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The first steps of paludiculture in Bûtefjild

A report on the development and growing conditions of cattail and peat moss at the pilot sites in Bûtefjild, Province of Fryslân, the Netherlands

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Table of Contents

Abstract

Sustainable approaches to land-use on degraded wetlands (paludiculture) could change the future of extensive agriculture in the Netherlands. In the area of Bûtefjild (Fryslân), experiments and monitoring were run on three such small-scale paludiculture pilots. The crops of research were *Typha spp*. and *Sphagnum spp*.

The *Typha* pilot (Field 1 & Field 2) aimed at the above ground biomass production of *Typha latifolia* and *Typha angustifolia*. In the *Sphagnum* pilot, growth of *Sphagnum spp*. was monitored. On a newly established site a transplantation experiment on the adaptation and development of *Sphagnum palustre, Sphagnum fallax/flexuosum* and *Sphagnum squarrosum* was executed.

All pilots containing *Sphagnum* were monitored six times in the time span of 78 days. Coverage estimations and changes seen through the pH-development were the most interesting.

Distributed in 24 plots, 15 patches of *Sphagnum spp.* were planted. The pH and EC (Electrical conductivity), visual development and water level showed the impact the changing conditions at the site had on the different species.

To estimate the total biomass, *Typha spp*. was harvested. Before drying the plants at 110 °C and 70 °C, they were divided into flower heads, leaves and stalks due to differences in their water content. Through nine days the changes were tracked.

Different methods of the growth estimation of *Sphagnum spp.* proved incomparable to previous monitoring. However, the surrounding growing environment improved continuously.

S. fallax/flexuosum developed the most acidic environment (pH < 4,7). The relation between *S. palustre* and *S. squarrosum* compared to the conditions at the site were much closer (pH > 4,9 & pH > 5,1 vs. pH > 5,1). This left the impression that different *Sphagnum spp*. adapted differently to the same conditions.

In 2018, the yield of *Typha* above ground biomass was higher than in 2017 (4,6 ton/ha vs. 1,6 ton/ha). *T. latifolia* developed the best. In one of the two fields the yields were not promising, with a total dry weight of 668 grams in Field 2 compared to a dry weight of 5 558 grams in Field 1. At 110 °C, *Typha spp.* lost more moisture than at 70°C in the same amount of time.

Based on the development of the pilots, an indication could be made on the areas suitability for paludiculture. Although positive changes were noted, parameters such as fluctuating water levels, changing site conditions and pH, and late harvesting influenced the results. No definite conclusion could be drawn on the aptness of specific species. In its current state, the pilots demand for more research as to how faster growth rates can be obtained.

1 Introduction

This reports focus is the development of the paludiculture pilot sites for *Typha spp.* and *Sphagnum spp.* in Bûtefjild, Fryslân.

First, the report summarizes and continues on the monitoring of previous student projects by Vries (2018) and Zeephat (2018), including the biomass production of *Typha latifolia* and *Typha angustifolia*, and growing conditions of *Sphagnum* spp.

The second concern of the report is to set up a transplantation experiment where the Sphagnum species *Sphagnum fallax/flexuosum* (in this report referred to as one species), *Sphagnum palustre* and *Sphagnum squarrosum* are tested, to see which of them would perform the best under the current conditions of the site.

This assignment is part of the Better Wetter project, a partner of the Interreg North Sea Region CANAPE-project, under the supervision of Jasper van Belle, researcher and lecturer of landscape ecology at van Hall Larenstein University of Applied Sciences.

Today, the Netherlands seems completely dominated by human activity and expansive agricultural land-use. Still, the Netherlands is not exclusively a cultural landscape. Some forest and nature areas remain (Figure 1). Land reclamation gave the Dutch the advantage to settle on wet inhabitable peat and clay rich soils. This was possible due to historic land-use practices, which resulted in loss, decay, and consolidation of these soils and subsequent land subsidence. Coinciding with this subsidence was a period of postglacial sea level rise, which resulted in flooding and subsequent loss of large areas (Hoeksma 2007).

FIGURE 1 LAND USE IN THE NETHERLANDS (CBS 2010) *TRANSLATED FROM DUTCH TO ENGLISH

In Medieval times, the Netherlands experienced increased flooding frequencies, something that changed the Dutch coastline. As human settlements moved from low-lying areas to peat swamps in the beginning of the eleventh century, land-use approaches changed. To transform these wetlands into agricultural land, the construction of drainage ditches drained the water into natural streams or larger canals (Hoekstra 2007). A consequence of the continuing drainage of the peat was the redirection of the excess water into small rivers. This caused the areas around the rivers to subside and letting them grow into lakes, something that projected a serious safety threat. The solution to prevent a further growth of these lakes was to remove the water, which again created new land for agriculture. After 1400, the so-called "polder mills", i.e. windmills adapted to pumping water, drained these smaller lakes.

Had it not been for the construction of dikes, which laid the groundwork for drainage, most of the Dutch land area would still lay above sea level. Figure 2 explains how new inventive methods accelerated drainage over time and its close relation to soil subsidence.

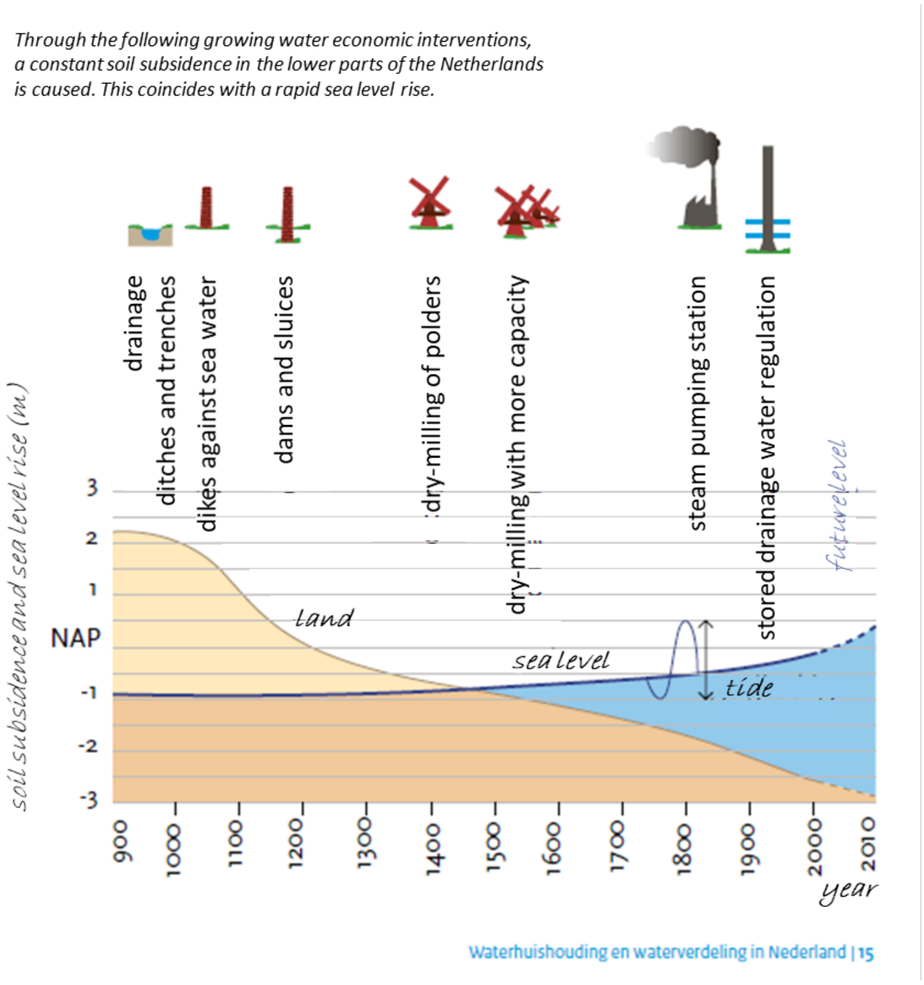


FIGURE 2: CONSTANT SOIL SUBSIDENCE FOLLOWED BY SEA LEVEL RISE THROUGH NEW INVENTIONS OF DRAINAGE (ARNOLD ET AL. 2009) *TRANSLATED FROM DUTCH TO ENGLISH

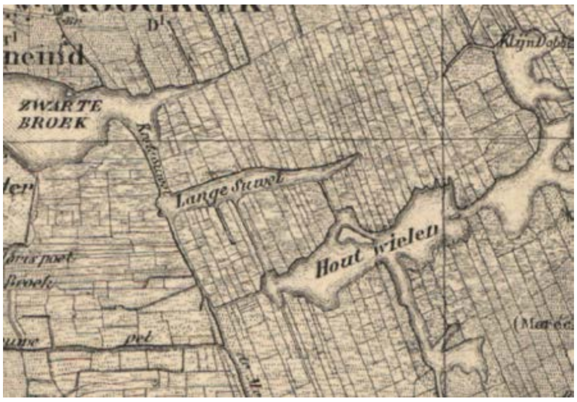
This development of the Dutch draining systems provides the historical frame for understanding how the area of research has changed since the beginning of the 20th century. The following maps show the development of the Bûtefjild-area in the period from 1910-2017 (Figure 3A-F).

Lake Zwarte Broek (Figure 3A) originally fed the whole area. It slowly turned into a polder by the 1950s (Figure 3C). Throughout the timeline, the changes in the land-use become obvious. What looks like rugged lines (peatland) and a somewhat unsystematic structure of the landscape in the 1930s (Figure 3B), changed into straight-lined fields with polders by the 1950s (Figure 3C). The end of the

Second World War caused a paradigm shift in the approach to drainage (Figure 3C). Intensification of agriculture required drainage that was more effective, resulting in lower groundwater levels, increased drainage rates and more drought stress in dry periods (Ritzema & Stuyt 2015). By the 1980s, the awareness had shifted and a new urgent problematic issue arose: man-induced land subsidence. Through the extensive drainage in the years before, land subsidence had gained a noticeable momentum. Studies showed that reversing or stopping the problem was not possible. The process was only likely slowing down by proper water control and good land management. Regardless of the efforts, subsidence would still continue at an undesirable rate (Stephens et al. 1984). Stephens et al. (1984) also saw general solutions for lengthening the life of organic soils by growing water-tolerant crops such as rice.

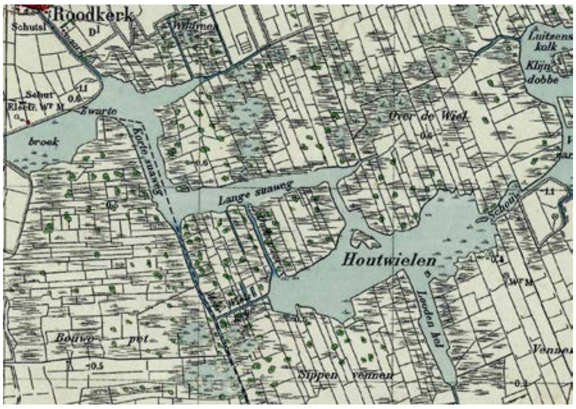
Today, the landscape of Bûtefjild is leaving almost no remnants of the historical references from the early 20th century. This portrays the polderisation in Dutch land-use, including the effects of strict water level regulations controlled by Water Boards (regional water authorities). Apart from this, one can also note the re-opening of polders during the last 20 years (Figure 3D-E). In the 1990s, the focus of land-use had changed to paying more attention to space for nature and recreation, while urbanisation continued. In most recent years, drastic changes were set into action. Between 2011 and 2017 (Figure 3E-F), the area slowly regained almost the same appearance as in the 1930s (Figure 3B). These changes came about after almost seventy years of extensive drainage (Figure 3C). Keeping up such a development and land-use activities required and still requires a solid and strong water management.

With soil subsidence, not only costly problems but also problems arise that can project a concern for the general safety and wellbeing of the humans living in the area. This includes the usage executed on this very soil. Other challenges include water management costs and damage to houses and infrastructure. This increases a demand for projects that take into account these rapid changes and adapt around them. Research projects work on using water resistant crops to find new solutions for the future of sustainable agriculture. It is the aim of these projects to enable farmers to maintain a productive land-use despite of water level increase due to ground water seepage. This is where paludiculture appears.



(A) 1910: The Bûtefjild-area a hundred years ago

(D) 1982: Establishing of the Ottema Wiersma-reserve



(B) 1930: First attempts of draining Zwarte Broek

(E) 2010: Small areas rewetted near the reserve

(C) 1952: Polderisation and extensive drainage

(F) 2017: Re-establishing original landscape structures

FIGURE 3A-F: THE DEVELOPMENT OF THE LAND-USE AND WATER MANAGEMENT IN THE BÛTEFJILD-AREA (KADASTER 2018)

2 Theoretical Background

Especially in the province of Fryslân, fertile peatland forms the majority of agriculture. When soils grow infertile due to excessive usage and nutrient pollution, following bad growing conditions, the land will not be profitable for the farmer anymore. A possible solution of using these degraded peatlands is to rewet them in order to create a new approach to agricultural land-use.

This is exactly what paludiculture aims for. Paludiculture is the productive use of wet peatlands (Wichtmann et al. 2016) and derives from the Latin word “palus”, which translates to “swamp” or “mire” (Greifswald Mire Centre 2017). The aims include traditional peatland cultivation and new approaches for utilization, including the energetic use of biomass from wet peatlands (Greifswald Mire Centre 2017). What make this type of cultivation valuable for the future is its sustainability: New underground biomass accumulates and new peat formation may take place when skimming off the above ground biomass during the harvesting of the biomass for further production (Greifswald Mire Centre 2017). In theory, this could also be an option to reduce soil subsidence.

From a climate perspective, paludiculture might become an interesting method for future investments. To bring more attention to paludiculture, the Interreg North Sea Region CANAPE-project (which this project is part of) organised a stakeholder meeting in September 2018, followed by sending out a questionnaire. The results show an overall interest for paludiculture and the aims it envisions. In the public eye, this is something to take into account when talking about measures regarding nature conservation and climate change. However, as soon as one is talking about the initiative of setting this into action, many farmers are doubtful. Scepticism arises mostly in terms of profitability.

Although paludiculture promises being a sustainable method for the future, it is important to note, that paludiculture does not focus on nature conservation but on the productive use of wet peatlands. Further, the Mire Centre Greifswald (2017) assumes that its practices may contribute to nature conservation objectives but might also contradict these.

2.1 Crops of research

Successful paludiculture requires reliable crops. Two of the most researched crops until now are *Sphagnum spp*. (peat moss) and *Typha spp.* (cattail). This project revolves around these two. The next section briefly sheds light on the usage of peat moss and cattail and the species used in the project.

2.1.1 *Sphagnum spp.*

The collection of peat moss biomass aims to produce a renewable raw material for high-quality horticultural growing media (Wichtmann et al. 2016). The aim is to replace fossil peat moss in horticulture with fresh peat moss, since fresh peat moss biomass has similar properties as white peat (Greifswald Mire Centre 2017). Some of the characteristics of peat moss are low pH, low nutrient content and an excellent rewetting ability, high storage capacity for air and water, and low nitrogen immobilisation capacity (Wichtmann et al. 2016). Compared to traditional turf cutting, *Sphagnum* harvesting reduces greenhouse gas emissions by stopping the further oxidation of existing peat. To get the most out of peat moss cultivation, a stable water table is required, fluctuating as little as possible. Ideally, the soil water should settle a few centimetres below the moss surface.

2.1.1.1 Sphagnum fallax/flexuosum

This report refers to *S. fallax* and *S. flexuosum* as one species. The reason is the difficult distinguishing between these two, since they often grow together. Other than that, the demands regarding the soil and the nutrient availability are similar. *S. fallax* prefers permanently damp or wet habitats, including nutrient-poor to intermediate fens (Amphlett & Payne 2010). It creates green to yellow mats in lime-deficient mires, but can represent quite a task to determine (Flatberg n.d.). A growth experiment by Grosvernier et al. (1997) reported that *S. fallax* is more sensitive to water table depth and to peat properties than other species (Grosvernier et al. 1997). *S. flexuosum* grows in slightly mineral-rich sites, for example poor fens and wet woodland, and demands a slightly higher alkalinity than *S. fallax* (Amphlett & Payne 2010).

2.1.1.2 *Sphagnum palustre*

As one of very few *Sphagnum* species, *S. palustre* grows in the warm temperate zone. Fukuta et al. 2012 argues that *S. palustre* is able to remain productivity under warm climatic conditions, the moss temperatures during the daytime being much lower than the air temperature.

As the Latin name indicates, the habitat of this peat moss is primarily in bogs of the lowlands and in moist hills (Flatberg n.d.). This species is quite shade-tolerant and grows on sites that are moderately enriched in nutrients such as wet woodlands, ditches, stream margins and flushes (Amphlett & Payne 2010).

2.1.1.3 *Sphagnum squarrosum*

From the species mentioned in 2.1.1.1 and 2.1.1.2, the physiognomy of this peat moss species is probably the easiest to recognise in the field due to its robust and spiky appearance. It prefers swampy ground of moderate to high nutrient levels, such as in wet woodland, amongst sedges (*Carex*) or rushes (*Juncus*) or purple moor-grass (*Molinia*) (Amphlett & Payne 2010). Moderate calcareous conditions are also favourable (Clymo 1970). The species has some tolerance towards saline conditions created through brackish water and might be the species the most in favour of nutrients and nitrogen in the whole of Europe (Flatberg n.d.).

The species mentioned all have in common, that they are indicators of soil water and are rarely to not at all found on raised bogs (Flatberg n.d.). Higher acidity characterises the soils of these areas, almost entirely fed by mineral-poor precipitation. The sites monitored in this report, receive groundwater supply from a nearby lake when the inlet/outlet is not closed, reconstructing fen-like conditions. This causes a mineral enrichment, which acidic-soil demanding *Sphagnum* might have problems coping with.

2.1.2 *Typha spp.*

Cattails are interesting for paludiculture due to their high productivity (Wichtmann et al. 2016). They have the ability to form dense stands in nutrient-rich water bodies and ditches, and are especially valuable due to their nutrient uptake. After the vegetation period, nutrients translocate from the above ground biomass getting stored in the rhizome (Dubbe et al. 1988; Wichtmann et al. 2016). The preferred harvesting season of *Typha* is in winter over frozen ground. This helps to reduce the damage made to the soil and the rhizomes. A cutting height of 10-20 cm preserves the already formed young shoots, and prevents water from seeping into the plants, which averts the possibility for the plant to rot. The biomass yield of native cattail species depends on harvest time, water level and nutrient availability (Wichtmann et al 2016). Although cattail is in preference of high water tables, *Typha* should not be cut under water level since it will die because of anoxic conditions (Sale & Wetzel 1986; Colbers et al. 2017)

Another advantage of *Typha* is its water cleaning ability. For at least 90 years, constructed wetlands have been used to treat wastewater. When rewetting former agricultural land though, it is important to keep in mind that the wastewater in the soil tends to contain high levels of nutrients such as nitrogen and phosphorus. Excess nutrients can reduce water quality by encouraging the overgrowth of algae and reducing levels of oxygen (University of Guelph 2012). In order to make use of such nutrient enriched rewetted peat- or wetlands there is a need for efficient solutions of water cleaning.

