natural landscapes with oxbow lakes such dispersal would have been facilitated by the proximity of existing populations serving as propagule sources and by the ample availability of dispersal vectors water, wind and waterfowl. In the turf ponds, past dispersal capacities likely consisted also of dispersal by these same vectors, while the direct connections via surface water to nearby propagule sources compensated for the lack of flowing (river) water. In the current situation, where early-successional stages in the landscape are sparse and far apart, dispersal limitation has become an issue likely to limit the re-colonization of newly created ponds. Ponds that had terrestrialized before and are being re-excavated will have a better chance than newly created ponds to already contain diaspores left over in the seed bank of the shore or the pond bottom (Bekker *et al.* 1998, Klimkowska *et al.* 2010). However, due to excavation activities a large part of the existing seed bank is removed and colonization by dispersal in space also becomes important. Arrival of propagules to new habitats is often a time-consuming process, with species that possess traits enhancing long-distance dispersal arriving sooner and in greater numbers (Brederveld *et al.* 2011, Fraaije *et al.* 2015). However, also the distance between habitats and their connectivity plays an important role: nearby source populations facilitate colonization. In the successional series relevant here, three main dispersal mechanisms determine the dispersal of plant species and the connectivity between habitat areas: dispersal by water, wind, and waterfowl.

For species characteristic of aquatic and shoreline vegetation, and for the early-succession, aquatic phases of the series, species dispersal by water is particularly important. Water is widely available as a dispersal vector, and, perhaps even more importantly, is likely to connect wet, suitable sites. Seeds of early-succession species may float for months, particularly in stagnant or slow-flowing water (Van den Broek *et al.* 2005). Vegetative fragments may float for much shorter periods of time, but may be highly effective in colonizing new areas (Boedeltje *et al.* 2003, Boedeltje *et al.* 2004, Boedeltje *et al.* 2008). A disadvantage of the turbary system in regard to water dispersal is that the water in the system hardly flows – the system resembles a set of interconnected lakes rather than a stream. Hence, dispersal by water is very slow and directed by wind, pushing the floating seeds downwind, particular in ditches and linear ponds (Soomers *et al.* 2013, Sarneel *et al.* 2014). It has been shown that the orientation of the fen pond complexes towards the prevailing wind direction may affect dispersal distances to a considerable degree (Soomers *et al.*, 2013). The fens in our study area are orientated in a NE→SW direction, so that wind- enhanced hydrochorous dispersal is expected to be quite effective considering the prevailing south-westerly winds. Eventually, water-dispersed seeds in such systems are likely to be deposited at (north-eastern) shorelines at times of receding water levels in spring, followed by a rapid germination and locally high seedling densities (Sarneel & Soons 2012, Van Leeuwen *et al.* 2014). Another limiting factor to seed dispersal by water is that it only reaches sites

Figure 7. Experiment with floating platforms to speed up the terrestialization process from aquatic vegetation to floating rich fens (Loeb et al. 2016; in Dutch).

that are connected via surface water so that dispersal between different catchments or hydrological units is not possible. The scale at which dispersal by water takes place is therefore highly site-specific, and dependent on the hydrological connections by surface water and the flow velocity and direction of the system.

Dispersal by wind is a common phenomenon in particular for later successional species. Increasingly terrestrial stages have increasingly higher proportions of species with traits facilitating long-distance dispersal by wind (Soons 2006). The advantage of this mechanism is that wet, unsuitable patches can be bridged and suitable sites across the water can be connected. In addition, this dispersal mechanism is not limited to catchment boundaries or hydrological units. A disadvantage is that this process is not limited to wetlands but rather distributes seed across the landscape, so that dispersal is not directed towards suitable sites (Soons 2006). The scale at which dispersal by wind takes place is much less site-specific than for water dispersal, and much more dependent on the traits of the species dispersing: plant species that release their seeds from a great height and produce very light seeds (with a low terminal velocity) may disperse their seeds over hundreds to thousands of meters (Soons *et al.* 2004a, Soons *et al.* 2004b, Soons *et al.* 2005). Typical emergent species such as *Phragmites* and *Typha*, but also carr forest trees *(Alnus, Betula, Salix)* disperse very well by wind.

Other problems with terrestrialization

In In the past few years, it became clear that succession in the new ponds was not very successful yet, despite improvement of surface water quality. This may have been due to dispersal problems (see above), or lack of time, as it takes about 50-60 years for new rich-fens to develop (Bakker *et al.* 1994; Faber *et al.* 2017). We tried to speed up this process with the use of floating platforms (Loeb *et al.* 2016; in Dutch), but this did not really help (Figure 7). When protected from grazing, aboveground plant biomass could become extremely high, and in the best case still mainly consisted of eutrophic plant species. When the floating platforms were not protected, the vegetation was eaten by Grey goose *(Anser anser)* or American crawfish *(Procambarus clarkii).* Especially the latter species is becoming a real problem, and will be the focus of a new OBN-project starting this year.

