Rapport de stage individuel

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What is the effect of topsoil removal on soil phosphorus and pore water chemistry?

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List of illustrations :

List of tables :

List of abbreviations :

BD-P : bicarbonate-dithionite extractable phosphorus
P : Phosphorus
DRP : Dissolved Reactive Phosphorus
N : Nitrogen
DOP : Dissolved Organic Phosphorus
TSR : Topsoil Removal
DBD : Dry Bulk Density
DM : Dry Mass
LOI : Loss of Ignition
ICP : Inductively Coupled Plasma
SRP : Soluble Reactive Phosphorus
TOC : Total Organic Carbon
OM : Organic Matter
TP : Total Phosphorus
TDP : Total Dissolved Phosphorus

Table of content

I. The host organisation

1. Aarhus university

Aarhus, Denmark's second-largest city, is home to Aarhus University, a leading research and education institution established in 1928. With approximately 37,000 students and 8,700 employees, the university is organised into five faculties : Arts, Business and Social Sciences, Health, Natural Sciences, and Technical Sciences, each comprising multiple departments. The Department of Ecoscience, within the Faculty of Technical Sciences, conducts research spanning the entire spectrum of life, from microorganisms to large mammals, and from fundamental biology to applied work in nature management and biotechnology (Aarhus University, 2025). The department employs about 275 staff, split between the Aarhus campus and the Roskilde site, and hosts numerous PhD candidates, postdoctoral researchers, and fixed-term staff.

2. Section : upland analysis and environmental management

Within the Department of Ecoscience, the Upland Analysis and Environmental Management section addresses three main research areas: (1) monetisation and modelling of nutrient dynamics and hydrology; (2) development and application of instruments to reduce nutrient loss to the aquatic environment; and (3) investigation of the relationships between wetlands and greenhouse gas emissions (Aarhus University 2024). Its work contributes to long-term national recovery initiatives, such as those launched under the 1998 Aquatic Environment Plan II, focusing on restoring freshwater wetlands and removing large organic low-lying areas from agricultural rotation. Since 2010, the section has also been developing and designing constructed wetlands aimed at nutrient removal from drainage water systems better known as mini-wetlands with open water surfaces and mini-wetlands with matrices (Aarhus University 2024).

II.Introduction

1. Peatlands : characteristics and functions

Peatlands are ecosystems that represent 3% of planet's land surface and fresh water. These ecosystems accumulate dead organic material (the peat) which is slowly decomposed due to anoxic conditions (Gorham, 1957 ; Joosten and Clark, 2002). They are nearly permanently under water saturation conditions. In these ecosystems, hydrological characteristics rule their evolution over time. A taxonomic classification of peatlands is possible based on the provenance of their water supply, which can be divided into two primary categories. According to Joosten and Clark (2002), ombrogenous mires are defined as mires that are filled by precipitation, while geogenous mires are those in which water originates from underground sources. Their water chemistry is respectively acidic and alkaline except for poor fens which can also have a pH lower than 4. In these environments with low availability of nutrient and high-water level, most of the plants which are able to grow are helophytes such as *Carex spp*., *Sphagnum spp*., reed or other species. Peatlands shelter a rich biodiversity essential for the planet. They are essential ecosystems, playing a significant role in flood mitigation and soil erosion control (Harenda et al., 2018). Finally, their natural functions are also essential for humans by storing and sequestering carbon. Indeed, peatlands are the second greatest carbon storage after oceans.

2. The impact of human activity on peatlands

However, these areas are also affected by many human activities. Peatlands are used for tourism, pollution control as buffer zone and mostly for agriculture and forestry. Human influence on peatland leads to a loss of functions (Joosten and Clark, 2002). Due to the growing need for agricultural productivity to support human nutrition, more and more peatlands have been drained and converted into farmland (Gorham, 1957 ; Van Diggelen et al., 2006). To practice agriculture on these lands, drainage is mandatory to lower the water table and help the crops to get oxygen. Thus, it promotes more macropores and withdraws the anoxic conditions (Holden et al., 2006). Unfortunately, these changes in peat structure result in a loss of its natural carbon storage functions. In fact, under oxic conditions, the rate of peat decomposition exceeds that of primary production.

3. Peatlands restoration

The recovery of these ecosystems is imperative for the preservation of a rich biodiversity and the function of carbon storage, which plays a crucial role in the mitigation of global warming. Peat accumulation is a gradual process; thus, peatland restoration is a type of restoration that requires a long time to be effective. Achieving this objective necessitates mainly the restoration of peatland hydrology (Craft, 2022). This restoration also involves raising the water table through the removal of drainage systems, which allows water to accumulate and supports the growth of wetland plants that capture carbon dioxide. Thus, anoxic conditions are coming back, and the organic matter is again slowly decomposed.