Over the past years, the utilisation of durable aquatic plants has become an effective method. Wu (2014) suggest cattail (*Typha*) to be an effective plant for wastewater treatment. An American study on *Typha* refers to its ability to sustain repeated sludge application and to efficiently removing solids, phosphorus and nitrogen from the sludge waste (Wu 2014). By being one of nature's swamp plants, another advantage of cattail is its resistance to moulds and thus a very well equipped plant to deal with moisture. The leaves of the plant have a fibre-reinforced supporting tissue, filled up with a soft sponge tissue. Through this special construction, they are extraordinarily stable and possess an excellent insulating effect (Fraunhofer-Gesellschaft 2013).

2.1.2.1 *Typha angustifolia*

In the *Typha* pilot site described in this report, the accidental planting of *T.angustifolia* unintentionally turned the fields into a competition experiment between the species. Thin leaves and a low leaf surface area characterises the species, as also expressed in its English name "narrow-leafed cattail" (Grace & Wetzel 1982). Experimental studies of competitive displacement between *T. latifolia* (L.) and *T. angustifolia* (L.) have shown *T. latifolia* to be restricted to shallow water and *T. angustifolia* to be restricted to deep water partly due to their competitive interactions (Grace & Wetzel 1982; Grace & Wetzel 1981a). In exchange for the adaptation to stress conditions, narrow-leafed cattail experience a lower productivity and less perseverance at a site where the growing conditions are favourable for a competitor (such as *T.latifolia*). Grace & Wetzel (1982) and Smith (1967) suggest a restriction of *T. angustifolia* populations to disturbed or newly colonized sites or to the habitats that *T. angustifolia* can colonize because of its more specific soil and water tolerance (Grace & Wetzel 1982; McNaughton 1975).

2.1.2.2 *Typha latifolia*

As mentioned, *T. latifolia* grows the best in shallow and or muddy water and is quite sensitive to water movement. The Grime C-S-R-Chart (Figure 4) illustrates the contrast between habitats that are either low or high in stress, or low or high in disturbance (Grime 1977; Grime et al. 1988; Wilson & Lee 2000). Following the Grime C-S-R-Chart (Figure 4), broad-leafed cattail falls in the category "competitor". Competition is the key adaptation for this species. *T. latifolia* is exploitative in its ability to clone rapidly and colonize available space, and is in fact the stronger competitor (Grace and Wetzel 1982; Grace and Wetzel 1981a) of the two species. These plants invest their energy in growth. This requires a certain stability in the growing conditions, since a focus on higher productivity draws back on the species ability to cope with stress. Nevertheless, *T. latifolia* can persist even in late successional marshes (Grace & Wetzel 1982; Smith 1967).

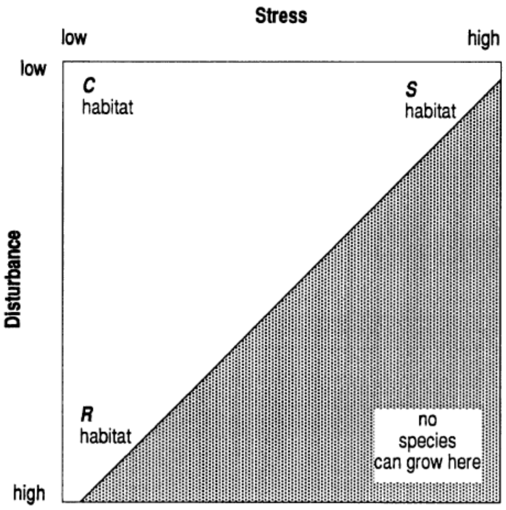


FIGURE 4: THE GRIME CHART CONCEPT: ORIGINS OF THE C-S-R TRIANGLE* (C=COMPETITION, S=STRESS, R=RUDERAL) (WILSON & LEE 2000)

**C-S-R habitat types consist of*

(C) Productive= high competition, low stress and low disturbance

(S) Stress= high stress, low competition and low disturbance

(R) High-disturbance= high disturbance, low competition and low stress

2.2 Site description

2.2.1 Elevation

Based on values from the AHN-viewer, the *Typha*-pilot has a NAP-level (Normaal Amsterdams Peil or Normal Amsterdam Level) of -0,937 m, the level of the *Sphagnum* pilot is even lower, at - 1,156 m NAP. The negative values indicate the meters below the Amsterdam ordnance date. To the north and west from the pilot, the height increases to about 0,0 NAP (Figure 5). The highest elevation is about 3 m NAP. The yellow colours mostly show the elevation caused by villages, streets, farms and houses.

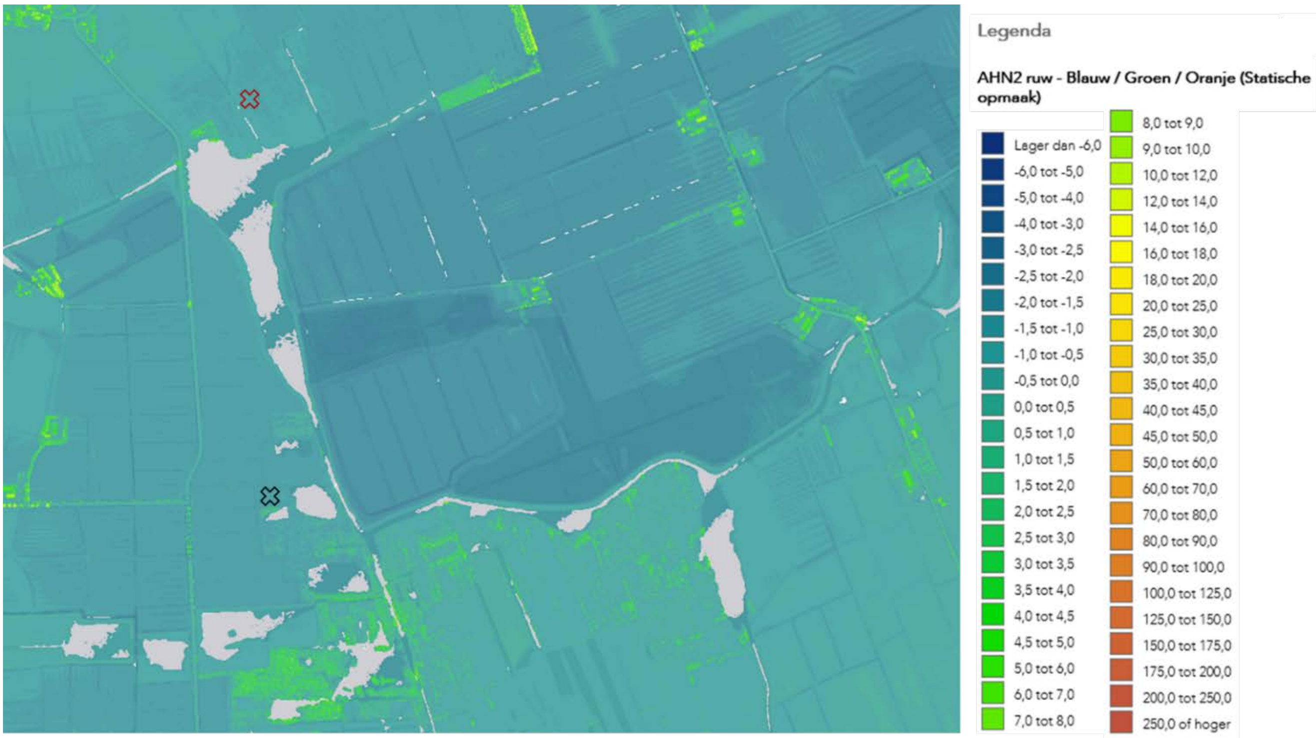


FIGURE 5: ELEVATION MAP OF THE BÛTEFJILD AREA, BLACK CROSS= *SPHAGNUM* PILOT, RED CROSS= *TYPHA* PILOT; NUMBERS REPRESENT NAP (NORMAAL AMSTERDAMS PEIL OR NORMAL AMSTERDAM LEVEL). ADAPTED FROM AHN VIEWER.

2.2.2 Soil

The province of Fryslân mostly consists of peat and clay deposits. The BOD50 soil map of the Netherlands (Figure 6) is a helping tool to get an overview of this (Legend in Appendix A). The *Sphagnum* pilot lies in an area classified as Vc II on the map (Figure 6). This stands for "Vlierveengrond"- old Histosol on Reed-sedge peat or "broekveen", a mesotrophic type of peat consisting of sedges and wood remains of alder and sometimes reed (Geheugen van Drenthe n.d.). Other than the characteristics of *Sphagnum* peat, the underground tends to be less acidic. These soils form under waterlogged conditions typical for peat, bogs, moors and swamps (The Editors of Encyclopaedia Britannica 2011). They are characterised by the strong accumulation of organic material (Bundesverband Boden e.V. 2013). The world reference base for soil resources (WRB) emphasizes, that the drainage of Histosols (dependant on the peat soil underneath) causes the oxidation of sulfidic minerals, which accumulate under anaerobic conditions (IUSS working Group WRB 2015).

At the *Typha* pilot, there is a change of the soil type, on the map referred to as hVz II (Figure 6). The soil dominating this area is the "koopveengronden" ('Koop' peat soils) on sand, another typical soil for the Netherlands, as described in the "Systeem van bodemclassificatie voor Nederland" (Bakker & Schelling 1989). Koopveengronden are found at the border of peatlands, where clay deposition in the soil has almost ended, such as in the bordering areas of the provinces Noord- and Zuid-Holland and Utrecht (Bakker & Schelling 1989).

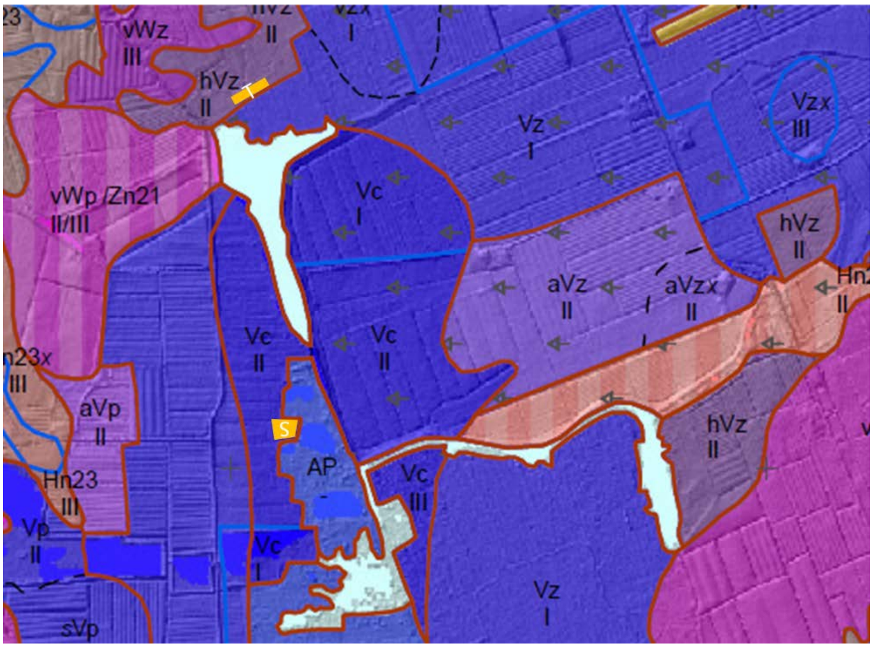


FIGURE 6: SOIL MAP (BOD50 2009 BODEMKAART VAN NEDERLAND) OF THE BÛTEFJILD AREA INCLUDING THE *SPHAGNUM* AND *TYPHA* PILOTS (ALTERRA, WAGENINGEN 2008). FOR COLOUR CODE SEE APPENDIX A.

Note that the BOD50 is from 2009. See Figure 3 to track the changes in the landscape until today.

2.2.3 Water management

Water management is of highest importance in the Netherlands and in Bûtefjild. Without proper water control, flooding of the land inside of the polder would be inevitable. Figure 7 indicates the individual water level demand a field requires. The main task is to manage the amount of water flowing from field to field to ensure the maintenance of a specific water level. The Sphagnum pilot has a required water level of -1,5 NAP in winter and in summer (Figure 7). Pumping stations, dams and sluices work to control the level of surface water. In natural areas, such as the Ottema-Wiersma Reservaat (NAP -1,05 in winter and in summer), water retention aims at preventing land from drying out (Steen & Pellenbarg n.d). In other fields, crop growth desires lower water levels to ensure crop growth. This system allows water level regulation according to specific demands.

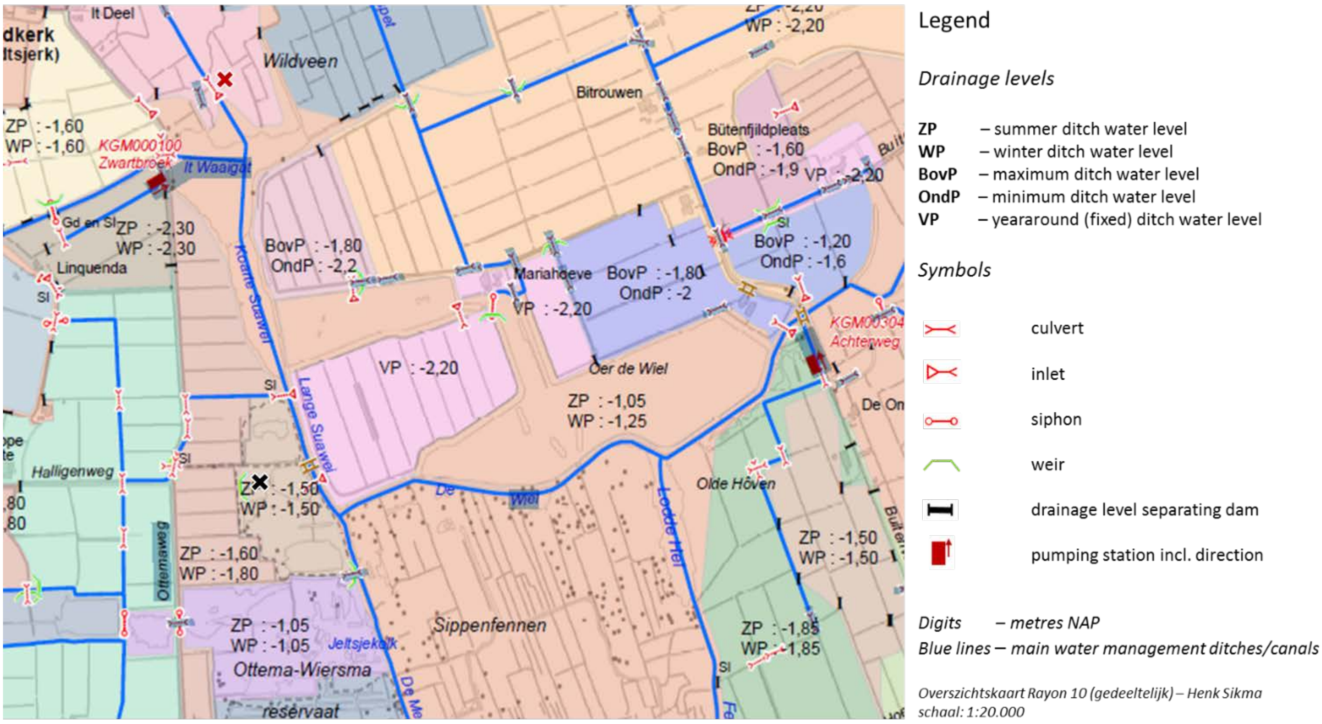


FIGURE 7: WATER MANAGEMENT IN THE BÛTEFJILD AREA, RED CROSS= TYPHA PILOT, BLACK CROSS= SPHAGNUM PILOT (WETTERSKIP FRYSLÂN 2017)

3 Methodology

TABLE 1: FIELD ACTIVITIES OF ALL PILOTS

Field activities	Frequency throughout the period of fieldwork	*Sphagnum pilot*	*Transplantation experiment*	*Typha pilot*
Horizontal coverage	1	A11-A32 B11-B32	---	---
Vertical coverage	1	A1-A3 B1-B3	---	---
Multimeter measurements *-ditch-*	5	C1-C8	PC1-PC4	---
Multimeter measurements *-plots-*	2	A11-A32 B11-B32	P3,8,10,14,21-Sff P1,7,9,16,19-Sp P4,5,15,20,22-Ss	---
pH-test strips	5	A11-A32 B11-B32	P1-P24	---
Circumference	2	---	P3,8,10,14,21-Sff P1,7,9,16,19-Sp P4,5,15,20,22-Ss	---
Water depth	1	---	P1-P24	---
Visual development (photographs)	6	---	P3,8,10,14,21-Sff P1,7,9,16,19-Sp P4,5,15,20,22-Ss	---
Growth length	1	---	---	X
Water samples	1	---	---	WS1-WS6
Biomass harvesting	1	---	---	1-A – 1C 2-A – 2-B

The methods used throughout the project, all had the aim to make a prediction about the general site and growing conditions.

3.1 Objectives

***Sphagnum* pilot → Growth**

Objectives:

1. Testing *Sphagnum* growth under the conditions of the Bûtefjild area.

2. Testing the use of leftover mowing-material from the nature management for *Sphagnum* growth.

Research questions:

1. How well does *Sphagnum* grow in the pilot site?
2. Is there a difference in growth rate between area A seeded with *Sphagnum* rich material and area B seeded with less *Sphagnum* rich material?

***Typha* pilot → Above ground biomass production**

Objective:

Research questions:

1. How much biomass does *Typha* produce in the Bûtefjild area?
2. Did it have an effect, that the *Typha spp*. dried at different temperatures?
3. Is there a difference in biomass production between *T.latifolia* and *T. angustifolia*?

Transplantation experiment → Adaptation and development

Objective:

To see which species is best suited for biomass production in the Bûtefjild area

Research question:

1. Which of the three most promising *Sphagnum spp.* for paludiculture grows best under the current conditions at the pilot site?

3.2 *Sphagnum* pilot

The site was established during the fall of 2017. The pilot consists of two sectors (Figure 8): The idea was to seed sector A (green) with grass biomass containing relatively much *Sphagnum*, evenly spread over the area. The seeding of sector B (yellow) occurred with grass biomass containing much less *Sphagnum*, but distributed evenly in larger patches over the area. The mowing-material originated from nutrient poor hay fields in the neighbouring nature reserve Ottema-Wiersma Reservaat.