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Peat meadows in The Netherlands; a millennium of soil subsidence

Jos Verhoeven, Ab Grootjans

Intensively drained agricultural polder areas

Peat meadows are drained peatlands that are in use for agriculture. Peat meadow areas in the Netherlands have mostly originated from drainage and reclamation of extensive bogs and fens in the coastal plain that used to be the most important land cover until 1000 AD (Figure 1). Most of these reclamations started in the 12th – 15th century and have brought farmers centuries of relatively high crop production and grazing, particularly in the initial phases. These 'polders' (diked areas with a manipulated water level) have been in agricultural use for centuries. Right from the start, these areas have been subject to peat shrinkage and soil subsidence, which has created the typical polder landscape with water levels in ditches that are higher than the land (Figure 2).

The rate of subsidence has risen strongly in the past 50 years as a result of deeper drainage and intensive agricultural use and has increasingly been accompanied by deterioration of water quality. There is concern that

Figure 1. Wetlands in The Netherlands in the year 100 AD (after Zagwijn 1975).

Figure 2. Typically Dutch peat polder landscape with the water higher than the land. Photo: Hans Joosten.

climate change will further aggravate the problems in these areas and necessitates adaptations of land use and water management.

Between There are two regions with substantial areas of peat meadows in the Netherlands, i.e. the western peat meadow area and the northern peat meadow area (Figure 3), which also shows the current area of peat soils, covering less than 20% of the original peatland extent).

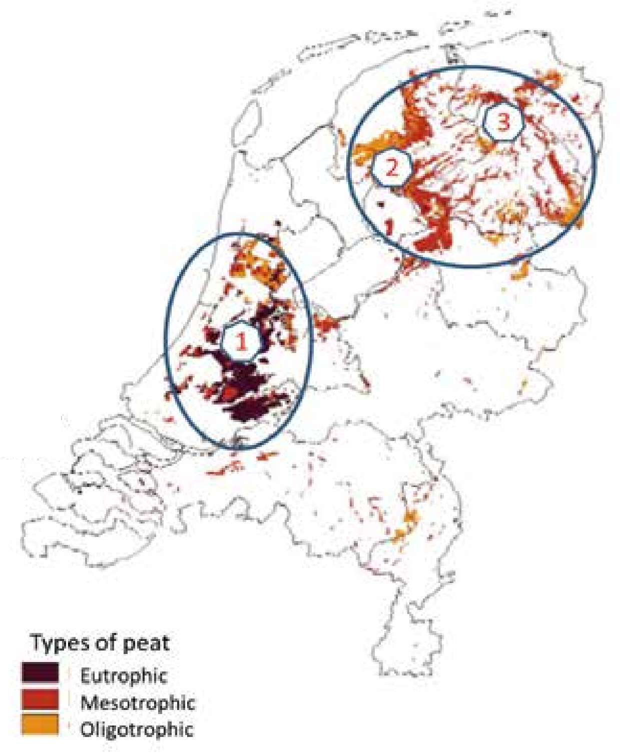


Figure 3. Peat soil is The Netherlands; western area (left), northern area (right) (Rienks & Gerritsen 2005). 1= Zegveld, 2= Tjeukemeer, 3= Bovensmilde.

The western area encompasses parts of the provinces of Noord- and Zuid-Holland and Utrecht, whereas the northern part is located in the provinces of Friesland, Overijssel and Drenthe. The largest area in the western region is characterized by its location within a ring of urbanized and densely populated areas (the 'Randstad') and is often called the 'Green Heart'. The peat meadow areas are in use for intensive dairy production, but at the same time are visited by large numbers of people from the surrounding cities for recreation and leisure. In the western peat meadow region, current water tables are mostly around 60 cm below ground level, whereas in the northern peat meadows (Friesland) water tables are often kept down to 100-120 cm below ground level (see Figure 4). This reflects a greater emphasis on agricultural targets and smaller interest of nature conservation values in the latter region. As a result of the actions of private land owners (farmers), the lowest parcels in the landscape are the ones with the most intensive agricultural use.