While restoring water conditions is essential, peatlands are also affected by another issue: nutrient runoff. The long-term accumulation of phosphorus (P) in peatland is determined by the rates of decomposition and mineralization of dead plant material, as well as the incorporation of organic P into the soil system and the removal of inorganic P from water by soil adsorption (Richardson et al., 1986). Due to high amount of nutrient and the anoxic conditions, many are losses by runoff and end up polluting surrounding water bodies. Indeed, redox-sensitive phosphorus, or bicarbonate-dithionite extractable phosphorus (BD-P), is associated with Fe(III) compounds in the soil, and under anoxic conditions it is transformed into soluble phosphorus (P) due to the reduction of Fe oxides and can easily move along water (Zak et al., 2017). This reaction will be detailed later. These nutrients then contribute to accelerate eutrophication of surface water and lead to excessive growth of macroalgae (Kremser, 2002 ; Renou-Wilson, 2007). These phenomena are also visible in the ditches. The proliferation of these algae is linked to a higher demand of oxygen. This low concentration of oxygen represents a threat for the well-being of fishes and others aquatic plants. While phosphorus may be major source of surface water pollution, it remains a vital nutrient for all living organisms. A clear understanding of the phosphorus cycle is vital for evaluating its mobility, availability, and retention in natural systems.

4. Phosphorus remains important for life. Phosphorus Cycle

Phosphorus is a key nutrient for life, it is an essential biochemical element in the proper functioning of Deoxyribonucleic Acid (DNA) and other genetic material (Ruttenberg, 2003). It resides in rocks (mostly apatite) and is weathered by dissolution. The availability of phosphorus relies mostly on and this phenomenon, only a small part comes from atmospheric aerosol deposit (Ruttenberg, 2003). Phosphorus resulting of such a chemical weathering is considered as bioavailable whereas P from physical weathering is unavailable (FILIPPELLI, 2022). Phosphorus is transport from continental rocks to ocean by rivers and in two forms : particulate and dissolved. Most of the phosphorus delivered to ocean is particulate-P and never participate in the biogenic cycle of phosphorus.

Inside this cycle, wetlands can be considered as buffer zones before phosphorus reach oceans. Indeed, these ecosystems can retain P by both biotic and abiotic processes. P loss is minimized thanks to plants and microorganism's uptake and a constant recycling of litterfall (Ruttenberg, 2003). *T.latifolia*, *G.maxima* and *P.australis* are temporary P sinks. During the growing season, their high nutrient uptakes help to lower the risk of P losses to downstream water bodies (Zak et al., 2014). Meanwhile, plants only take up dissolved reactive phosphorus (DRP) also called orthophosphates. Their form (H_3PO_4, $H_2PO_4^-$; HPO_4^{2-} ; PO_4^{3-}) depends on pH (Figure 1) and influence their sorption behaviour with metals in the soil.

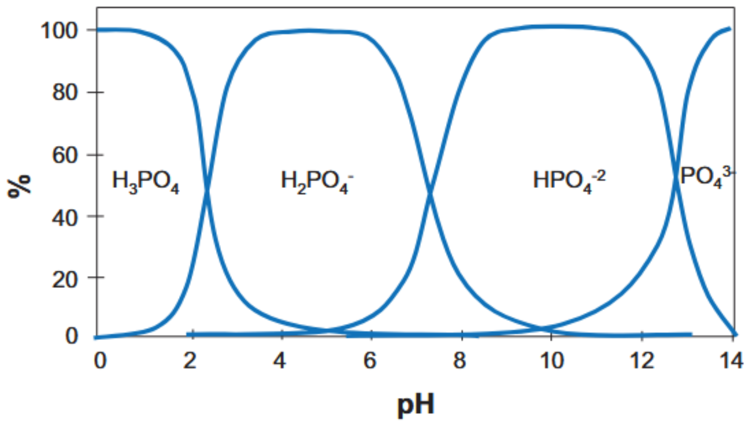

Figure 1 : Relative distribution of phosphate as a function of pH (Reddy et al., 2022)

Moreover, in drained peatlands, aerobic condition leads to bounding of inorganic P with oxidized forms of iron to ferric phosphates ($FePO_4$), one of its mineral forms is called strengite. When these peatlands are rewetted and anaerobic conditions are recovered, ferric iron (Fe^{3+}) functions as electron acceptors and FePO4 is reduced into ferrous iron (Fe^{2+}) and orthophosphates (PO_4^{3-}) is released (Reddy et al., 2022).

$$FePO_4 + e^- \rightarrow Fe^{2+} + PO_4^{3-}$$

As this reduction happens, phosphorus is released in the ecosystem.
In alkaline soils, DRP reacts easily with calcium and magnesium and in acidic soil, it reacts with iron and aluminium (Reddy et al., 2022).