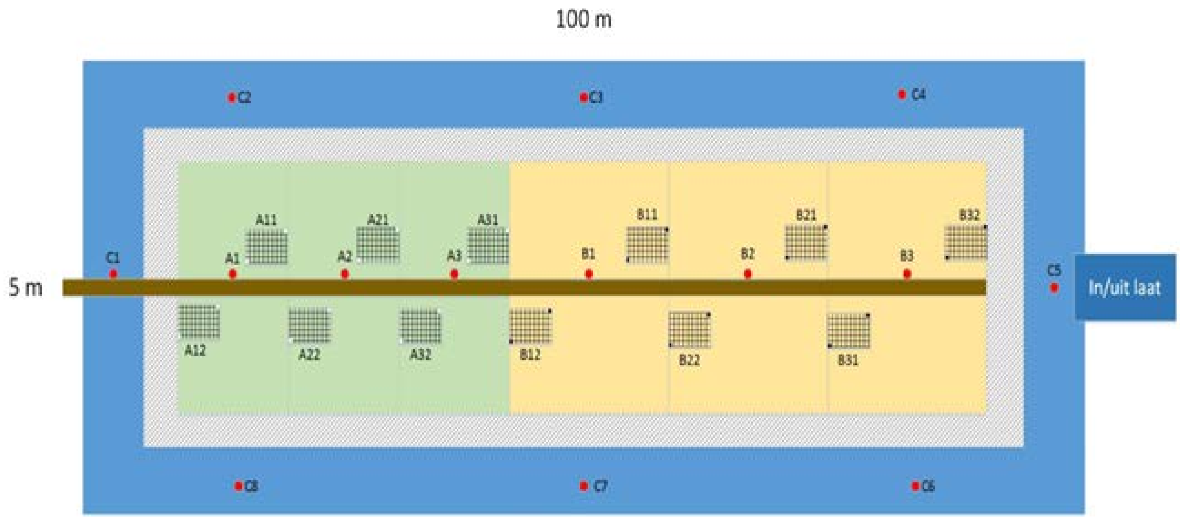


FIGURE 8: *SPHAGNUM* PILOT (53°14'32.7"N 5°56'37.2"E), BÛTEFJILD

3.2.1 Biomass production

Horizontal coverage: The use of a 1x1m frame consisting of 10x10cm squares helped estimating the coverage. At twelve spots on the pilot, two sticks marked the corner points of the frame. The upper corner had a yellow marker. In the field, each small square of the frame was taken into account (Figure 9-left). In an equivalent template, the estimated frequency of peat moss was recorded with a pencil. This was done by mentally "shoving" the relevant species into one corner (Figure 9-middle). To estimate the total coverage (in percent) of the peat moss in each frame, a 10x10cm plastic frame was cut out and put on top of the template, then every square was traced manually, collecting the coverage in one corner (Figure 9-right). For the first round of monitoring, only the total coverage of *Sphagnum spec.* was estimated.

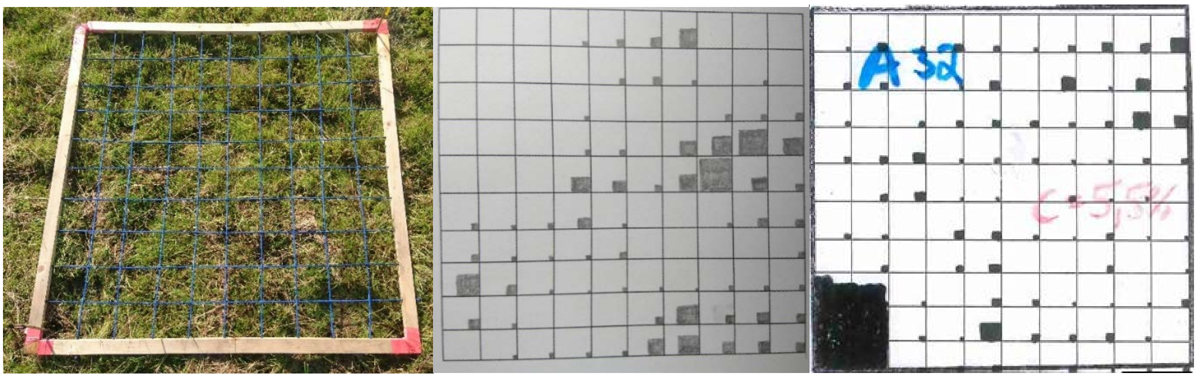


FIGURE 9: 1X1M HORIZONTAL COVERAGE (LEFT) FROM FIELD ESTIMATE (MIDDLE) TO RAW DATA (RIGHT)

Vertical coverage: At six locations in the *Sphagnum* pilot (Figure 8/Table 1), measuring poles had been placed in the ground. Although the digits on the pole had faded, measurements could still be taken. Vries (2018) mentions that the ground zero of the poles started at 15 cm. For this project, a measuring tape was held against the pole where it surfaced.

3.2.2 Site factors

The site factors described in 3.2.2 were the same for the Sphagnum- and transplantation experiment pilot.

Monitoring of surface water quality: As part of the previous monitoring work, eight spots (Figure 8) were measured in terms of pH, EC (Electrical Conductivity) and temperature. Due to inaccurate ORP (Oxidation-Reduction Potential) readings, this parameter was consequently left out of all measurements. The measurements were taken about 0,3 m from the shore and were about 0,3 m deep. As a remark to upcoming projects, the only marking pole still to be found was C7. Therefore the most convenient solution was to measure at about the same spots each week.

The same measuring instrument (a Multimeter) was used to utilise pH, EC, and temperature. This instrument combined different apparatuses. In the next paragraphs the main purpose of the parameters are explained. Each day, before going on fieldwork, the multimeter had to be calibrated. Due to the sensitive and unstable readings of the pH glass electrode, this was necessary in order to get exact measurements in the field.

pH

As an important site factor, the measurement of pH was executed with different objectives and methods throughout the project. Through the pH, indirect and direct depictions (dependant on the method of execution) could be made on the effect it had on plant growth.

The approaches chosen in this report were:

- ➔ to make conclusions on the accuracy between two different methods,
- ➔ how much error the results of an effortless and time saving method projected compared to a time consuming method
- ➔ the interpretation of the individual results in terms of the pH development over time.

Time saving – pH-test strip method

For a quick field analysis, Dosatest pH test strips have become popular. In this project, pH test strips with a range from 4,0-7,0 were used. This narrow range supposedly added a higher veracity to the results. Readings of the results could follow 30-60 seconds after dipping the strip into the desired solution by following the colour Chart on the package.

Time saving – Multimeter

Due to its long cord, the multimeter was useful, when measuring pH or other parameters in an open system such as a ditch or a lake. When the digits on the device had stabilised after 1-2 minutes, readings could follow. Downside of the tool was the fragile glass electrode that measured pH. When testing in open water, the instrument had to be encapsulated by a protective case. This required the multimeter to be completely submerged in water so that water could flow through the penetrable case. This made exact measurements in shallow water or ponds difficult.

Time consuming – Rhizons and Multimeter

The pH measurement of soil water was one of many field activities completed throughout the project. To extract soil water, a filter device called a "Rhizon" was carefully stuck in the soil (Figure 10). The extraction was completed with a syringe, which was attached to the Rhizon through a plastic tube. To create a stable vacuum without the necessity of supervision, a rectangular piece of wood was placed between the plunger and barrel. Soil water extraction was by no means a fast method. Dependant on the environment, season, and moistness of the soil, a 50 ml syringe could take 3-24 hours to fill up completely. When the syringes had filled up with enough liquid, the content was either transferred from the syringes into a beaker, which could be attached to the multimeter instead of the protective case, or measured in small sample beakers by only placing the glass electrode into the beaker.

For selectively picked measurements, this method was used with the intention to obtain as exact pH-readings in the field as possible.

FIGURE 10: SOIL WATER EXTRACTION WITH THE RHIZON

EC

EC (or electric conductivity) measures the amount of salts dissolved in a solution. Conductivity expresses the capacity of a solution to conduct an electric current. Thus, the more dissolved salts in a solution, the higher the increase of conductivity. Demineralised water, for instance, will therefore have a very low conductivity reading, since the electricity in the solution is low. The HANNA Multimeter, which was used for all measurements, measured EC in µS/cm (microsiemens per centimetre).

3.3 Transplantation Experiment

The already established Sphagnum pilot site mostly consisted of *S. fallax/flexusoum* colonies. However, the growth development until now was unsatisfactory. This experiment was set up to test if another species was more suited for the pilot. The causes might be the nutrient poor original soil seeded into the pilots in contrast to the high nutrient availability of the pilot. As mentioned in 3.2, *S. fallax/ flexuosum* might react sensitive to such changes. To execute the experiment, a newly constructed site, close to the *Sphagnum* pilot (in the Bûtefjild area) was used (Figure 11).

The transplantation experiment aimed to transplant different species of peat moss to the pilot to find out how these would grow under the current conditions. As a first step, conclusions should be drawn on whether or not the *Sphagnum spp.* caught on to their plot and if this development should be followed up.

The two main aspects of the experiment, were water quality, growing conditions and development.

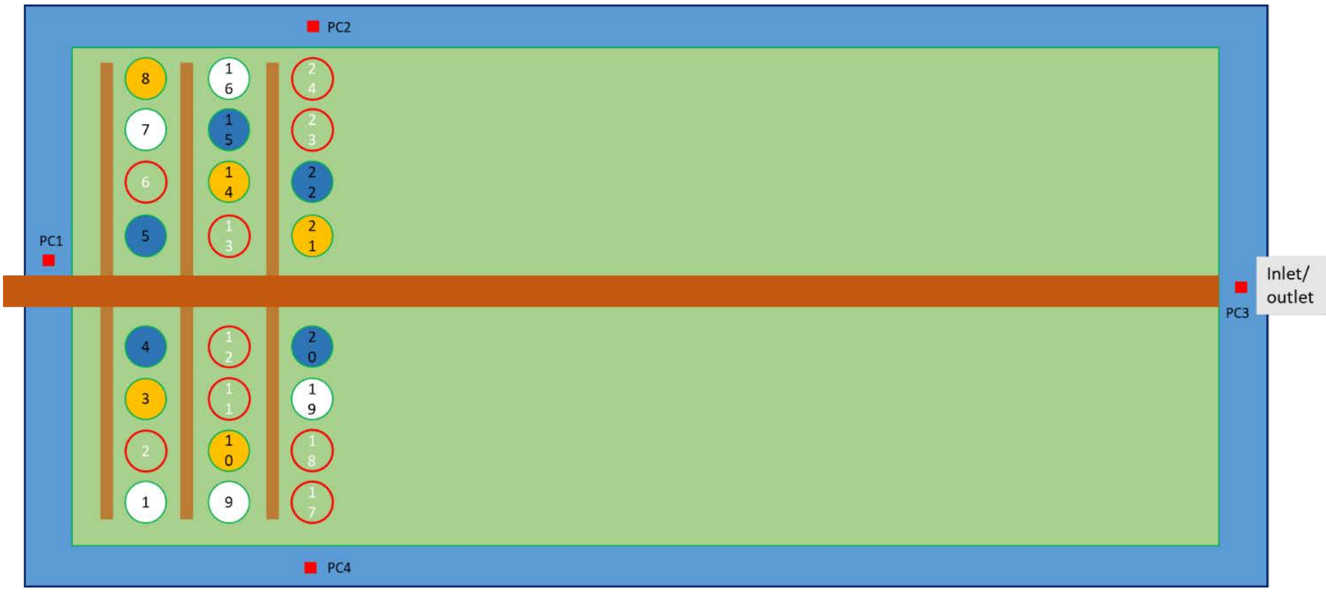


FIGURE 11: SITE OF THE TRANSPLANTATION EXPERIMENT, BÛTEFJILD (53°14'32.2"N 5°56'37.3"E).

3.3.1 Growing conditions/ development

Circumference: Five and seventy-eight days after transplantation, the circumference of each patch containing *Sphagnum* was measured by estimating the diameter with a measuring tape and multiplying this by 3,14 (number π). The values measured are meant to be references, in order to compare the growth development in future projects of monitoring. As the patches were measured for the first time shortly after the transplantation, the *Sphagnum* had yet not had time to spread out entirely and were not harshly influenced by weather conditions. After storing the *Sphagnum* in buckets, they had taken on circular forms. For indication on whether or not this made a difference on the size of the patch was then measured on the last day of fieldwork, as well as the growth development.

Water depth: Before transplantation the water depth in each patch was measured, by pressing a measuring tape to the bottom of the water hole, and reading of the digit at the water surface. These were the individual starting conditions of the patches, and should be taken into account when evaluating the development of each species.

pH- test strips: Each week, the plots were measured for pH with pH-test strips. This was done to quickly determine how well the Sphagnum had caught onto the plot. As soon as the peat moss had created a stable ground to grow on, the evidence could be found in the pH of the soil water inside the patch. Since this is a quick method with a large room for interpretation of colour, the reliability of the results might be questionable, and should be concluded on with caution.

Photographs: The patches were documented with photos each week, in order to track a visual development.

3.3.2 Site factors

Mulitmeter measurements: EC and pH were measured before transplantation to get an overview of the starting conditions. On two occasions throughout the period of monitoring, multimeter measurements of the patches were executed with the help of syringes and Rhizons. Weekly, multimeter measurements in the surrounding ditch were taken (Figure 11/ Table 1).

See 3.2.2 for the explanation of the site factors for the *Sphagnum* pilot and transplantation experiment pilot.

3.3.3 Set up

To set up the experiment, peat moss had to be collected. The samples were taken from the Phragmites fields in de Falom (53°15'33.7"N 5°59'37.1"E) on the 13th of September 2018 (Figure 12). The collected biomass consisted of:

- ➔ 5 buckets of *Sphagnum fallax/flexusoum*
- ➔ 5 buckets of *Sphagnum palustre*
- ➔ 5 buckets of *S. squarrosum*

(See 3.2 for the individual description of the species)

FIGURE 12: OVERVIEW OF THE AREA WERE THE *SPHAGNUM SPEC.* WAS COLLECTED (RIGHT) AND WHERE IT WAS TRANSFERRED (LEFT) (GOOGLE MAPS 2018)

Until the day of transplantation the buckets were stored inside under moderate open conditions and watered with demi-water every second day to prevent drought stress. All buckets with peat moss contained 1,5 litres of water when they were transferred to their plots on the 20th of September 2018.

The site was mostly overgrown by *T.angustifolia* and *Juncus effusus*. To make room for the peat moss, the vegetation was removed at the exact spot where the patch was planted. This method could not prevent that surrounding vegetation could reclaim the freed spots.

Premises for the transplantation experiment (See Figure 11):

- ➔ Each plot was given a code ranging from P1-P24
- ➔ A 50cm gap between each plot
- ➔ A pathway of 1m between each row
- ➔ The plots were divided into three rows, with four plots on each side, seen from the main path
- ➔ Each row of four was not allowed to contain the same species twice

15 of the 24 plots contained *Sphagnum spec.* The order, in which they were placed, was not randomized. Fortunately, the different water depths of the plots and the varying size of the peat moss patches caused a slight difference in the starting conditions. For the sake of a random outcome of the results, this projected a good reference for monitoring. However, whether or not this made a noticeable difference in the development of the *Sphagnum spec.* is to be discussed in the interpretation.

Figure 13 shows the final distribution of the patches and explains how to understand each individual code. By assigning different colours to the species, the distinguishing in the field became much easier.

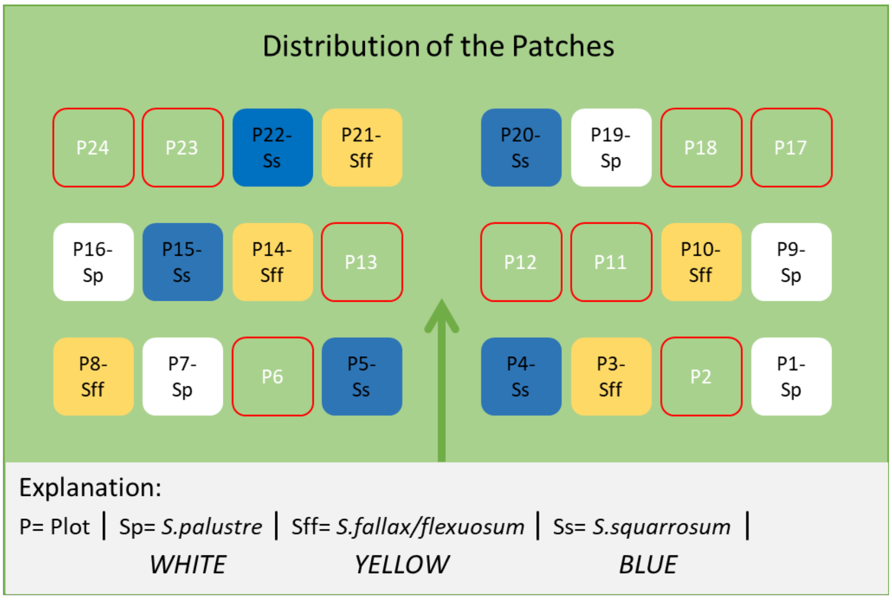


FIGURE 13: DISTRIBUTION OF THE *SPHAGNUM SPEC.* PATCHES WITH CODE AND COLOUR. PATCHES WITH A RED OUTLINE CONTAIN NO *SPHAGNUM.*

Each patch was marked with a bamboo-stick and a plot number (Figure 14A-D) the stick was then placed in the middle of the plots. This had three advantages; firstly, the plots could be recognised without a lot of effort and secondly, in the plots with peat moss, they acted as stabilisers for the first two weeks, preventing the patches from floating around due to the water depth in the plot. Lastly, it created a "natural" hole in the patch in which pH-test strips could be stuck to measure the exact soil water of the patch. In the field, this method added to the efficiency and saved a lot of time.

Figure 14: a) yellow - *S. fallax/flexusoum*; b) White – *S. palustre*; c) Blue – *S. squarrosum*; d) Label for the plots

3.3.4 Reference plots

As seen in Figure 11 and 13 the total number of plots within the pilot was set to 24. Of these, fifteen contained peat moss patches whilst nine were left empty (in Figure 11 and 13 these plots can be recognises through a red border and transparent inside. In the field, these plots were labelled with colourless sticks). The original purpose of these plots was to set up an additional two-species experiment to test for dominance between the species. The experiment was not possible to execute, but the open plots still became a valuable parameter for the experiment.

For all measurements, these plots were taken into account in terms of pH and electric conductivity, and were very good references in order to track the general changes in the pilot, without the interference of other vegetation.

3.4 *Typha* pilot

The *Typha* pilot consisted of two fields (*Typha* field 1 and *Typha* field 2) (Figure 15). Field 1 was laid out with a mix of rhizomes of *T.angustifolia* and *T.latifolia*. In Field 2, the *Typha* was sown. The fields are connected with each other through a pipe, with the "boezemwater"* first flowing into the first field with the potted cattails (Zeephat 2018). As Zeephat (2018) already observed in his project, there was a visible difference in growth success between the two fields. The sown *Typha spec.* in the second field were noticeably behind in their development.