The water management in the peat meadow areas is complex and primarily geared towards the current agricultural use. To maximize agricultural production, water tables are kept low (0.6 – 1 m below ground level) by collecting drainage water in ditches and reservoirs eventually pumping it out of the polders. Current agricultural practice requires relatively dry field conditions in early spring to enable access by heavy machinery and pasturing of dairy cattle. Land use planning programs in the 1960s-1990s have aimed at

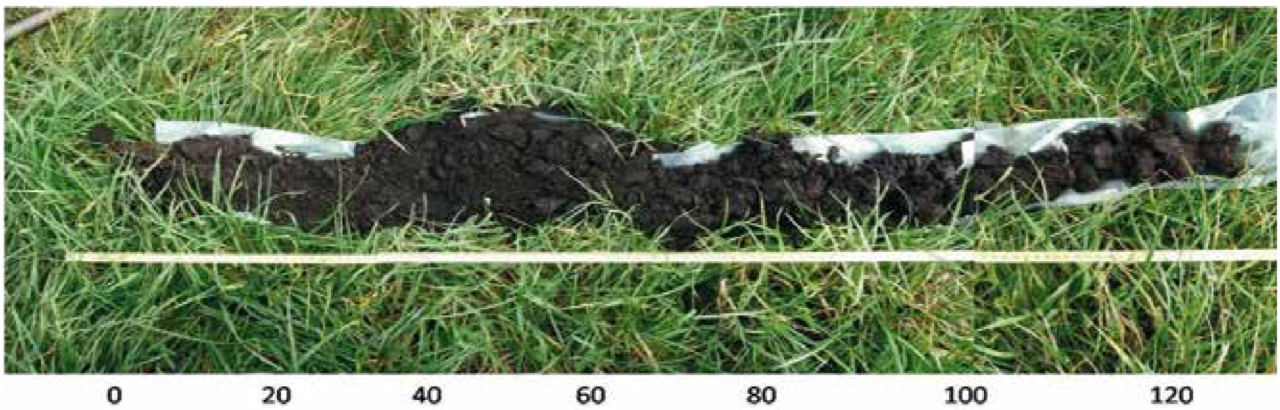


Figure 4. Typical soil profile of a peat meadow in the Province of Friesland. The top 80 cm are well drained and show amorphic, very decomposed peat, while the layers deeper than 90 cm are clearly much less decomposed and show well structures plant remains.

maximizing agricultural production by re-allotments and by deeper and more effective drainage.

As a result of the oxidation of peat after exposure to oxygen has been accelerated substantially in this period. Soil subsidence in organic soils is not restricted to The Netherland, but it is a world-wide problem. Soil subsidence may amount to 2 cm annually (in tropical areas) and generates enormous greenhouse gas (GHG) emissions (20-40 t CO_2 per ha and year annually) and eventually often loss of productive land (Joosten 2015). Subsidence and erosion of the peat soil provoke insufficient drainage, ponding water following soil compaction and drought prone top soils due to the hydrophobic nature of degraded peat (Zeitz & Velty 2002; Wallor & Zeitz 2016; Joosten *et al.* 2017). These adverse soil conditions raise costs of water management including a higher water demand for irrigation (Regional Water Authority Hunze en Aa's 2018).

In The Netherlands the height of the water table in polders is fixed by the water authorities based on the requirements of agriculture, nature conservation or housing. Individual landowners often install small-scale pumps for additional water level control. This implies that there are various water level sections ('peilvakken') within one polder. Decisions on the height of the water tables are made every 10-15 years, to adapt to subsidence of the ground level and to new insights in optimal land use. The height of the water table in polders is fixed by the water authorities based on the requirements of agriculture, nature conservation or housing. Individual landowners often install small-scale pumps for additional water level control. Decisions on the height of the water tables are made every 10-15 years, to adapt to the progressing subsidence of the ground level and to new insights in optimal land use.

Peat losses are accelerated by ploughing and by addition of lime and fertilizers (which increase peat oxidation) and by wind and water erosion (by which bare peat is blown or washed away). The resulting lowering of the surface necessitates – in case of continued conventional exploitation – a continuous deepening of the drainage ditches. This again enhances peat oxidation, surface lowering, ditch deepening, etc. in what is known as 'the vicious circle of peatland utilization'. The continuously lowering surface makes gravity drainage increasingly difficult and necessitates more and more complex and expensive hydrological management to keep the areas drained and conventional agriculture possible. In coastal peatlands subsidence increases the risk of floods and salt water intrusion, which is especially relevant in the light of climate change induced sea-level rise (Joosten *et al.* 2015; Hooijer *et al.* 2012).

The maintenance of fixed water tables all year round leads to an output of surface water through pumping in winter and in wet periods in summer, as well as an input of surface water from the rivers (Rhine, IJssel) during dry summer periods. The river water flows into the polders through inlets in the reservoirs ('boezems'). As a result of climate change, the occurrence of more severe droughts in summer is expected to become more frequent, leading to an increase in the demand for fresh water from outside. Apart from soil subsidence and water quality deterioration, the availability of fresh water in dry summers is another point of great concern in discussions on the future management of these areas.

Challenges for the future after one millennium of soil subsidence

In the year 1000 AD, the average level of fens and bogs in the western coastal plain was still more than 2.5 m above mean sea level (see Figure 5). During the centuries thereafter, initial drainage and reclamation operations led to the first areas of any importance on drained peat where agricultural crops were grown. The drained soils started to subside, so that the agriculture started to become hampered by very wet soils again. The invention of the wind mill in the 15th century led to new opportunities to drain more effectively, so that water levels went further down with the subsiding land. The reclamation became quite widespread since 1550,

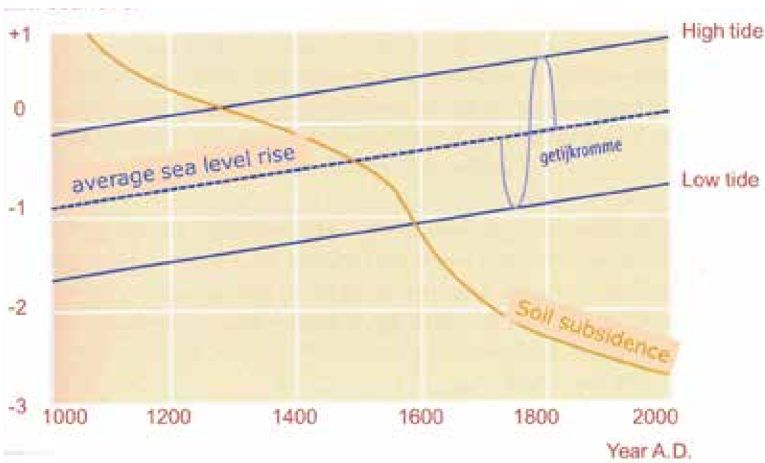


Figure 5. 1000 years of sea level rise and soil subsidence in the Western Netherlands.

so that subsidence rates increased, which, together with sea level rise, led to a situation where current peat soil levels are lower than 2.5 m below sea level. The expectations are that climate change will aggravate the situation because it will lead to faster sea level rise but also faster rates of subsidence.

Greenhouse gas emissions

The The peat meadow region is a major source of greenhouse gases (GHG). Emissions of CO_2 amount to 2.26 tons per ha for each cm of soil subsidence, so that they are directly proportional to the depth of the water table below soil surface. In areas which are intensively used for dairy production there is an additional emission of N_2O, whereas wet fen and marsh areas are subject to CH_4 (methane) emissions. A recent compilation of emission studies at different scales in the peat meadows of The Netherlands in the framework of the research program 'Climate Changes Spatial Planning' has demonstrated that rewetting of previously drained peat meadows has a strongly reducing effect on the GHG emissions, with reductions in CO_2 by far outweighing increases in CH_4 emission (Schier-Uijl 2010).

Figure 6 shows that total GHG emissions expressed as CO_2 equivalents were lowest in the rewetted polder Horstermeer, mostly because restored peat formation fixed carbon rather than releasing it as in the two polders where drainage had continued. Stopping fertilizer use did reduce the N_2O emissions (polder Stein in comparison with polder Oukoop), but that only marginally affected the GHG balance.

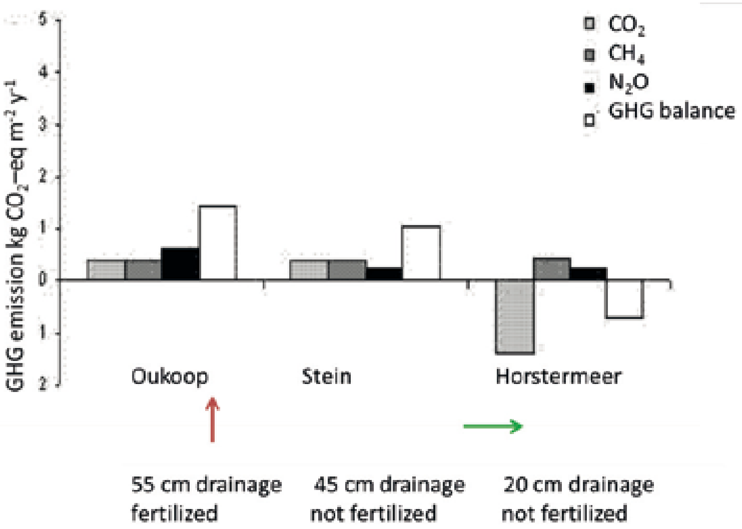


Figure 6. Greenhouse Gas (GHG) emissions in three peat meadow polders with different land use and water table management (Schier-Uijl 2010).