*(*accurate translation for "boezemwater" not found.* Dutch definition: Surplus water collected in a polder storage for later dischargement i.e. to a specific field (Woorden.org 2018))

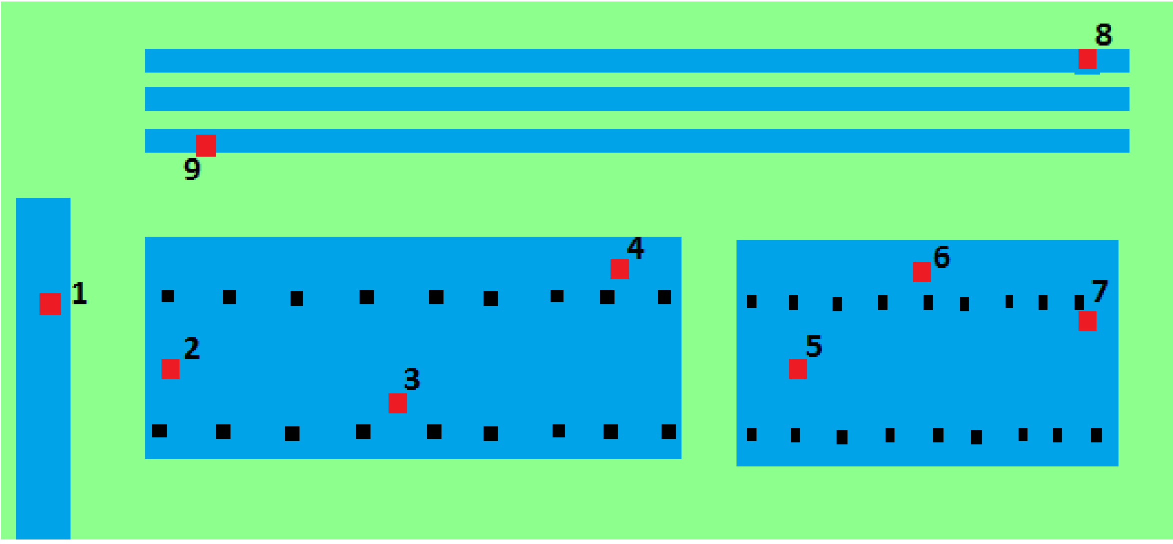


FIGURE 15: *TYPHA* PILOT- LISDODDEVELD BÛTEFJILD BETTER WETTER (53°15'13.3"N 5°56'35.3"E). (VRIES 2018)

Biomass harvesting: 11 October 2018, five 2x2m plots were harvested in the Better Wetter Lisdoddeveld. The plots were marked by four sticks, an installation also set up by Vries (2018). All plots were measured again before harvesting. For each of the plots a simple Braun Blanquet recording was made (Appendix B), three soil-grab-samples were taken and the above ground biomass cut. The biomass was sorted into broad-leaved cattail, narrow-leaved cattail, and other vegetation. They were separated in bags for further analysis in the laboratory.

Estimation of total dry weight biomass production

In order to analyse the total biomass production of the species in each plot, the harvested biomass of *T.latifolia* and *T.angustifolia* was cut into three pieces; flower heads, leaves and stalks. After weighing their respective measuring tins, the parts were weighed individually (including the tins) and placed in the drying stove, either at 70 or 110 degrees. Through a period of 9 days, the tins were re-weighed five times or until there was no noticeable fluctuation in the weight anymore. All of the tins were taken out of the drying stove on the same day.

Remark: up-coming projects on biomass production must keep in mind that Typha-flower heads will pop when dried at high temperatures. Suggestively, aluminium-foil or other heat resistant closable equipment should be used to prevent seeds from distributing at free will.

Comparison of total organic loss at different temperatures

To see which drying method was the most conserving of organic matter, two drying stoves were used. One reaching 70 degrees, the other 110 degrees. To compare the changes, two bags each of *T.latifolia* and *T.angustifolia* were chosen, and divided into about two equal fractions. These were then placed in the stove at different temperatures.

4 Results

4.1 *Sphagnum* pilot

(Hereafter referred to as SPH-pilot and TEXP-pilot). If not explained otherwise, the pH-measurements with the multimeter are classified as pH or pH-measurements. Measurements completed with pH-test strips are referred to as such.

Although some fluctuation can be noticed, the pH in the ditch went down for all plots on the last day of fieldwork (Chart 1).

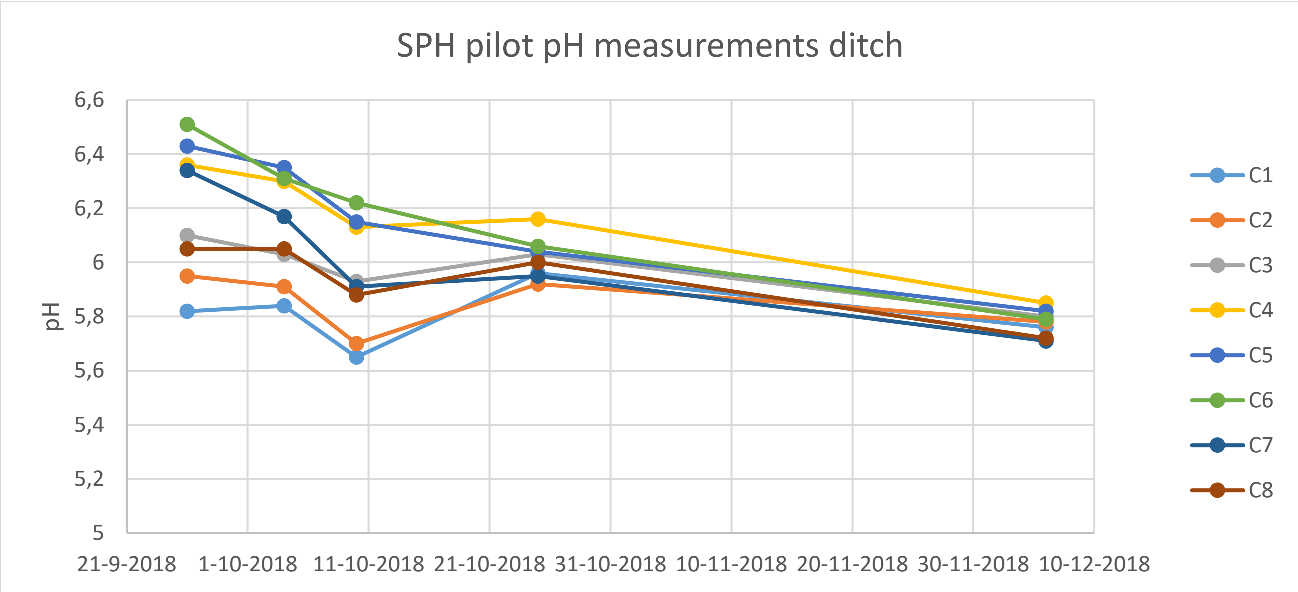


CHART 1: PH MEASUREMENTS IN THE *SPHAGNUM* PILOT; FOR PLOT NUMBERS SEE TABLE 1.

There seems to be a correlation between the plots C1,C2,C3,C7 and C8, which all were measured in the middle and end of the pilot (Chart 2). EC measurements went up for C5 and C4.

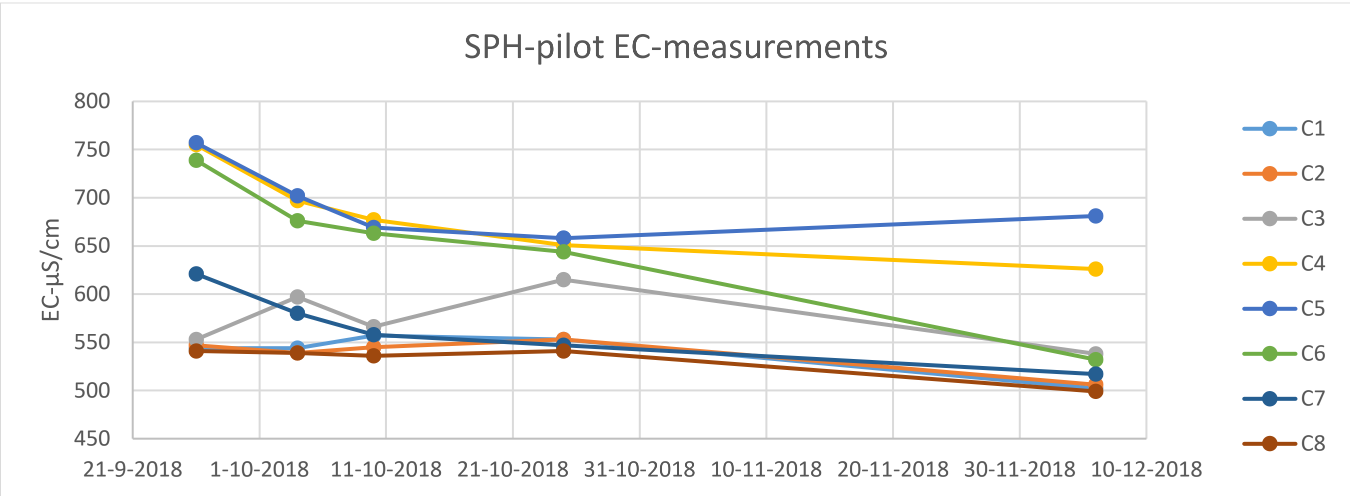


CHART 2: EC MEASUREMENTS IN THE SPHAGNUM PILOT; FOR PLOT NUMBERS SEE TABLE 1.

In order to track the changes in the SPH-pilot, the results from the first half of 2018 were compared to the results from the last half of 2018 (Chart 3). It seems that there has been a major reduction in *Sphagnum* especially in the plots A32, B11 and B12. Other than in the previous monitoring project, all plots now contained *Sphagnum*. In sector A, the distribution of the peat moss seems slightly more even than in sector B. Here the variation in total peat moss coverage per plot is higher. This is the case for both measurements.

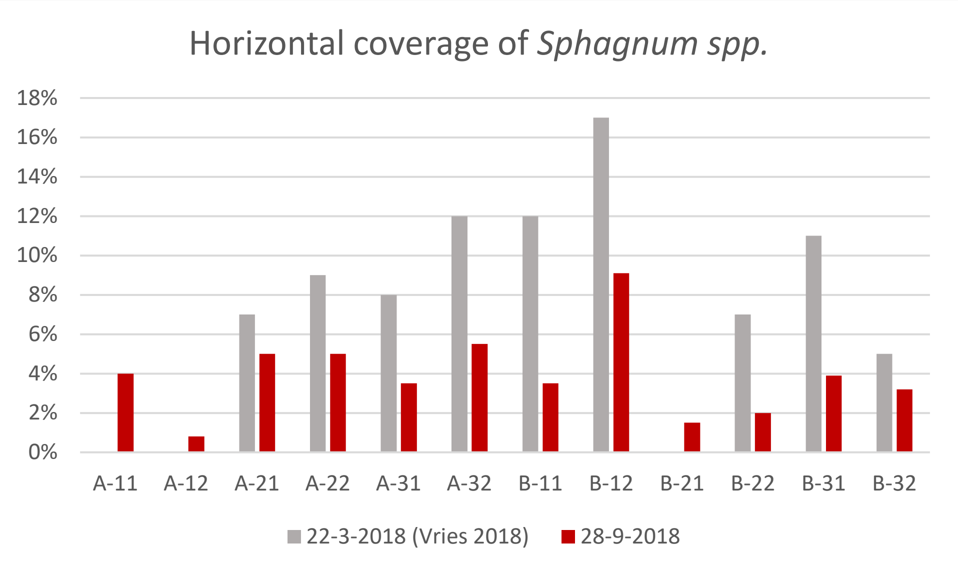


CHART 3: COMPARISON OF THE HORIZONTAL COVERAGE, MARCH 2018 AND SEPTEMBER 2018; FOR PLOT NUMBERS SEE TABLE 1.

To test the reliability of pH-test strips, the pH- value was measured in the plots A11-A32 with Rhizons. The content of the syringes was filled in a separate beaker. First, the test strip was held into the fluid for 30 seconds, followed by the multimeter. Chart 4 shows, that the test strip consequently gave a higher result, than the multimeter. Taking the mean of the results into account, the pH measured with the test strip shows a pH-value 0,58 times higher than the multimeter.

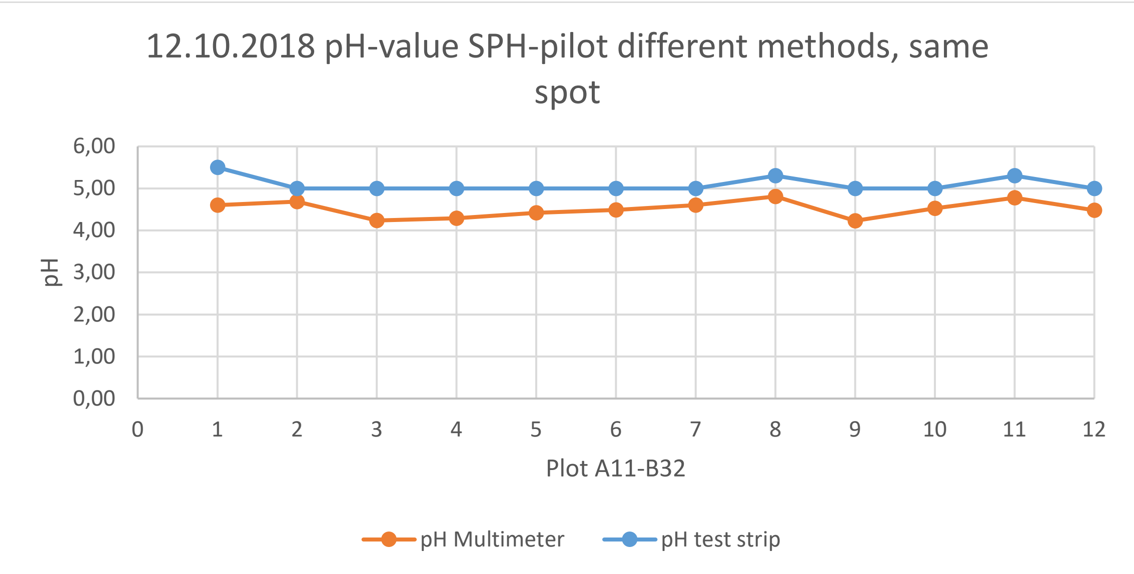


CHART 4 TESTING DIFFERENT PH-MEASUREMENT METHODS, SPHAGNUM PILOT; FOR PLOT NUMBERS SEE TABLE 1.

4.2 Transplantation Experiment

Table 2: Fieldwork days explained

Explanation of the measuring days in the field			
Day 0	=	20.09.2018	Day of transplantation
Day 5	=	25.09.2018	
Day 14	=	04.10.2018	
Day 20	=	10.10.2018	
Day 35	=	25.10.2018	
Day 78	=	06.12.2018	Last day of fieldwork

The pH in the ditch showed a decrease throughout the whole period of fieldwork for the plots PC2, 3 and 4. (Chart 5)

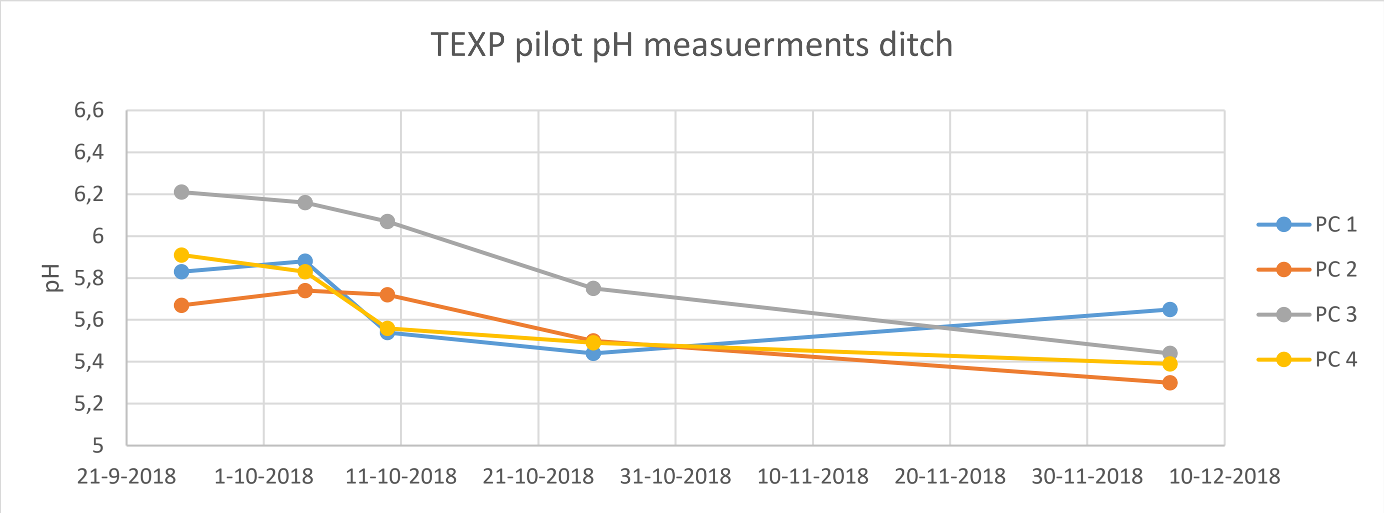


Chart 5: pH measurement in the Transplantation Experiment pilot; for plot numbers see Table 1.

A slight increase can be noticed in the EC development in the ditch (Chart 6). Although it seems as if there is a relationship between decreasing pH (Chart 5) and increasing EC in Chart 6, the two concepts are not generally related. The inlet was opened before measurements were taken on the last day, which could explain the increase of PC 3. For the EC, PC1, 2 and 3 correlate strongly.

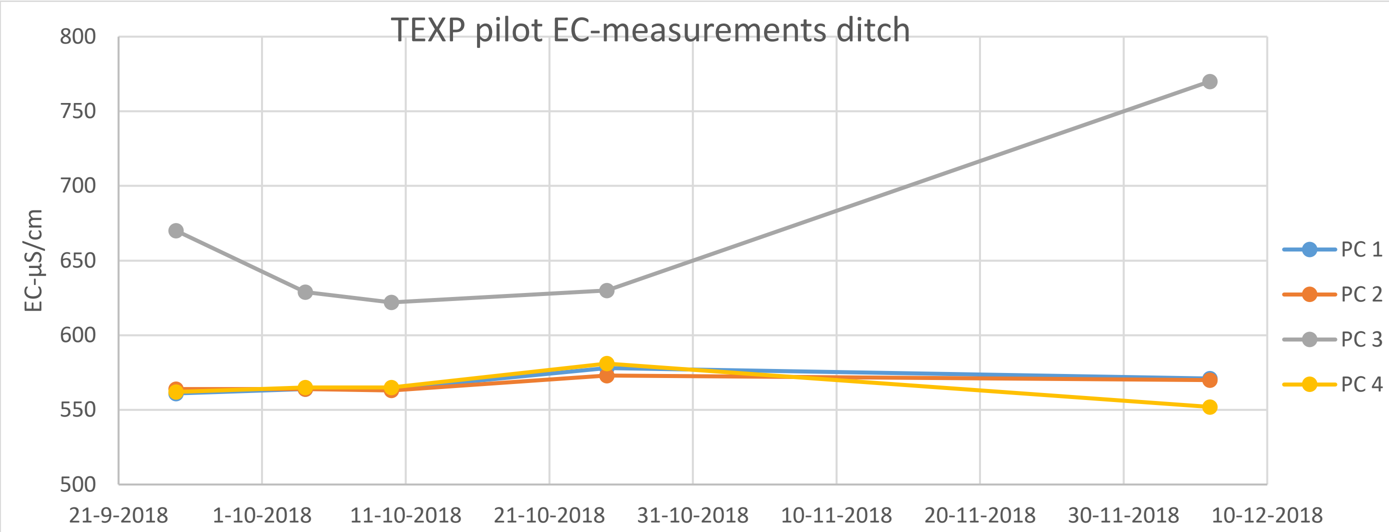


CHART 6: EC MEASUREMENTS IN THE TRANSPLANTATION EXPERIMENT PILOT; FOR PLOT NUMBERS SEE TABLE 1.