Effects on agriculture and urban areas

The peat meadow regions are primarily in agricultural use. The dominant land use type is dairy production with less than 5% maize fields. In the western peat meadows (provinces of Noord- and Zuid-Holland and Utrecht) the farmer incomes are at or just below the national average owing to the optimal spatial allotment. There are opportunities for broadening the sources of income by providing facilities for recreation, health care and nature conservation. In the northern peat meadows (provinces of Friesland and Drenthe), the dairy farmers are among the strongest in The Netherlands and will see agriculture as their main economic function in the future. It is to be expected that the tendency towards larger farms will be continued. The requirements for fresh water will become imminent at times that the availability of high-quality fresh water is limiting at the national level. The accelerated soil subsidence will lead to increased differences in elevations within polders, which will create major problems for dike maintenance. It will also generate enormous cost for upgrading the infrastructure in urban areas, such as for instance in the city of Gouda, situated in the 'Green Heart' of Holland. This city is well known for its cheese. But one could say that the success of Gouda cheese has left present and future generations with enormous unpaid bills.

Effects on nature

There are two types of nature reserves in the peat meadow area, both of which are strongly controlled by human management; (i) the peat meadows characteristic bird fauna, and (ii) peat-forming fen ecosystems (Verhoeven *et al.* 2010). Peat meadow nature reserves are characterized by species-rich grassland communities and dense meadow bird populations. These meadows have high water tables and low fertilizer additions and are not in commercial agricultural use (Van de Riet *et al.* 2010). Large fractions of the European Godwit and Lapwing populations are breeding in these meadows, which has created a special responsibility according to EU legislation. Shallow ponds and lakes are inhabited by a range of plant communities characterizing the succession from open water to marsh habitat to fen or carr vegetation.

In the western peat meadows, the national government has allocated 12,000 ha of (semi-)natural areas to the Ecological Main Structure (EHS). Both types of nature reserves described above are part of EHS. For thousands of hectares, this objective still

Figure 7. Three different scenarios for future water management of the Dutch peat polders. Left business as usual, mid: slow-down soil subsidence, and right stop soil subsidence by rigorous rewetting (https://www.provincie-utrecht.nl/onderwerpen/alle-onderwerpen/bodemdaling/).

has to be realized by buying land and modifying the land and water management. In the northern peat meadow areas, the nature areas have been identified and separated from the farming areas at a higher scale, resulting in large areas of either complete agricultural use or complete nature protection. In the western areas, there are more transitions between the two.

Water quality issues are related to eutrophication and to the leaching of sulfate from the peat meadows. These sulfates are formed by oxidation of pyrite, which is quite common in most peat soils on the coastal plain. High sulfate concentrations lead to mobilization of phosphates from lake and ditch sediments and lead to loss of mesotrophic plant communities (Lamers *et al.* 1998, Smolders *et al.* 2006, 2010, Lamers *et al.* 2015, Geurts *et al.*2008).

Policies and adaptation strategies

Water The national Dutch planning policy for peat meadow areas is reflected in the policy documents 'Nota Ruimte' (VROM, 2004) and the 'Programma voor de westelijke veenweidegebieden' (VROM, 2009). The Nota Ruimte calls for conservation of the peat soil and the peat meadow landscape. Vulnerability for soil subsidence is given as the main criterium for regional development. Grassland-based dairy production is an important economic function which is required to conserve the typical peat meadow landscape. However, farmers must respect the ecological and cultural-historic value of this region. Areas with rapid soil subsidence or saltwater intrusion require a new water management with higher water tables and responsible authorities should consider these options. The Agenda for the western peat meadow areas proposed to make water management schemes leading for land use decisions ('function follows water table'), implying that land uses have to be adapted to the water tables arising from a water management scheme that is most sustainable. This is in contrast to current practice, where water management is always adapted to the needs of farmers, nature conservation and settlements. This new policy is still in the discussion and planning phase; it is definitely controversial in some parts of the region. As indicated earlier, the problems identified for these regions (soil subsidence, but also drought, flooding, eutrophication and salinization) are not caused by climate change but they are certainly accelerated and aggravated by it.

In the Netherlands intensive discussions are taking place about the future of the peatland landscape, see graphics below. Currently large peatland areas are subject to drainage-induced subsidence ('bodemdaling') leading to ever increasing height differences between deeply drained and pumped, intensively used agricultural lands on the one hand (left picture foreground) and low intensity agriculture, settlement and nature conservation sites with much higher water levels on the other hand (left background).

It is clear that continued pumping and subsidence ('loslaten', left picture) is impossible, but what are the alternatives: continuing conventional land use but raise the water levels somewhat to slow down subsidence ('remmen', central picture), or stopping subsidence completely by raising the water level to at or over the surface and changing land use towards wet livelihoods, including paludicultures, floating solar energy, and wet tourism (right picture).