The following results (Table 3) are meant to give a general prediction of the development of the different *Sphagnum* species in the pilot;

The results of the circumference in Table 3 show, that the sizes of the peat moss patches were very different. In comparison with the water depth, it becomes clear, that these parameters cannot be regarded individually. For the first 14 days, plot 15 and 22 (Both *S. squarrosum*) were swimming in water. Eventually, due to evapotranspiration, the water level in the whole pilot sunk by 4-5cm over the period of five weeks. The inlet/outlet was kept closed throughout the whole period, leaving the pilot to rely on water supply from precipitation only. This caused a heightened water level by day 78. However, Table 3 shows no reduction in size. Eleven of the 15 Sphagnum patches grew in size.

TABLE 3: STARTING CONDITIONS AND SUCCESSIVE *SPHAGNUM* CIRCUMFERENCE OF THE TRANSPLANTATION EXPERIMENT PILOT.

Plot	Species	20.09.2018; Day 0 Water depth (cm)	25.09.2018; Day 20 Circumference (cm)	06.12.2018; Day 78 Circumference (cm)
1	*S.palustre*	8,5	108	108
2	***reference****	4,2	…	…
3	*S.fallax/flexuosum*	6	80	80
4	*S.squarrosum*	7	70	80
5	*S.squarrosum*	7	66	89
6	***reference***	4,2	…	…
7	*S.palustre*	8,7	79	83
8	*S.fallax/flexuosum*	8	86	86
9	*S.palustre*	10,5	72	82
10	*S.fallax/flexuosum*	7	70	82
11	***reference***	8	…	…
12	***reference***	9	…	…
13	***reference***	11,5	…	…
14	*S.fallax/flexuosum*	11	79	100

15	*S.squarrosum*	12	85	97
16	*S.palustre*	9	83	91
17	***reference***	9,5	...	...
18	***reference***	8	...	...
19	*S.palustre*	8	79	86
20	*S.squarrosum*	7	66	83
21	*S.fallax/flexuosum*	11,4	79	100
22	*S.squarrosum*	12	61	75
23	***reference***	10,5	...	...
24	***reference***	9	...	...

*reference= reference plots, see 3.3.4

Similar as in Chart 4, the pH-value measured with test strips showed higher result, than with the multimeter. Interesting to note, is how the blue line (pH test strip) follows the same pattern as the orange line (Chart 7). The mean of the measurements show, that the test strip measures a pH 1,0245 higher than the multimeter, this explains the pattern in Chart 7.

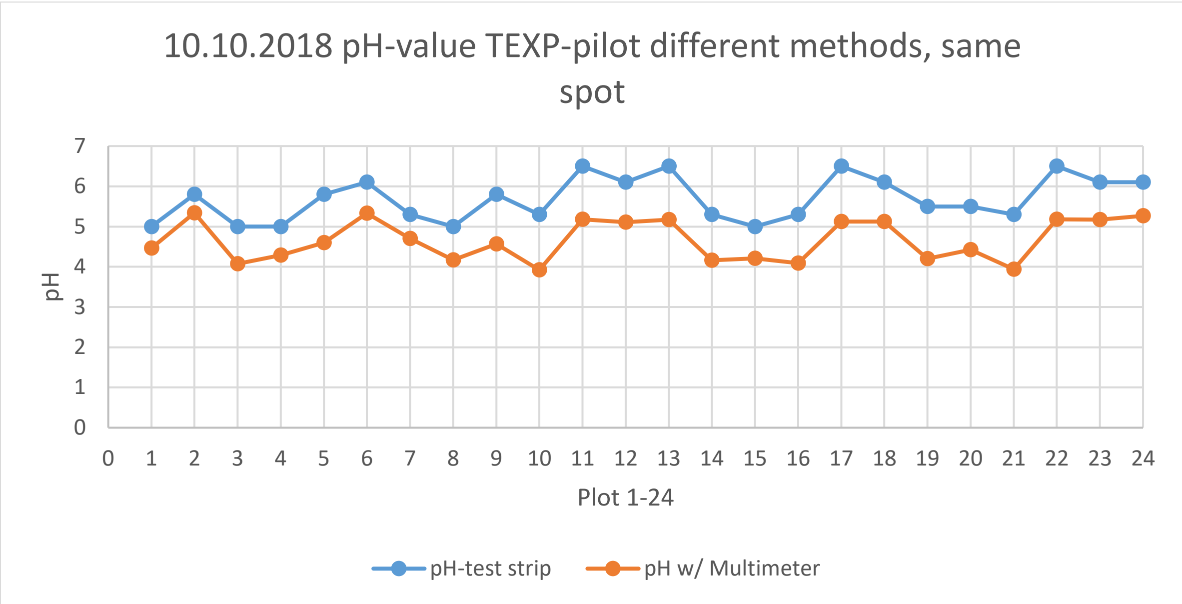


CHART 7: TESTING DIFFERENT PH-MEASUREMENT METHODS, PET PROJECT; FOR PLOT NUMBERS SEE TABLE 1.

All 24 plots had almost exactly the same starting conditions before transplantation. Compared to the reference plots (plots without peat moss), major changes can be seen in the plots with *Sphagnum* (Chart 8). This suggests that all species caught on to their plots by day 20. *Sphagnum fallax/flexuosum* stands out as the species creating the most acidic environment in the soil and surrounding water. As the inlet was closed throughout a rainy period, most of the patches were immersed with water by day 78. *S. squarrosum* (blue line) even slightly surpassed the average pH of the reference plots, probably due to dissolved CO_2 in the water.

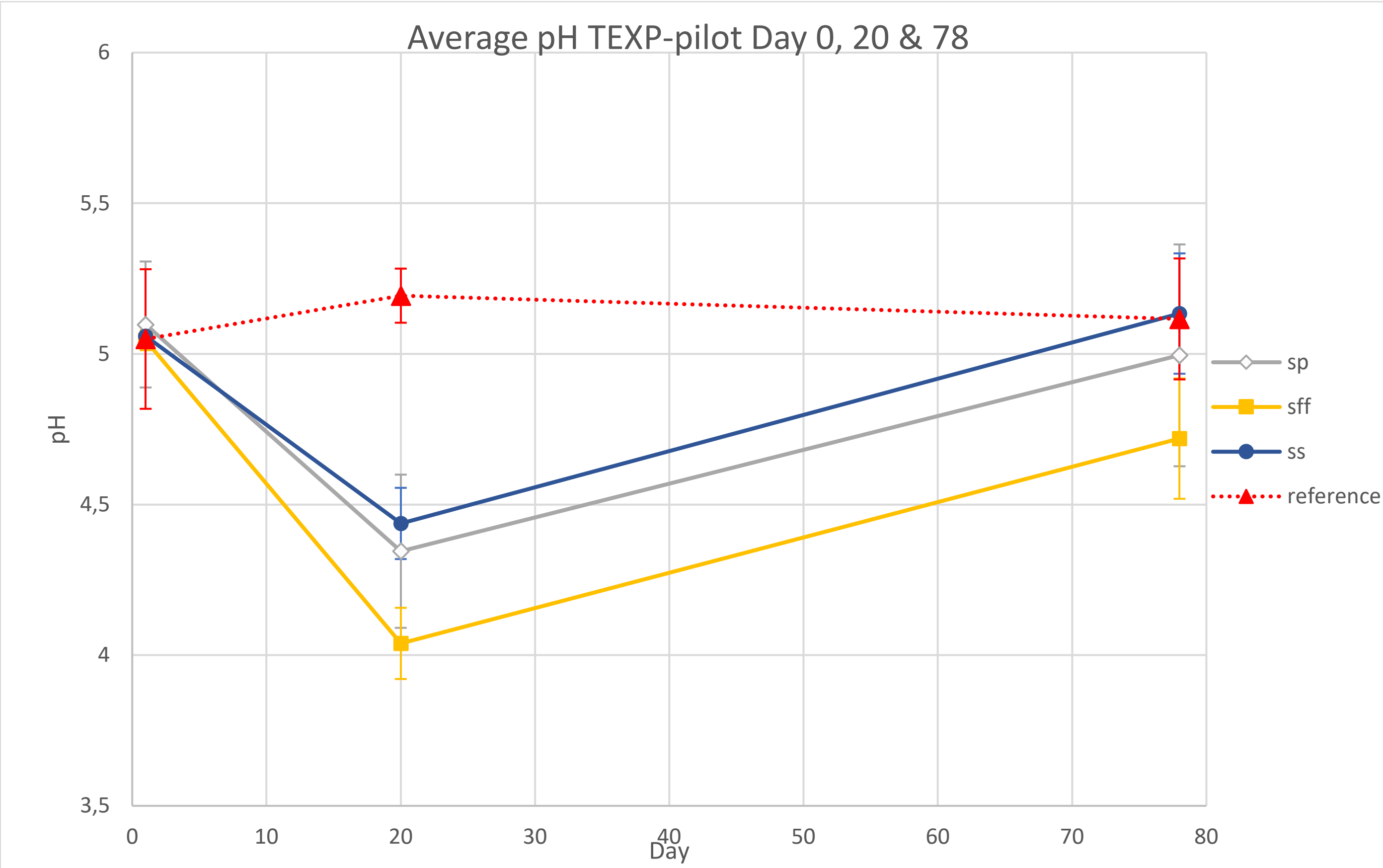
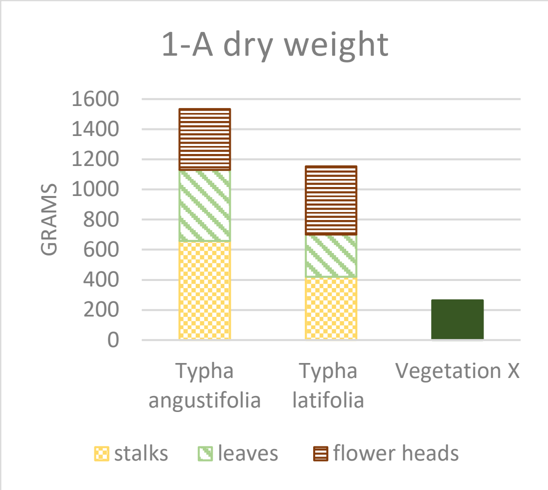


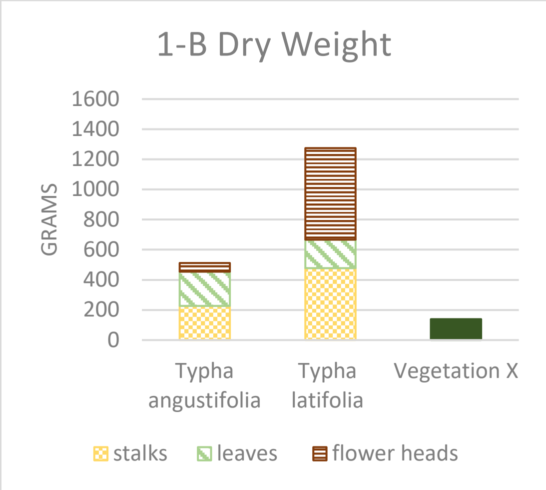
CHART 8: OVER TIME-DEVELOPMENT OF THE IN-PILOT CONDITIONS FOR *SPHAGNUM SPP.* AND REFERENCE PLOTS. VERTICAL LINES INDICATE ERROR BARS; FOR SAMPLE NUMBERS SEE TABLE 1.

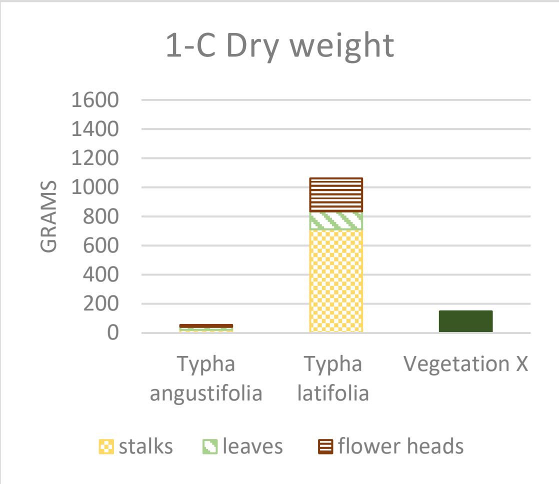
4.3 *Typha* Pilot

***FW** stands for fresh weight, **DW** for dry weight*

The total distribution of the different *Typha* parts per species per plot are shown in Chart 9A/B/C/D/E. For the plots 1-A, 1-B and 1-C, other vegetation was measured additionally.







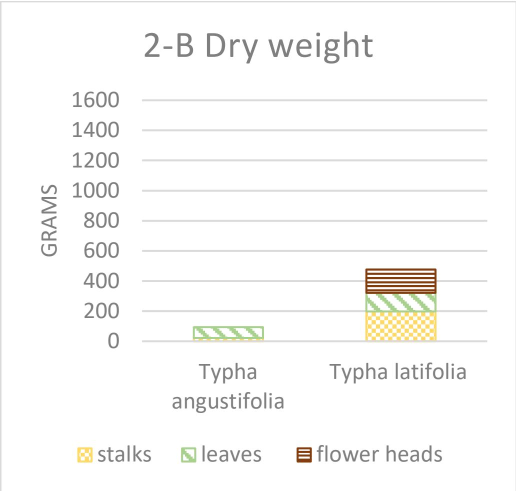


CHART 9A(1-A), 9B (1-B), 9C(1-C), 9D(2-A), 9E(2-B): TOTAL DRY WEIGHT OF THE BIOMASS PRODUCTION IN *TYPHA* FIELD 1 & 2 PER PLOT.

When looking at the total weighed biomass for both species, large differences can be seen. Chart 10 suggests that the average above ground biomass production of *T.latifolia* is higher in both fields. The Chart also gives a clear indication, that the total yield of biomass in field 1 was higher than in field 2. In field 1 *T.latifolia* had a yield of 6553g FW/3457g DW compared to 648g FW/500g DW in field 2. *T.angustifolia* experienced similar differences with a yield of 3387g FW/2101g DW in field 1 and 286g FW/188g DW in field 2. Field 1 produced almost 90% more above ground biomass (FW) than field 2. This clarifies that the neighboring fields experienced very different growing conditions.

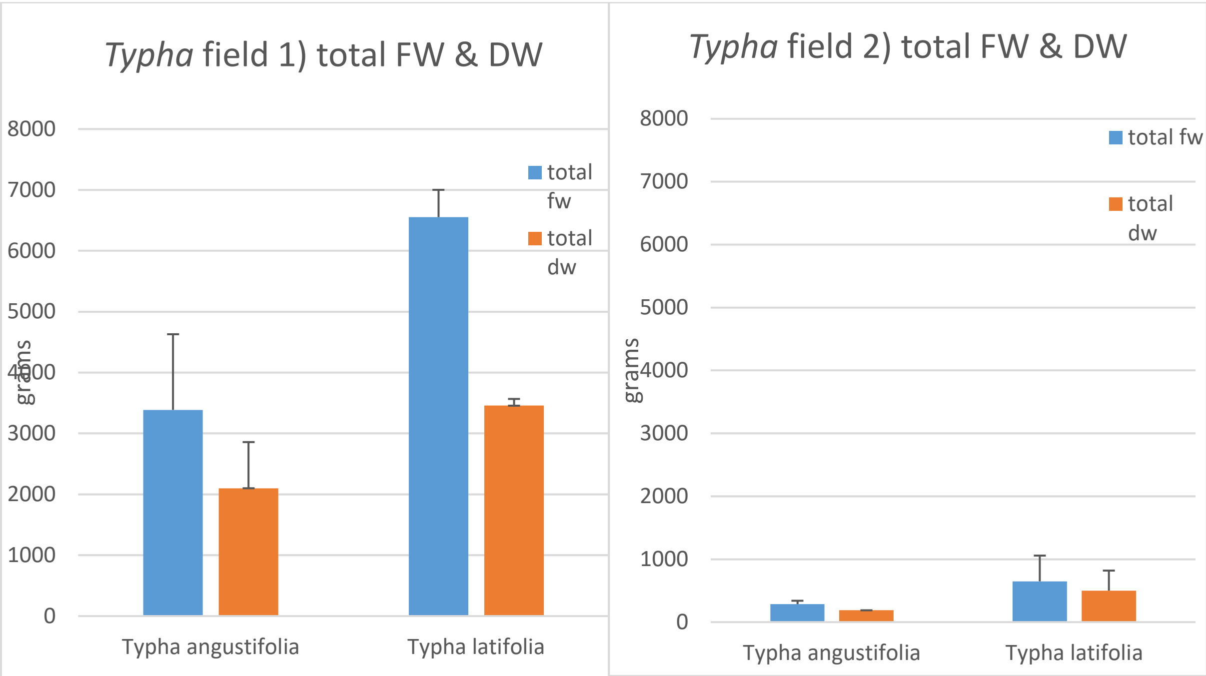


CHART 10: THE TOTAL FRESH- AND DRY WEIGHT OF *TYPHA SPEC.* IN *TYPHA* FIELD 1 AND 2

The results from the drying stove (Chart 11) show that the total loss of the biomass content was noticeably higher at 110°C than at 70°C?. Since this was the case, moisture could not have been the only factor of evaporation. Each sample was weighed for the last time on the same day, though all of the samples had shown very small changes in their weight the days before. Compared to the second to last weighing, the weight-loss of *T. latifolia* averaged at 0,86 grams for the samples at 110°C and 0,43 grams for the samples at 70°C. For *T.angustifolia* the loss of biomass compared to the previous weighing averaged at 0,83 grams for samples at 110°C and 0,30 grams for samples at 70°C. This stagnation was a good sign, since this showed that the excess moisture in the plants had almost vanished completely. As seen in Chart 11, the stalks contained the most amount of moisture, since their weight loss, regardless of temperature, was significantly higher than for the leaves.