In the past decade, studies have been carried out to identify the problems in the peat meadow areas when current land use and water management will continue in a context of climate change (Woestenburg 2009, Schier-Uijl *et al.* 2014). At the same time, measures have been designed to improve the situation, which could decrease the rate of soil subsidence and enhance water quality without harming the most important economic functions in the area, i.e. agriculture and recreation, mostly 'ecotourism' linked to nature values.

These measures can be subdivided into two major categories, i.e. (1) measures affecting the *water system*, mostly by modifications of physical water control structures and of the water regime and (2) measures affecting *land use and economic functions.* Some major examples of such measures are:

(1) Water system

a. Flexible water level regime; increasing water levels in ditches; larger units with equal water levels; larger shallow ponds and lakes. These measures can prevent extremely low water levels in dry summers and slow down subsidence.
b. Buffer zones bordering ditches and canals, wetlands for water quality improvement.
c. Drainage systems (tubing) below the water table ('under-water drainage'), which deliver water to the central parts of grassland parcels so that water levels do not become extremely low in summer. This is a measure with a claimed subsidence reduction of 30%, but this is based on limited data and is still disputed.

(2) Land use and economic functions

a. Robust and climate-proof crops; salt-tolerant crops; energy crops.
b. 'Green-blue services', i.e. farmers allow water to be stored in reservoirs to be used in dry period or to prevent flooding events in villages and cities.
c. Maintaining biodiversity in the landscape by funding farmers for measures stimulating meadow birds and botanical diversity.
d. Measures to stimulate recreational use (swimming, camping at the farm, hiking).
e. Building residential areas in a robust, 'water-proof' way.

In practice, Regional Adaptation Strategies will consist of packages of such adaptation and mitigation measures. Although most of the measures have been tested for efficacy and cost effectiveness, it is quite complicated to evaluate which combination of measures is optimal in a particular area.

Paludiculture; an example of harvesting wet crops while fighting soil subsidence

The concept of 'paludiculture', in which new (wet) crops are being cultivated in rigorously rewetted peat polders has been developed in Eastern Germany is well known in some parts of Germany (Wichtmann *et al.* 2016), but in the Netherlands it is still in a stage of early scientific experiments and small scale pilot studies (Geurts & Fritz 2018). Paludiculture is a form of productive land use that allows rewetted peatlands to produce food, fiber and energy. Typical crops grown in paludicultures ('paludicrops') are perennial crops that thrive on waterlogged or flooded soils, for example *Sphagnum* (peat moss), *Phragmites* (reed), *Typha* (cattail), *Salix* (willow) and *Zizania* (wild rice).

In 2015 the international, transdisciplinary research project CINDERELLA, was started to investigate the productive use of rewetted peatlands and the simultaneous restoration of ecosystem services, including reduction of greenhouse gas (GHG) emissions and land subsidence, water and nutrient retention, and water purification. The main objective was to extend the scientific base for a sustainable, productive land use of wet peatlands and making alternative uses accessible to farmers and land authorities.

We will report here some results from a pilot study in Zegveld, which we will visit.

Zegveld: experimental paludiculture plots with high and low water tables (2015-2018)

Renske Vroom, Jeroen Geurts (Radboud University Nijmegen)

In 2015 experimental paludiculture plots were established on the experimental farm of the Veenweide Innovatiecentrum (VIC) in Zegveld (Province of Utrecht). First 5-10 cm of the topsoil of the peat meadow were removed to build little dikes around two basins of 10x120m. Very young cattail plants *(Typha latifolia)* were planted by hand in 8 random plots of 48 m². In other plots, reed *(Phragmites australis)*, willow

Figure 8. Left: plots drying out in July 2015 (groundwater level > 30-40 cm below the surface). Right: stable high water level in July 2016 (20 cm above the surface). Pictures by Jeroen Geurts.

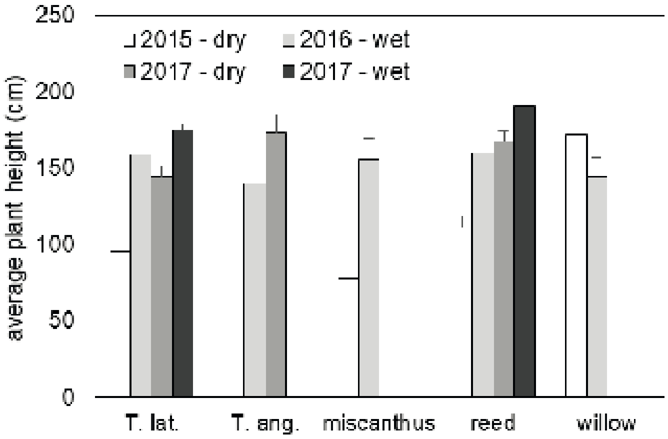
(Salix alba), and silvergras *(Miscanthus giganteus)* were planted. Water was supplied from the adjacent ditch by a pump. In the beginning plots were regularly drying out in summer to more than 40 cm below the surface (Figure 7). In August water levels fluctuated between 0 and +20 cm and from October onwards, water levels were definitely raised to 20 cm above the surface.