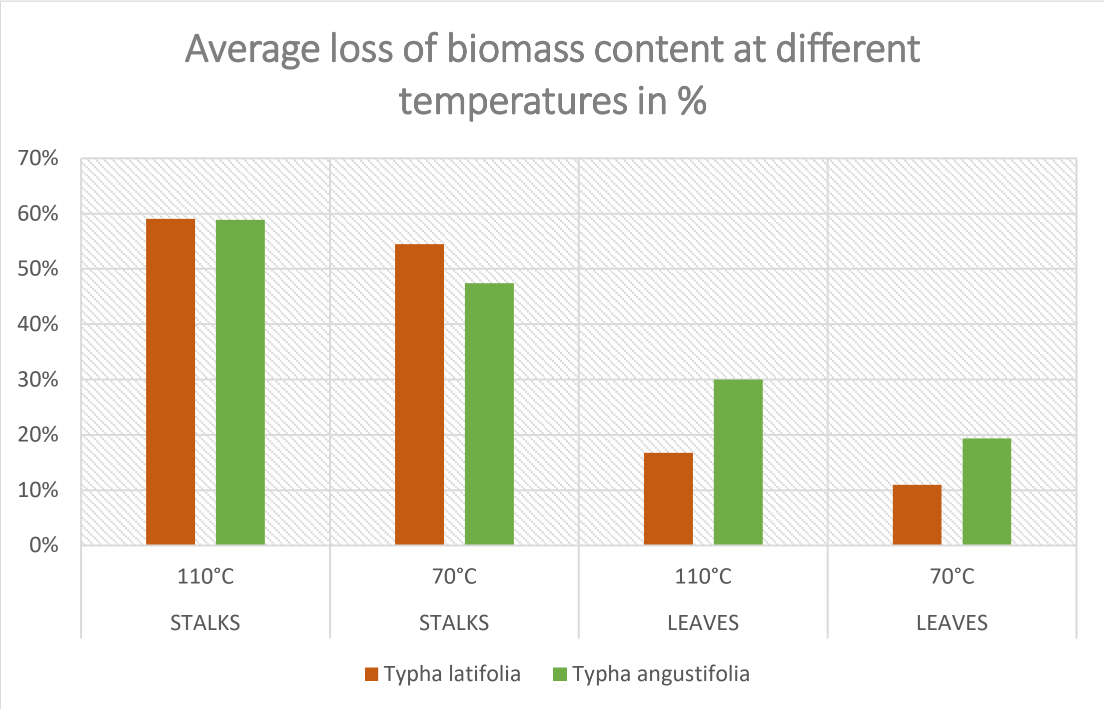


CHART 11: COMPARISON OF THE REDUCTION IN WEIGHT IN THE SAME PLOTS FOR *TYPHA SPEC.* DRIED AT 70°C AND 110°C

5 Interpretation & analysis

The following Charts show results for the *Sphagnum* pilot and the Transplantation Experiment pilot

In Chart 12, the different conditions around the pilots are shown. A clear difference can be noted between the two sites. In average, the pH in the ditch was 0,3 pH points higher in the SPH-pilot. Both sites dropped to favourable conditions for Sphagnum growth after the last measuring day (pH<6,0).

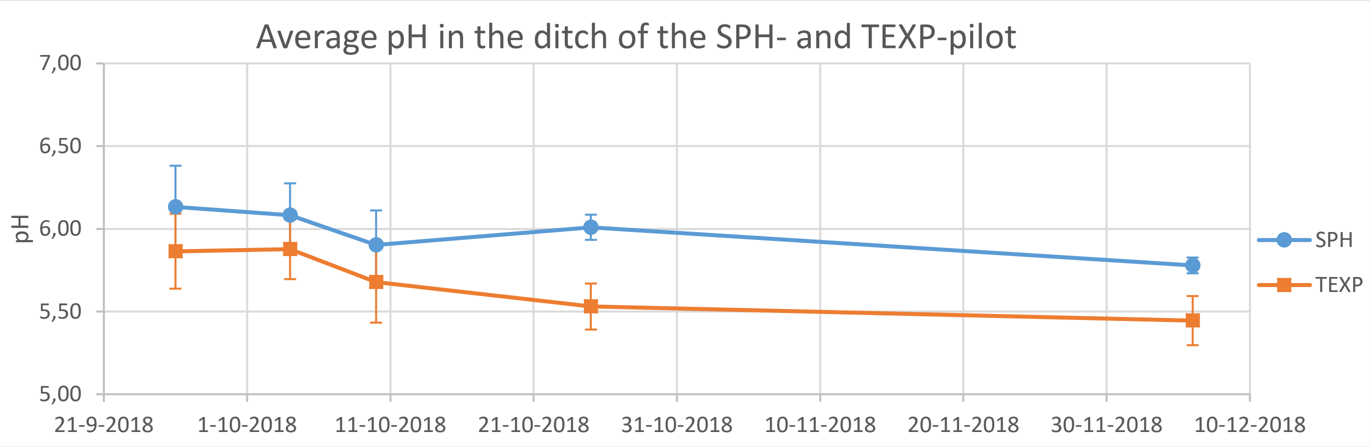


CHART 12: A DIRECT COMPARISON OF THE CONDITIONS IN THE DITCH SURROUNDING THE PILOTS.

As seen in Chart 13, the EC values in the ditch for both pilots settled at about the same value by day 35. A week before the fieldwork period begun, the inlet of the pilot was closed. At this time the values exceeded 900 µs/cm. This high value suggests that the water contains salt, which seems to come from the sandy layer below the peat: In this layer the groundwater EC was 5.854 µS/cm on 13 april 2018. It seems that low phreatic groundwater levels in the extremely dry summer led to exfiltration of this brackish groundwater into the ditch surrounding the pilot site. This is the reason for the high values at the beginning of the fieldwork period. By the end of the fieldwork period, the EC in the SPH-pilot decreased strongly. One reason could be that the vegetation in the pilot had stored an excess of precipitation that also fed the ditch.

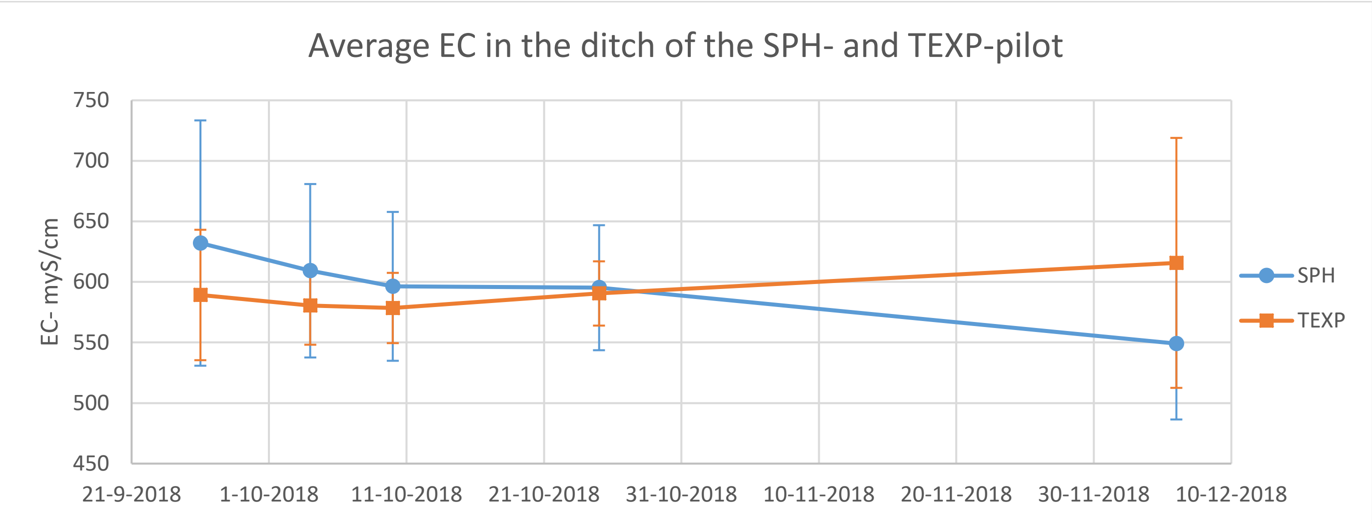


CHART 13: DIRECT COMPARISON OF THE EC-VALUES IN THE DITCH AROUND THE PILOTS

A nearby weather station tracked the change in water level for the *Sphagnum* pilot (Chart 14). The results are used for both pilots, as they had the same in-pilot conditions throughout the same period. The period of low water level between October and November reflects the dropping tendencies for the pH in the *Sphagnum* patches (Chart 8) as well as in the ditch (Chart 12). Between November and December, the ditches filled up due to longer periods of rain. Without the help of evapotranspiration, the water level had risen above the soil surface (Chart 14, grey line). Chart 8 shows how this had major influences on the growing conditions of the peat moss, as the pH rose drastically. As mentioned in 2.2.1 the original elevation of the Sphagnum sites was -1,156 m NAP. In Chart 14, the soil surface is suggested to be -1,40 m NAP, which is nearly 0,30 m lower than the map suggests. The reason for this is that the pilots were dug deeper initially, to create a new soil surface which the Sphagnum could grow on.

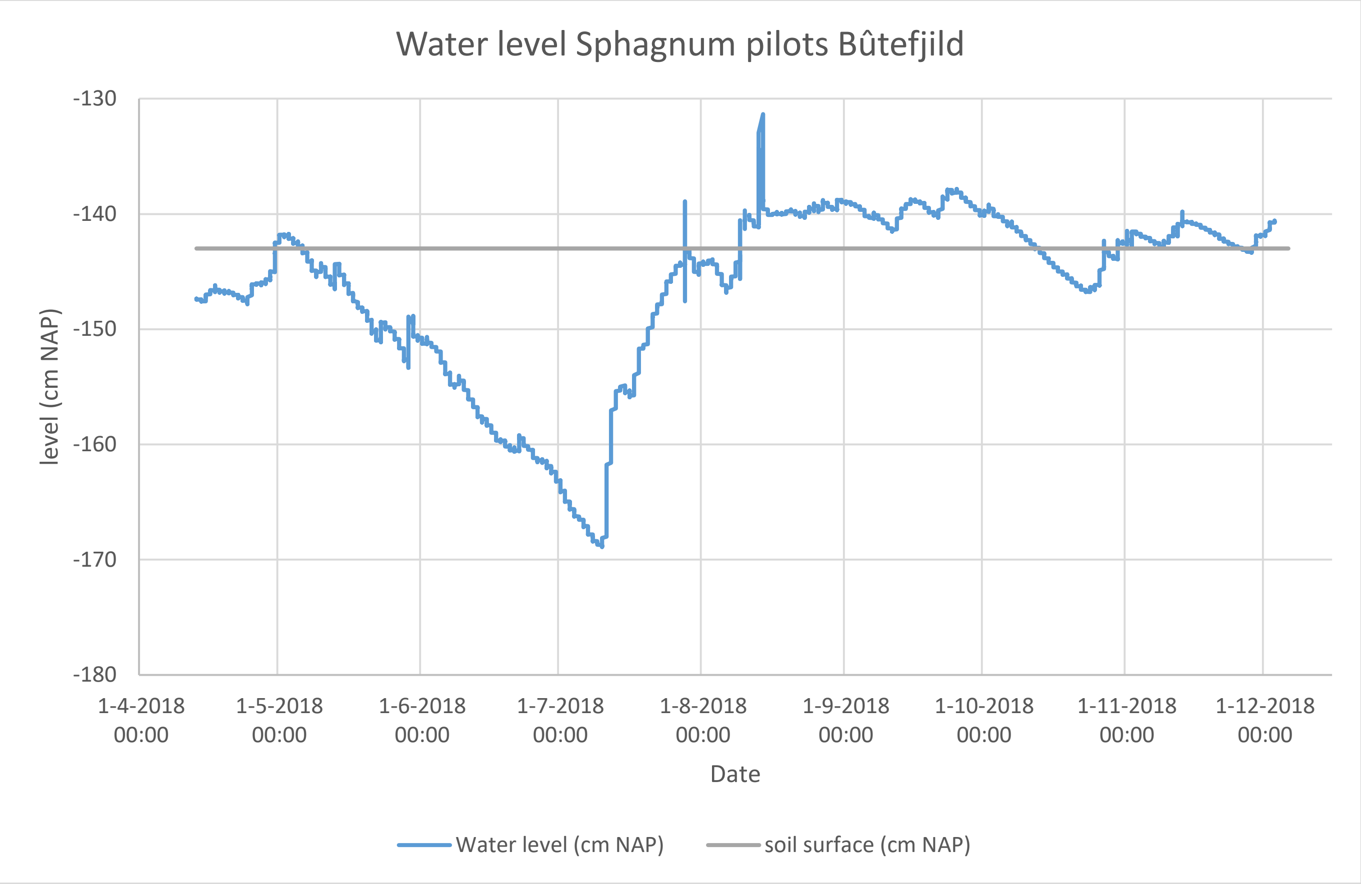


CHART 14: WATER LEVEL TO SOIL LEVEL DEVELOPMENT IN THE SPHAGNUM PILOT

To compare the effect of using different pH measuring methods in the same plots, the mean of each *Sphagnum* species is shown in Chart 15. Although the box-plots approximately show the same general results (*S. fallax/flexusoum* has the lowest pH – values, followed by *S. palustre* and *S. squarrosum*), the contrast between the methods is significant. For accurate values, where the exact pH is interesting for the results, specific measuring instruments should be considered such as the glass electrode on the multimeter.

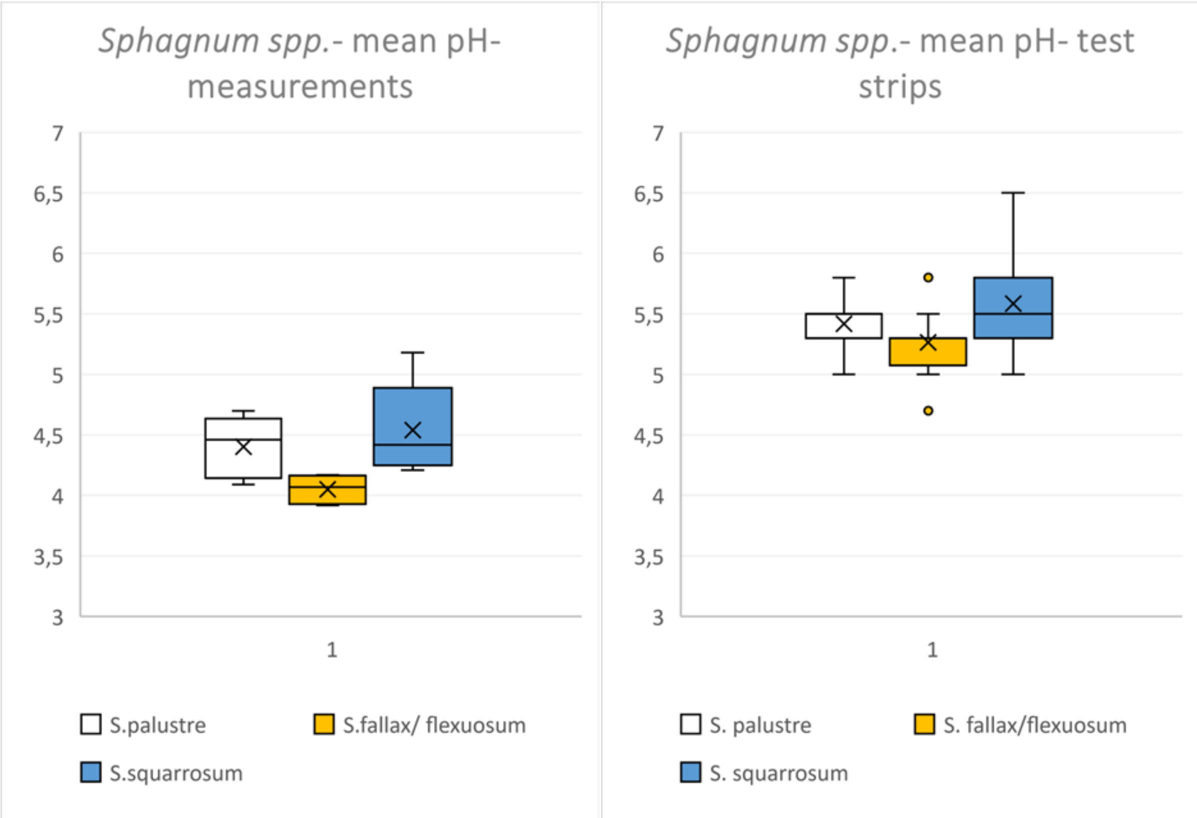


CHART 15: MEAN COMPARISON OF THE PH OF SPHAGNUM SPEC. TESTED THROUGH DIFFERENT MEASURING METHODS

On different occasions, pH-test strips and the pH measured with the multimeter were compared while measuring the same water sample (Chart 16). In the *Sphagnum* pilot, test strips were slid directly in the soil (orange line). The test strips in the transplantation experiment were immersed in the same vial of soil water used in the glass electrode measurements (yellow and blue line). Glass electrode values were derived from extraction of soil water using syringes or Rhizons, where moisture content was insufficient for collecting with syringes. The grey dashed line in figure 16 indicates the linear results measured with the multimeter. The dots (with correlating regression line) compare the pH measurements with test strips to pH values determined with a glass electrode in the same sample or (in the Sphagnum pilot) from the same soil. Dots below the regression line show where the test strip yielded lower pH values, while the dots above the line show where test strip methods yielded higher values. The aim was to look for correlation between measuring methods. As chart 16 shows, different measuring approaches can change the outcome of the results. Although far below the regression line, the test strip method used in two of the comparing cases seemed to correlate. The orange line (*Sphagnum* pilot) on the other hand showed no relation at all.

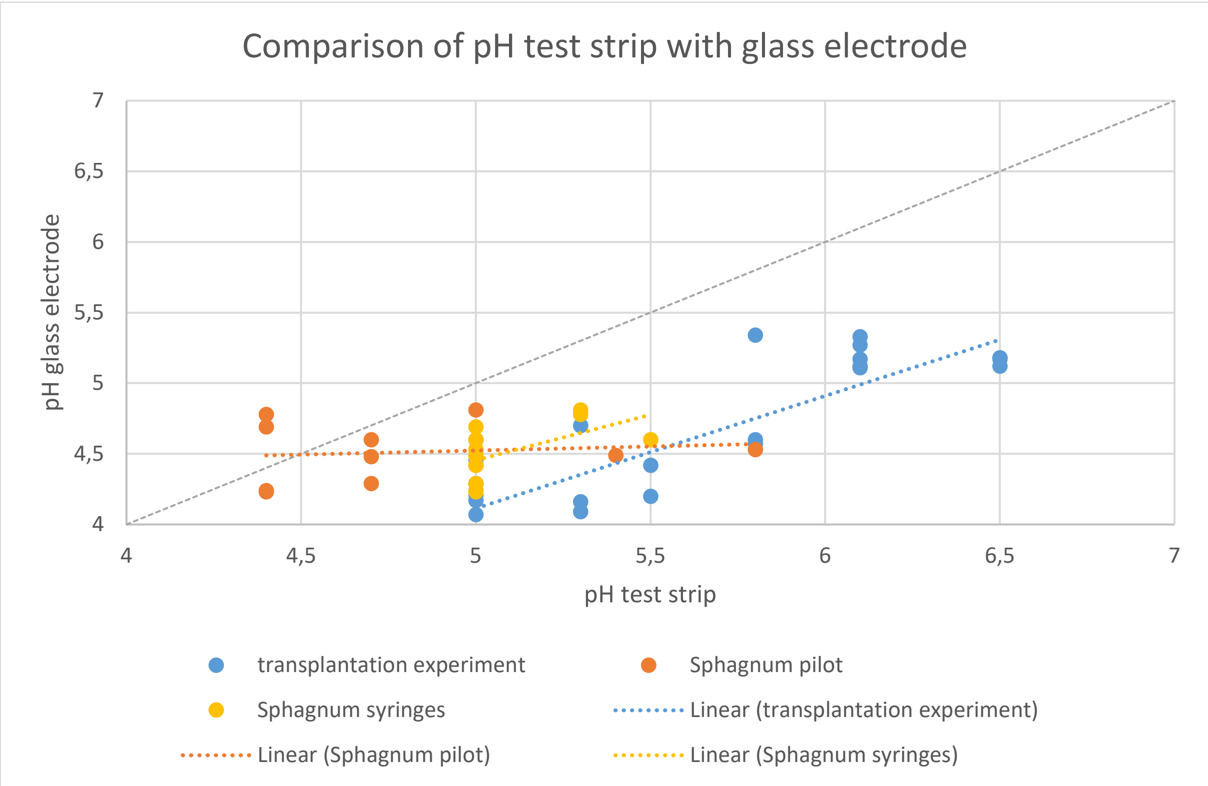


CHART 16: CORRELATION BETWEEN THE POTENTIAL REGRESSIVE ACCURACY OF PH MEASUREMENTS WITH THE MULTIMETER AND PH-TEST STRIPS

Biomass production in the second growing season

The results in Table 4 show favourable changes of the total biomass production after the growing season of 2018. The density of biomass in grams per square meter have improved with 123,3 grams (+70%) for *T.angustifolia* and 176,7 grams (+61%) for *T.latifolia*. The comparing results only apply for *Typha* field 1. In 2018, 2x2m plots were harvested, while harvesting was done in 1x1m plots in 2017. The results were re-calculated accordingly.

TABLE 4: COMPARISON OF THE BIOMASS YIELD THROUGHOUT THE GROWING SEASON OF 2017 AND 2018 (FIELD 1)

	First growing season Zeephat (2017)	Second growing season this study (2018)
g/m^2 *T.angustifolia*	51,8 g	175,1 g
ton/ha *T.angustifolia*	*0,5 (± SD 0,4)	1,75 (± SD 1,89)
g/m^2 *T.latifolia*	111,4 g	288,1 g
ton/ha *T.latifolia*	*1,1 (± SD 0,3)	2,88 (± SD 0,27)
Total ton/ha T.a+T.l	***1,6** (± SD 0,3)	**4,6** (± SD 1,93)

**Results by Zeephat (2017) modified from kg/ha to ton/ha*

The dry weight to fresh weight ratio was calculated in order to estimate the percentage (scale 0,0-1,0) of biomass conserved in the plants after the drying process (Table 5). A narrow DW/FW ratio equals a greater loss from the original weight. For the first growing season, Zeephat (2017) concluded that *T.angustifolia* had a higher DW/FW ratio, which would mean, that this species had a higher density of biomass in the plots than *T.latifolia* (Zeephat 2017).

In the growing season of 2018, similar results could be seen in *Typha* field 1. *T.angustifolia* kept 15% more of its biomass than *T.latifolia* (Table 5). Over all the biomass was preserved at a much higher rate in the growing season of 2018. One of the reasons for this was that the *Typha* biomass harvested in 2017 was greener, while large parts of biomass already had dried out in 2018. The cattail harvesting dates were similar: the 6th of October in 2017 and the 11th of October in 2018. Due to a late harvesting, a dry summer and low water levels in the pilot, the *Typha* biomass in this project had started to dry out even before it was prepared for the drying process. Fresh biomass contains more moisture, which can evaporate. The results for both growing seasons are closely comparable due to their similar harvesting dates.

TABLE 5: FW/DW RATIO FOR *TYPHA SPEC.* IN DIFFERENT GROWING SEASONS

	First growing season Zeephat (2017)	Second growing season this study (2018)
T.angustifolia (Field 1)	0,28	0,69
T.latifolia (Field 1)	0,23	0,54
T.angustifolia (Field 2)	---	0,71
T.latifolia (Field 2)	---	0,74
***Typha spec.* mean DW/FW ratio**	**0,255**	**0,67**

6 Conclusion

In this section the outcome of the results will be compared to the objectives/research questions of the report

***Sphagnum* pilot → Growth**

Question: How well does Sphagnum grow in the pilot site?

As seen in Chart 3 the distribution of *Sphagnum* has apparently decreased from the last growing season. The reason for this might have been a different monitoring method applied to the horizontal coverage. Additionally, the measuring plots had to be replotted due to large-scale damages to the previous set-up. Essentially this means that the results cannot be directly compared to one another. Nevertheless, in this growing season all plots estimated for coverage contained *Sphagnum*. This was a good sign for the expansion of the *Sphagnum*. In conclusion, the *Sphagnum* seems to continue its growth at the site.

Question: Is there difference in growth rate between area A seeded with Sphagnum rich material and area B seeded with less Sphagnum rich material?

Although the differences between the two sections is not clear to determine, it is still possible to see a more even distribution of the *Sphagnum* in sector A (Chart 3). Based on the fact, that this sector was seeded with *Sphagnum* rich material, the results do not show a favourable development. One would assume the coverage to be noticeably denser in sector A than in Sector B, which it is not.

***Typha* pilot → Above ground biomass production**

Question: How much biomass do Typha spec. produce in the Bûtefjild area?

In the second year of biomass harvesting, both *Typha* fields contained more biomass than in the last growing season. One of the biggest differences in this year's crops was the amount of flowers produced for both species. Naturally, this increased the total biomass. *Typha* field 2 still had issues to create a homogenous distribution of the *Typha*. The results from this field are the least promising for harvesting and further paludiculture (Chart 9D, 9E and 10).

Question: Did it have an effect, that the Typha was dried at different temperatures?

The results of the drying stove showed, that there was a noticeable difference of drying plants at 70°C and 110°C (Chart 11). Especially *T. angustifolia* benefitted from the lower temperatures and lost 11% (leaves)/12% (stalks) less of its biomass at 70°C compared to 110°C. The biomass of *T. latifolia* was also preserved better at 70°C. The loss was 6% (leaves)/ 5% (stalks) lower than at 110°C. This difference in weight from higher to lower temperatures was not due to the differences in loss of moisture. There is ground enough for this statement, as all samples were left in the oven until no further loss of weight occurred. Hence, the results suggest that the drying cycle at 110°C, destroyed some of the biomass in the samples.

Question: Is there a difference in biomass production between T.latifolia and T. angustifolia?

The two *Typha* species do differ in their above ground biomass production. In three of the five plots harvested, *T.latifolia* dominated in dry weight (Chart 9A-9E). With a total dry weight of 3957g, the biomass of *T.latifolia* is higher than the dry weight of *T.angustifolia* with 2288g. It should however not be left unnoticed, that *T. latifolia* lost a total of 3244g or 45% of its original weight through the drying process, while *T. angustifolia* only lost 1386g or 38% of its fresh weight. Nevertheless, there is enough reason to conclude that the total biomass production of *T.latifolia* was higher.

Transplantation experiment → Adaptation and development

Question: Which of the three most promising Sphagnum species for paludiculture grows best under the current conditions at the pilot site?

Out of the three species, *S. fallax/flexuosum* created the most acidic habitat. It distinguished itself clearly from *S. palustre* and *S. squarrosum* through its low pH values (Chart 15) and new shoots, which developed at a faster rate. Although the starting conditions were different for all plots, all Sphagnum patches survived. The development of *S. squarrosum* was the most surprising. The patches of this species, transplanted to the field, had a noticeably smaller circumference compared *to S.fallax/flexuosum* and *S.palustre*, and where thus forced to cope with a proportional greater water depth (Table 3). Due to these worsened starting conditions, two of the patches did not catch on to the soil for two weeks, but managed to adapt well after 78 days. A welcoming sign was the production of fresh shoots and a slight expansion in all plots (Table 3). This might have been influenced by a linear decrease of the water level (until it suddenly rose rapidly by the end of November). Interestingly, *S. squarrosum* always showed higher pH values than the other species. This might be linked to the species favourability for nutrient enriched soils, more than other peat moss species. *Sphagnum palustre* also showed slightly higher pH-values than *S. fallax/flexuosum* and overall showed a very good adaptation to the plot.

Due to constantly lower pH-values in the surrounding ditch of the transplantation experiment, it would be possible to conclude, that the in-pilot conditions might be better suited as *Sphagnum* growing ground than the already established *Sphagnum* pilot (Chart 12). As the site was newly established, the vegetation growing there was still in its early developing stages. In the surrounding ditch, almost no overgrowth was found. Thus creating perfect conditions for this experiment. Contrary to this, the ditch in the existing Sphagnum pilot had been infiltrated by various other aquatic plants such as duckweed and algae. Whether this was the reason for higher pH-values was not tested. However, there is reason to assume so since water plants have the ability to gather carbon dioxide from the water, which increases the pH.

Although *S. fallax/flexuosum* had the ability to form new shoots very fast, it showed restrictions to expand outside of the original soil contained in the patch. *S. squarrosum* and *S. palustre* on the other hand, unrestrictedly grew new shoots in the complete plot (this was the case for all 5 patches). Based on the growth performance, both species seemed to perform better under the pilot´s site conditions. Suggestions for future paludiculture cultivation, would thus be to consider a nutrient loving *Sphagnum spp*. such as *S. squarrosum* or *S. palustre*, since they seemed to have the highest tolerance towards extreme growing conditions and, compared to the other test species, showed a favour for the actual soil in the pilot.

7 Discussion

Paludiculture is a concept for the future. Small-scale pilot sites such as the *Typha* and *Sphagnum* pilot in Bûtefjild, are necessary steps to test its sustainability in different settings. Part of this is to get an idea of the profit potential. If, after several growing seasons, the yield of a crops seems stagnating in its development or the ideal potential of the site seems out of reach, questions should be asked in terms of how approaches can be changed and if the current method of execution gives reason and results enough for further monitoring.

The progress in the first field of the *Typha* pilot, showed a favourable yield of *Typha spec*. after the second growing season. However, in a context where the profitability is brought into question, the estimated 4.6 ton dm/ha in the 450m^2 basin only reached the bottom line of what can be expected from the crops. As Wichtmann et al. (2016) suggests, the above ground biomass may provide yields of 4.3-22.1 t DM ha^{-1} a^1 (Dubbe et al. 1988, Timmermann 2003, Cicek et al. 2006, Leffler 2007, Heinz 2011; all in Wichtmann et al. 2016 Table 3.3,). In comparison, similar pilots in the Netherlands show much higher yields under similar conditions after the same amount of time. In Zegveld (Province of Utrecht), a paludiculture site with *Typha* planted in plots with high and low water tables was set up (as part of the CINDERELLA project). In the second growing season, the yield of *T.angustifolia* in the dry plots was estimated to 6.6 ton dm/ ha and 4.4 ton dm/ha for *T.latifolia*. Although the biomass production of *T.latifolia* was two times higher at high water levels (9.2 ton dm/ha) (Geurts et al. 2018). Despite using the same method (stable high water level), the *Typha spec*. in Bûtefjild encountered low yields probably due to low plant densities and low nutrient availability (Mettrop et al. in; Geurts et al. 2018). Additionally, the overall lower water levels in the growing season of 2018 should be considered in the outcome of the upcoming year's harvesting.

To keep up good growing conditions in the first time after the establishment of a *Typha* paludiculture, it is very important to raise and keep the (ground) water level above the soil surface (Geurts et al. 2018). Wet conditions will stimulate germination, but water levels should maximally be 5 cm above the soil surface for seedlings (i.e. moderate surface flooding; Münxer 2001; Heinz 2012; Geurts et al. 2018). Taller plants should not endure longer periods with groundwater levels of -20cm and lower, since this will certainly harm the *Typha* plants and reduce biomass production, even on longer terms (Geurts et al. 2018).

Large-scale paludiculture pilots in Germany make a good comparison to set the *Sphagnum* pilot in Bûtefjild into perspective. In 2011, a 4 ha experimental area was established on bog grassland near Oldenburg (Lower Saxony) (…). After 1,5 years, a 95% cover of *Sphagnum* mosses (consisting of *S. palustre*, *S. fallax* and *S. papillosum*))with a medium lawn height of 8,3 cm (max. 22,4 cm) was obtained (Joosten et al. 2013; Wichtmann et al. 2016). After 3-4 years, it is possible to harvest the peat moss for the first time (Wichtmann et al. 2016). Despite of a dry summer, the *Sphagnum spec*. in Bûtefjild still performed well, and did not show a weakened growth rate. To keep up with paludiculture sites such as in Hankhausen though, performance rates would have to increase immensely. The average peat moss coverage in Bûtefjild for the fall of 2018 is estimated to 3,9% per 1m^2 (average of 12 1x1 m plots). With a total size of 500m^2, the *Sphagnum spec*. would thus only cover 19,5m^2 of the pilot. This amount does not project enough biomass yield for harvesting or horticulture growing media. The exact reasons for the poor performance of *Sphagnum* growth demand for further research. However, the peat moss was seeded together with biomass from grasses, which also have caught on well to the pilot. As of this, the *Sphagnum* in Bûtefjild has to compete with grasses. Other pilots or paludiculture sites seeded with *Sphagnum* only (such as in Hankhausen), will thus not take effect from this to the same extent.

For further improvement, measures should be taken to increase the growth rate. A study carried out by Gaudig et al. (2017) demonstrated that high *Sphagnum* yields can be achieved on cut-over (milled) bogs with black peat at the surface (Gaudig et al. 2017). To ensure steady growth rates, a high and constant water table of few centimetres below the moss surface can be achieved with controlled irrigation and drainage (Gaudig et al. 2014).

Necessary water reservoirs can also be used for *Sphagnum* farming by covering them with floating mats. Such mosaic of different production systems could represent an optimal arrangement for *Sphagnum* farming on rewetted bog sites (Wichtmann et al. 2016) (Figure 16). At this stage, the aim of the pilot in Bûtefjild is the *Sphagnum* growth on flooded cutover bogs to ensure permanent water submersion, whereas the water supply is regulated through the existing inlet. For a small-scale pilot, small steps are necessary to test for suitability and should not exceed these, unless the success rate passes the expectations.

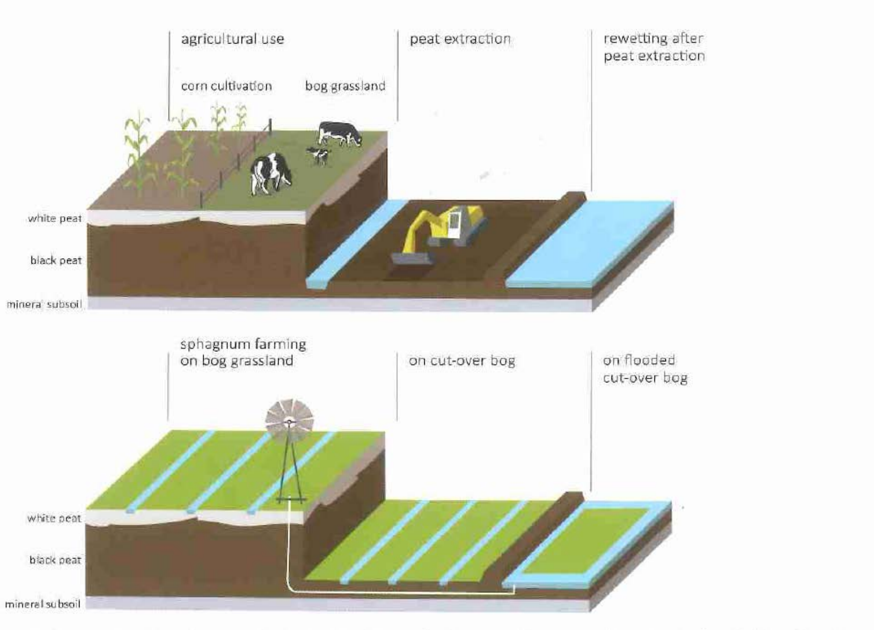


FIGURE 16: CONVENTIONAL LAND-USE ON DRAINED RAISED BOGS (TOP) VERSUS *SPHAGNUM* FARMING (BOTTOM) (AFTER GAUDIG ET AL. 2014; IN WICHTMANN ET AL. 2016)

The intertwined relationship between crops and site parameters is not to be neglected when establishing new experimental pilots. If the crop is not suited for the conditions of a site (and vice versa), results will be meagre. This is why time and effort has to be put into research to find the reason for why the crops perform well or not so well under the given site conditions. These results should be considered before a conclusive statement can be made.

Amongst others, *S. squarrosum*, *S. palustre* and *S. fallax*, proved to be suitable as growing media constituents in horticultural experiments (Gaudig et al. 2018). This was proven to be true, as all tested species were able to develop under changing conditions at a site based on degraded peatland. After a decade of research Gaudig et al. (2018) could conclude, that *S. palustre* is one of the most promising species for both growing media and *Sphagnum* farming (Gaudig et al. 2014). The *Sphagnum* pilot and the transplantation experiment looked upon in this report, showed the prediction, that the species is able to develop and grow in the pilots. Whether or not it performed better than other species has to be followed up through specifically aimed monitoring.