Because of the drying periods and subsequent weed development, only 20% of the *Typha* plants survived the first month of2015, whereas more than 75% of the *Phragmites* and *Salix* survived. Therefore, all experimental paludiculture plots, except for the high density plots, were reestablished in spring 2016 with new, more vital *Typha* plants and *Phragmites* rhizomes, and reused *Salix* and *Miscanthus* plants from the old experiment. Water levels in 2016 (first year of replanted plots) were maintained at +20 cm in all basins (Figure 8).

In October 2016 the water level in the northern basin was lowered to 20 cm below the surface ('drought treatment') and the connection pipe was closed. The reason for choosing lower water levels was the poor performance of *Salix* (little height increase and yellow leaves) and the very poor performance of *Miscanthus* at water levels of + 20 cm. In spring 2017, water levels regularly dropped to 30-40 cm below surface in the 'drought treatment' and therefore water was pumped in again in June to raise the water level above the surface for two weeks. After that, water levels were maintained at -20 cm again.

All species except for *Salix* grew better at higher water levels compared to the dry conditions in 2015, with average plant heights of about 160 cm in 2016 (Figure 9). Survival rates were also higher, especially for *Typha* and *Miscanthus*, although *Miscanthus* density still decreased and its biomass production was very low. Plant density of *T. angustifolia* increased to more than 50 plants/m^2, whereas *T. latifolia* even produced 80-100 new shoots per m^2. The number of *Phragmites* shoots increased more than 10 times in the first growing season.

Due to the higher water levels, weed development was much lower than in 2015: only 2% cover in the *Typha* and *Salix* plots, 4% in the *Miscanthus* plots, and 13% in de Phragmites plots. Instead of weeds,



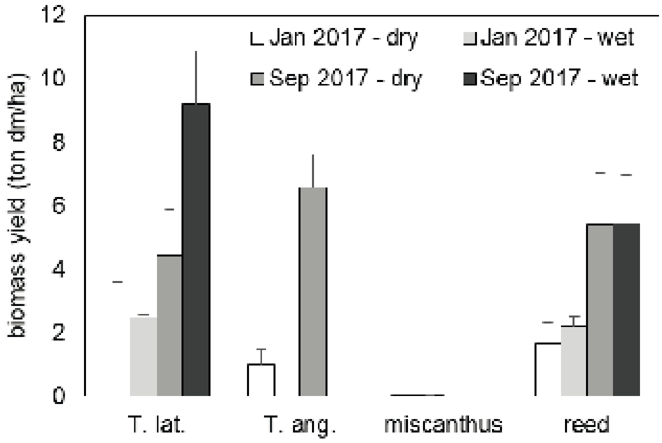


Figure 9. Left: Average plant heights1 in September 2015 (dry conditions), 2016 (water level +20 cm) and 2017 (water level +20 cm and -20 cm). Right: Dry biomass yield[2] in January and September 2017 (water level +20 cm and -20 cm). 1no data for Salix and Miscanthus in 2017; [2]no data for Miscanthus in September.

floating algae beds developed in the plots with low vegetation cover (*Miscanthus* and *Salix*). *T. latifolia* had the highest winter biomass in the first year (2.8 ton dm/ha), followed by *Phragmites* (1.9 ton dm/ha) and *T. angustifolia* (1.0 ton dm/ha; Figure 3). *Miscanthus* biomass was very low (45 kg dm/ha) and therefore not suitable to grow under permanent wet conditions.

For that reason only *Typha* and *Phragmites* plots were monitored in the growing season of 2017. *T. latifolia* biomass was two times higher at high water levels (9.2 ton dm/ha) than at low water levels (4.4 ton dm/ha). Moreover, plants were on average 30 cm taller and produced almost two times more flowers (19 vs 11 per m^2). *Phragmites* produced 5.5 ton dm/ha and did not differ between the dry and wet plots. However, plants were more than 20 cm taller under wet conditions, whereas plant density was almost 20% higher under dry conditions.

Our results showed that an early harvest in May is possible for *Typha*, after which an equivalent amount of biomass can be harvested at the end of the growing season. Multiple harvests are also possible, but the total cumulative biomass production of 10 ton dry matter per hectare was not dependent on the time of the first harvest (Figure 10). Biomass yield decreased 30-40% when plants were first harvested in October or January, due to senescence and physical damage after storms. The average number of shoots was 73 plants/m^2 in 2016 and did not increase in comparison with 2015. The average plant height was 180 cm, which is 50 cm higher than the year before.

However, the fodder value and nutrient composition was different at each harvest time, which is important for choosing the most suitable biomass application. Fodder value and nutrient content was highest in spring, with a raw protein content of 127 g/kg dm and a digestion coefficient (VCOS) of 63 % (Pijlman *et al.* subm.). At the end of the growing season a large part of the nutrients was stored in the rhizomes already and the aboveground biomass contained more fibers and less moisture (40-60%, depending on the weather). Therefore, biomass from a winter harvest is better suitable for e.g. isolation material or bedding.

Biomass production in the *Phragmites* plot was low (2.8 ton dm/ha) and did not differ between the harvested and unharvested side of the plot. However, plant density was higher on the harvested side (165 shoots/m^2) than on the unharvested side (148 shoots/m^2). The most likely reason for the low biomass production compared to the other *Phragmites* plots is that these plants were originally grown from seeds and not from rhizomes.

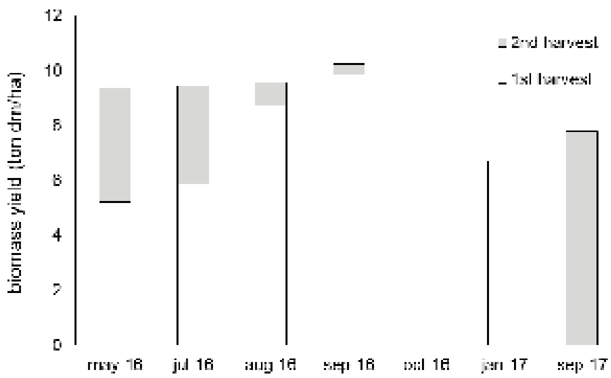


Figure 10. Biomass yield in case of multiple harvests of T. latifolia (dry weight). First harvest in the respective months. Second harvest in October of the same year. For September 2017, yield of the harvested side of the plot is shown.

Zegveld: establishment of 0.4 ha cattail *(Typha latifolia)* for fodder

Monique Bestman, Jeroen Pijlman (Louis Bolk Institute)Jeroen Geurts (Radboud University Nijmegen).

In July 2016, a 0.4 ha parcel (ca. 25x160 m) of cattail *(Typha latifolia)* was established in Zegveld. The purpose of this parcel is to grow enough biomass for feeding experiments with dairy cows, and to get more experience with weed control, fertilization, harvesting moment versus biomass production and nutritional values, and harvesting techniques on larger parcels. Young *Typha* plants were obtained from a professional grower. In July at planting, plants were 30-60 cm high. Right after removing the top soil layer, the surface was dry, which made it possible to use a small tractor for pulling an adapted vegetable planting machine followed by a light trailer (Figure 11). During the season a water level of on average 20 cm was realized using a solar-powered water pump (Solar Portmann) equipped with a water level sensor.

The plants grew well: in September (only 2 months after planting) 9-16 new shoots per m^2 were counted with plant heights up to 80 cm. At 8 and 30 November the amount of grown biomass at ±5-10 cm above water level was estimated at 371 kg ha-1 on both moments. The plants were not fertilized nor weed control was necessary; the water level and clean soil at establishment created good conditions against possible weeds.

At the 18^{th} of January 2017, during a period of frost, all *Typha* plants were mown at ±5-10 cm above water level with a brush cutter, while walking over the ice. The cut biomass was removed, but biomass yields were not determined. In May 2017, the field was fertilized with 150 kg N and 150 kg K in the form of coated urea and potassium nitrate, and in July and August the field was fertilized three times with each time 20 kg N in form of coated urea.

Figure 11. Planting the Typha plants and view on the parcel on the 2nd of September 2016 (Pictures: Monique Bestman).

In June 2017, the *Typha* plants flowered and their pollen were harvested by a company that grows predatory mites for application in greenhouses. After that, *Typha* was harvested twice (June and September) to make silage for feed experiments. At 23 June, the biomass yield was 6.81 ton dry matter ha^{-1}. At 19 September, biomass yield was only 1.94 ton dry matter ha^{-1} (Figure 12). Therefore the total yield in 2017 was 8.75 ton dry matter ha^{-1}. After the first harvest in June, it was observed that regrowth was mainly from new shoots.

Further information/further reading

Figure 12. Typha harvest using a two wheeled reaper-binder at the 19th of September 2017 (Picture: Monique Bestman).

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