As a paludiculture site, the Bûtefjild area shows potential. While not as promising as Typha and Sphagnum growth on larger sites in Germany or in the Netherlands, the pilots have proven that results can be achieved after just two growing seasons. Suggestions for upcoming projects would be to improve controlled conditions (i.e. a stable water table), the set-up of the pilot (for monitoring), and growth rates. A constant change from high to low water levels will influence the development of the crops. Nevertheless, further monitoring will prove, whether there is certainty in the information gathered and show if there is a future for small-scale paludiculture in Bûtefjild

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Appendix A

Legend BOD50 2009

Legenda

Veengronden

- hVb Koopveengronden op bosveen (of eutroof broekveen)
- hVs Koopveengronden op veenmosveen
- hVc Koopveengronden op zeggeveen, rietzeggeveen of (mesotroof) broekveen
- hVr Koopveengronden op rietveen of zeggerietveen
- hVz Koopveengronden op zand, beginnend ondieper dan 120 cm
- aVz Madeveengronden op zand zonder humuspodzol, beginnend ondieper dan 120 cm
- aVp Madeveengronden op zand met humuspodzol, beginnend ondieper dan 120 cm
- pVs Weideveengronden op veenmosveen
- pVc Weideveengronden op zeggeveen, rietzeggeveen of (mesotroof) broekveen
- pVr Weideveengronden op rietveen of zeggerietveen
- pVz Weideveengronden op zand, beginnend ondieper dan 120 cm
- kVs Waardveengronden op veenmosveen
- kVc Waardveengronden op zeggeveen, rietzeggeveen of (mesotroof) broekveen
- kVz Waardveengronden op zand, beginnend ondieper dan 120 cm
- zVs Meerveengronden op veenmosveen
- zVp Meerveengronden op zand met humuspodzol, beginnend ondieper dan 120 cm
- Vs Vlierveengronden op veenmosveen
- Vc Vlierveengronden op zeggeveen, rietzeggeveen of (mesotroof) broekveen
- Vz Vlierveengronden op zand zonder humuspodzol, beginnend ondieper dan 120 cm
- Vp Vlierveengronden op zand met humuspodzol, beginnend ondieper dan 120 cm

Moerige gronden

- kWp Moerige podzolgronden met een zavel- of een kleidek en een moerige tussenlaag
- vWp Moerige podzolgronden met een moerige bovengrond
- zWp Moerige podzolgronden met een humushoudend zanddek en een moerige tussenlaag
- Wo Moerige eerdgronden met een moerige bovengrond of moerige tussenlaag op niet-gerijpte zavel of klei
- vWz Moerige eerdgronden met een moerige bovengrond op zand

Moderpodzolgronden

Humuspodzolgronden

- Hn21 Veldpodzolgronden; leemarm en zwak lemig fijn zand
- Hn23 Veldpodzolgronden; lemig fijn zand
- cHn21 Laarpodzolgronden; leemarm en zwak lemig fijn zand
- cHn23 Laarpodzolgronden; lemig fijn zand

Leembrikgronden

Oude kleibrikgronden

Zand Brikgronden

Enkeergronden

- zEZ21 Hoge zwarte enkeerdgronden; leemarm en zwak lemig fijn zand
- zEZ23 Hoge zwarte enkeerdgronden; lemig fijn zand

Tuineerdgronden

Kalkloze zandgronden

- pZg21 Beekeerdgronden; leemarm en zwak lemig fijn zand
- pZg23 Beekeerdgronden; lemig fijn zand
- pZn23 Gooreerdgronden; lemig fijn zand
- Zn21 Vlakvaaggronden; leemarm en zwak lemig fijn zand

Kalkhoudende zandgronden

Niet gerijpte zeekleigronden

- MOo02 Slikvaaggronden; zand beginnend ondieper dan 80 cm
- MOo05 Slikvaaggronden; geen zand beginnend ondieper dan 80 cm
- MOb72 Gorsvaaggronden; zware zavel en klei; zand beginnend ondieper dan 80 cm
- MOb75 Gorsvaaggronden; zware zavel en klei; geen zand beginnend ondieper dan 80 cm

Niet gerijpte rivierkleigronden

Zeekleigronden

- pMo80 Tochteerdgronden; klei
- pMn85C Kalkarme leek-/woudeerdgronden; klei, profielverloop 5
- pMn55C Kalkarme leek-/woudeerdgronden; zavel, profielverloop 5
- Mv61C Kalkarme drechtvaaggronden; zavel en lichte klei, profielverloop 1
- Mv41C Kalkarme drechtvaaggronden; zware klei, profielverloop 1
- Mo20A Kalkrijke nesvaaggronden; zware zavel
- Mo80A Kalkrijke nesvaaggronden; klei
- Mo80C Kalkarme nesvaaggronden; klei
- Mn15A Kalkrijke poldervaaggronden; lichte zavel, profielverloop 5
- Mn25A Kalkrijke poldervaaggronden; zware zavel, profielverloop 5
- Mn35A Kalkrijke poldervaaggronden; lichte klei, profielverloop 5
- Mn45A Kalkrijke poldervaaggronden; zware klei, profielverloop 5
- Mn15C Kalkarme poldervaaggronden; lichte zavel, profielverloop 5
- Mn25C Kalkarme poldervaaggronden; zware zavel, profielverloop 5
- gMn53C Knippige poldervaaggronden; zavel, profielverloop 3
- gMn58C Knippige poldervaaggronden; zavel, profielverloop 4, of 4 en 3
- gMn83C Knippige poldervaaggronden; klei, profielverloop 3
- gMn88C Knippige poldervaaggronden; klei, profielverloop 4, of 4 en 3
- gMn15C Knippige poldervaaggronden; lichte zavel, profielverloop 5
- gMn25C Knippige poldervaaggronden; zware zavel, profielverloop 5
- gMn85C Knippige poldervaaggronden; klei, profielverloop 5
- kMn63C Knippoldervaaggronden; zavel en lichte klei, profielverloop 3
- kMn43C Knippoldervaaggronden; zware klei, profielverloop 3
- kMn48C Knippoldervaaggronden; zware klei, profielverloop 4, of 4 en 3

Rivierkleigronden

Oude rivierkleigronden

Leemgronden

Zeer oude mariene afzettingen

Zeer oude fluviatiele afzettingen

Kalksteenverweringsgronden

Keileem en Potklei

- KX Zeer ondiepe keileem, potklei, enz

Overige kleigronden

Associaties van vele enkelvoudige eenheden

- AAP Aangemaakte petgaten
- AP Petgaten

Algemene onderscheidingen

- Oude bewoningsplaatsen
- Bebouwing
- Moeras
- Water
- Dijk
- Opgehoogd of opgespoten

Toevoegingen

- b... kruinige percelen
- k... zavel- of kleidek 15 à 40 cm dik
- s... zanddek, 5 à 15 cm dik
- ...l plaatselijk katteklei beginnend ondieper dan 80 cm en tenminste 10 cm dik
- ...p pleistoceen zand beginnend tussen 40 en 120 cm
- ...v moerig materiaal beginnend dieper dan 80 cm en doorgaand dieper dan 120 cm
- ...x oude klei beginnend tussen 40 en 120 cm en tenminste 20 cm dik

- afgegraven
- opgehoogd
- geëgaliseerd
- vergraven

Grondwatertrappen

Grondwatertrap (Gt)	I	II	IIb	III	IIIb	IV	V	Vb	VI	VII	VIII
Gemiddeld hoogste grondwaterstand in cm beneden maaiveld (GHG)	(<20)	(<40)	25-40	<40	25-40	>40	<40	25-40	40-80	80-140	>140
Gemiddeld laagste grondwaterstand in cm beneden maaiveld (GLG)	<50	50-80	50-80	80-120	80-120	80-120	>120	>120	>120	>160	>160

b... buiten de hoofdwaterkering gelegen gronden; periodiek overstroomd
s... schijnspiegels; bij gronden met een fluctuatie (GLG-GHG) van meer dan 120 cm
w...water boven maaiveld gedurende meer dan 1 maand in winterperiode

ALTERRA
WAGENINGEN UR

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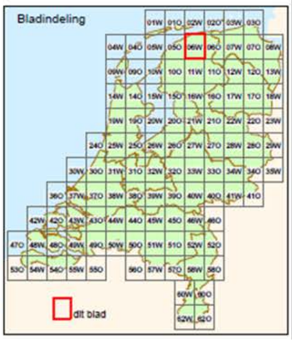
Hillshade: AHN © AGI, Rijkswaterstaat



Appendix B

Results Braun Blanquet Recording 11.10.2018

It is to be noted, that the results of the recording, only estimate the total coverage of species in the 2x2m plots, abandoning an individual coverage of dominance in each height layer of vegetation. The plots 1-A, 1-B, and 1-C are from Lisdoddeveld 1 whilst plots 2-A and 2-B are from Lisdoddeveld 2.

	Scientific species name	Common name (Dutch)	Common name (English)	Cover abundance values
Plot 1-A	*Typha angustifolia*	(Kleine lisdodde)	(Narrowleaf cattail)	2a
	Typha latifolia	(Grote lisdodde)	(Broadleaf cattail)	1
	Alisma plantago-aquatica	(Grote waterweegbree)	(European water-plantain)	1
	Juncus effusus	(Pitrus)	(Common rush)	1
	Juncus articulatus	(Zomprus)	(Jointleaf rush)	1
	Glyceria spec.	(Vlotgras)	(Sweet-grass)	1
	Agrostis stolonifera	(Fioringras)	(Creeping bentgras)	1
	Schoenoplectus tabernaemontani	(Ruwe bies)	(Softstem bulrush)	+
	Sparganium erectum	(Grote egelskop)	(Simplestem bur-reed)	+
	Rumex hydrolapathum	(Waterzuring)	(Great water dock)	r
	Persicaria hydropiper	(Waterpeper)	(Water-pepper)	r
	Rorippa spec.	(Waterkers)	(Yellowgress)	r

Average height: 160 cm
Max. height: 180 cm

	Scientific species name	Common name (Dutch)	Common name (English)	Cover abundance values
Plot 1-B	*Juncus articulatus*	(Zomprus)	(Jointleaf rush)	2b
	Typha angustifolia	(Kleine lisdodde)	(Narrowleaf cattail)	2a
	Typha latifolia	(Grote lisdodde)	(Broadleaf cattail)	2a
	Juncus effusus	(Pitrus)	(Common rush)	1
	Alisma plantago-aquatica	(Grote waterweegbree)	(European water-plantain)	1
	Glyceria maxima	(Liesgras)	(Reed mannagrass)	1
	Schoenoplectus tabernaemontani	(Ruwe bies)	(Softstem bulrush)	1
	Lythrum salicaria	(Grote kattenstaart)	(Purple loosestrife)	+
	Agrostis stolonifera	(Fioringras)	(Creeping bentgrass)	+

Average height: 160 cm
Max. height: 180 cm

	Scientific species name	Common name (Dutch)	Common name (English)	Cover abundance values
Plot 1-C	*Typha latifolia*	(Grote lisdodde)	(Broadleaf cattail)	2a
	Juncus effusus	(Pitrus)	(Common rush)	2a
	Juncus articulatus	(Zomprus)	(Jointleaf rush)	2a
	Typha angustifolia	(Kleine lisdodde)	(Narrowleaf cattail)	1
	Alisma plantago-aquatica	(Grote waterweegbree)	(European water-plantain)	1
	Glyceria spec.	(Vlotgras)	(Sweet-grass)	1
	Agrostis stolonifera	(Fioringras)	(Creeping bentgras)	1
	Eleocharis acicularis	(Naaldwaterbies)	(Needle spikerush)	1
	Lemna minor	(Klein kroos)	(Common duckweed)	+
	Agrostis stolonifera	(Fioringras)	(Creeping bentgrass)	+
	Rorippa spec.	(Waterkers)	(Yellowcress)	r

Average height: 150 cm
Max. height: 170 cm

	Scientific species name	Common name (Dutch)	Common name (English)	Cover abundance values
Plot 2-A	*Agrostis stolonifera*	(Fioringras)	(Creeping bentgrass)	3
	Typha angustifolia	(Kleine lisdodde)	(Narrowleaf cattail)	1
	Typha latifolia	(Grote lisdodde)	(Broadleaf cattail)	1
	Juncus effusus	(Pitrus)	(Common rush)	1
	Juncus articulatus	(Zomprus)	(Jointleaf rush)	1
	Eliocharis acicularis	(Naaldwaterbies)	(Needle spikerush)	1
	Alisma plantago-aquatica	(Grote waterweegbree)	(European water-plantain)	+
	Glyceria spec.	(Liesgras)	(Reed mannagrass)	+

Average height: 120 cm
Max. height: 130 cm

	Scientific species name	Common name (Dutch)	Common name (English)	Cover abundance values
Plot 2-B	*Typha latifolia*	(Grote lisdodde)	(Broadleaf cattail)	2a
	Juncus effusus	(Pitrus)	(Common rush)	2a
	Typha angustifolia	(Kleine lisdodde)	(Narrowleaf cattail)	1
	Persicaria hydropiper	(Waterpeper)	(Water-pepper)	1
	Agrostis stolonifera	(Fioringras)	(Creeping bentgrass)	1
	Eliocharis acicularis	(Naaldwaterbies)	(Needle spikerush)	1
	Alisma plantago-aquatica	(Grote waterweegbree)	(European water-plantain)	+
	Rorippa spec.	(Waterkers)	(Yellowgress)	+

	Ranunculus acris	(Scherpe boterbloem)	(meadow buttercup)	+
	Juncus articulatus	(Zomprus)	(Jointleaf rush)	+

Average height: 110 cm
Max. height: 120 cm

Artmächtigkeitsskala/ Braun Blanquet cover abundance scale

nach Braun-Blanquet (1928), modifiziert nach Reichelt & Wilmanns (1973) in Dierschke (1994)

Value	Number of Individuals	Coverage
r	1	< 5 %
+	2 - 5	< 5 %
1	6 - 50	< 5 %
2m	> 50	< 5 %
2a	beliebig	5 – 15 %
2b	beliebig	16 – 25 %
3	beliebig	26 – 50 %
4	beliebig	51 – 75 %
5	beliebig	76 – 100 %

Source: Schulz, C., HNEE (Teacher , University of sustainable development Eberswalde)

Appendix C

Plot	Species	pH-test strip	pH-Rhizon/ Multimeter	EC µS/cm	Water-Table Depth	Circumference	Height	Note
1	Sp							
2	**ref.plot**							
3	Sff							
4	Ss							
5	Ss							
6	**ref.plot**							
7	Sp							
8	Sff							
9	Sp							
10	Sff							
11	**ref.plot**							
12	**ref.plot**							
13	**ref.plot**							
14	Sff							
15	Ss							
16	Sp							
17	**ref.plot**							
18	**ref.plot**							
19	Sp							
20	Ss							
21	Sff							
22	Ss							
23	**ref.plot**							
24	**ref.plot**							

*ref.plot= *reference plots*

Appendix D

A11

A21

A31

A12

A22

A32

B11

B21

B31

B12

B22

B32

Comparison of pH-Measurement Methods – Sphagnum pilot

	A12	A11	A22	A21	A32	A31	B12	B11	B22	B21	B31	B32
pH test strip												
Rhizon												

Veenmos monitoring formulier

Weersomstandigheden:
Neerslag:……………………………………………….
Bewolking: ……………………………. % bewolkt
Buitentemperatuur:……………………………….
Wind:…………………………………………………

Monsternemer:

Datum:

Tijdstip:

Multimeter: 0,3 meter uit de kant in het water uitgevoerd. De metingen worden 0,3 meter diep gedaan.

C1	C2	C3	C4	C5	C6	C7	C8
pH: EC: µS/cm Temp.: (°C) ORP: mV	pH: EC: µS/cm Temp.: (°C) ORP: mV	pH: EC: µS/cm Temp.: (°C) ORP: mV	pH: EC: µS/cm Temp.: (°C) ORP: mV	pH: EC: µS/cm Temp.: (°C) ORP: mV	pH: EC: µS/cm Temp.: (°C) ORP: mV	pH: EC: µS/cm Temp.: (°C) ORP: mV	pH: EC: µS/cm Temp.: (°C) ORP: mV

Eens per twee weken:________________________

Hoogte veenmos (cm)

A1	A2	A3	B1	B2	B3

----------------Bedekking----------

Monstername (%) APRIL

MA1	M A2	M A3	M B1	M B2	M B3

Appendix E

	Typha latifolia - STALKS											
	Sample	Drying at 110°C		1-A-T.l^{S}		1-B-T.l^{S}		1-C-T.l^{S}		2-A-T.l^{S}		2-B-T.l^{S}
	Sample	Drying at 70°C		1-A70-T.l^{S}		1-B70-T.l^{S}		1-C70-T.l^{S}		2-A70-T.l^{S}		2-B70-T.l^{S}
°C	Weighing tin (grams)											
°C												
°C	Fresh weight + tin (grams)											
°C												
°C	Day I (grams)											
°C												
°C	Day II (grams)											
°C												
°C	Day III (grams)											
°C												
°C	Day IV (grams)											
°C												
°C	Day V (grams)											
°C												
°C	Total: dry weight (grams)											
°C												

	Typha latifolia - LEAVES											
	Sample	Drying at 110°C		1-A-T.I^{L}		1-B-T.I^{L}		1-C-T.I^{L}		2-A-T.I^{L}		2-B-T.I^{L}
	Sample	Drying at 70°C		1-A70-T.I^{L}		1-B70-T.I^{L}		1-C70-T.I^{L}		2-A70-T.I^{L}		2-B70-T.I^{L}
°C	Weighing tin (grams)											
°C												
°C	Fresh weight + tin (grams)											
°C												
°C	Day I (grams)											
°C												
°C	Day II (grams)											
°C												
°C	Day III (grams)											
°C												
°C	Day IV (grams)											
°C												
°C	Day V (grams)											
°C												
°C	Total: dry weight (grams)											
°C												

	Typha latifolia - FLOWER HEADS											
	Sample	Drying at 110°C		1-A-T.I^{FH}		1-B-T.I^{FH}		1-C-T.I^{FH}		2-A-T.I^{FH}		2-B-T.I^{FH}
	Sample	Drying at 70°C		1-A70-T.I^{FH}		1-B70-T.I^{FH}		1-C70-T.I^{FH}		2-A70-T.I^{FH}		2-B70-T.I^{FH}
°C	Weighing tin (grams)											
°C												
°C	Fresh weight + tin (grams)											
°C												
°C	Day I (grams)											
°C												
°C	Day II (grams)											
°C												
°C	Day III (grams)											
°C												
°C	Day IV (grams)											
°C												
°C	Day V (grams)											
°C												
°C	Total: dry weight (grams)											
°C												

	Typha angustifolia - *STALKS*											
	Sample	Drying at 110°C		1-A-T.a^{S}		1-B-T.a^{S}		1-C-T.a^{S}		2-A-T.a^{S}		2-B-T.a^{S}
	Sample	Drying at 70°C		1-A70-T.a^{S}		1-B70-T.a^{S}		1-C70-T.a^{S}		2-A70-T.a^{S}		2-B70-T.a^{S}
°C	Weighing tin (grams)											
°C												
°C	Fresh weight + tin (grams)											
°C												
°C	Day I (grams)											
°C												
°C	Day II (grams)											
°C												
°C	Day III (grams)											
°C												
°C	Day IV (grams)											
°C												
°C	Day V (grams)											
°C												
°C	Total: dry weight (grams)											
°C												

	Typha angustifolia – *LEAVES*											
	Sample	Drying at 110°C		1-A-T.a^{L}		1-B-T.a^{L}		1-C-T.a^{L}		2-A-T.a^{L}		2-B-T.a^{L}
	Sample	Drying at 70°C		1-A70-T.a^{L}		1-B70-T.a^{L}		1-C70-T.a^{L}		2-A70-T.a^{L}		2-B70-T.a^{L}
°C	Weighing tin (grams)											
°C												
°C	Fresh weight + tin (grams)											
°C												
°C	Day I (grams)											
°C												
°C	Day II (grams)											
°C												
°C	Day III (grams)											
°C												
°C	Day IV (grams)											
°C												
°C	Day V (grams)											
°C												
°C	Total: dry weight (grams)											
°C												

	Typha angustifolia – FLOWER HEADS											
	Sample	Drying at 110°C		1-A-T.a^{FH}		1-B-T.a^{FH}		1-C-T.a^{FH}		2-A-T.a^{FH}		2-B-T.a^{FH}
	Sample	Drying at 70°C		1-A70-T.a^{FH}		1-B70-T.a^{FH}		1-C70-T.a^{FH}		2-A70-T.a^{FH}		2-B70-T.a^{FH}
°C	Weighing tin (grams)											
°C												
°C	Fresh weight + tin (grams)											
°C												
°C	Day I (grams)											
°C												
°C	Day II (grams)											
°C												
°C	Day III (grams)											
°C												
°C	Day IV (grams)											
°C												
°C	Day V (grams)											
°C												
°C	Total: dry weight (grams)											
°C												

	Other vegetation *X*											
	Sample	Drying at 110°C		1-A-X		1-B-X		1-C-X		~~2-A-~~		~~2-B-~~
	Sample	Drying at 70°C		1-A70-X		1-B70-X		1-C70-X		~~2-A70-~~		~~2-B70-~~
°C	Weighing tin (grams)											
°C												
°C	Fresh weight + tin (grams)											
°C												
°C	Day I (grams)											
°C												
°C	Day II (grams)											
°C												
°C	Day III (grams)											
°C												
°C	Day IV (grams)											
°C												
°C	Day V (grams)											
°C												
°C	Total: dry weight (grams)											
°C												