Phosphorus can be found in both inorganic or organic form in the soil and it is stored in multiple ways; throughout a living being as plants and algae, animals or either microbe. Bound to metal (Figure 2)

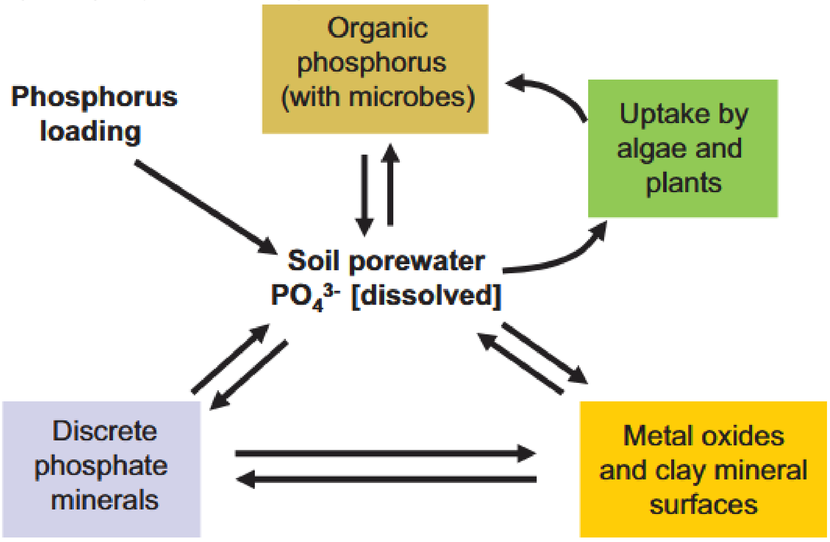

Figure 2 : Influence of biotic and abiotic processes and external loading on soil porewater phosphorus (Reddy et al., 2022)

Finally, rivers deliver phosphorus from weathering of soil or wetlands run off to ocean. Much of the net P eroded is delivered unaltered to the oceans. Where it is fixed in the deep-sea sediments. Throughout the time with subduction and accretion it will eventually be exposed again to the surface land. However, human induced nutrients have significant impact on this cycle and alters this balance. In land dominated by intense and large-scale farming such as Denmark, various strategies have been implemented to lower this environmental influence.

5. Brief Denmark historical review

In Denmark, most of the lakes were subject to significant levels of eutrophication due to high nutrient input from domestic sources and agricultural activities. Denmark has a high potential for creation and restoration of wetlands. As European member, Denmark tries to follow the EU Habitats Directive, the Water Framework Directive and the Nitrates Directives (Graversgaard, 2021).

To get rid of this eutrophication and achieve countries’ environmental goals, the Danish Government set up action plans with two objectives : reduce external loading, improve nutrient retention and removal by wetland. In 1987, the “Action Plan on the Aquatic Environment” planned to reduce nitrogen (N) and phosphorus loading by 50% and 80% respectively. To reduce nutrient loading in water bodies, the retention capacity of catchment areas (wetlands and lakes) has been improving. They have been re-established in their older areas and channelised streams have been remeandered. In addition, in the 1980’s, Denmark strengthened environmental regulations by requiring more efficient wastewater treatment and that companies also improved their environmental performance using cleaner technologies (Su et al., 2010). These measures reduced by 73% the mean of total phosphorus concentration of point-source polluted streams from 1978 to 1999. Perhaps, there was not any significant change in the total N concentration (Jeppesen et al., 1999). In 1998, the first public plan on wetlands in Denmark has been set up with the adoption of the second aquatic action plan (AP-II). Its objectives were to highly reduce N with 350 kg N/ha/year and restored 16 000 ha until 2003. These objectives were very ambitious and lowered in the following programme, the AP-III. Meanwhile, the Green Growth Agreement and the River Basin Management Plans (RBMPs) were also put in place in 2009. The goals were significantly increased (Graversgaard, 2021). Unfortunately, only half of the aims were achieved with 15 454 ha of wetlands restored during the period 1999-2015. The new target was to reach 30 000 ha restored through 2021.

6. Topsoil Removal method

During hydrological restoration efforts, excessive phosphorus loading in drained and fertilized peatlands poses additional challenges. When water levels are raised to re-establish anoxic conditions, previously bound P may be released into the porewater, increasing the risk of internal eutrophication. Rewetting results in the re-mobilization of P bound to redox-sensitive-compounds. Due to climate change higher net precipitation in the north temperate zone are also intended. Runoff of sediments, dissolved organic phosphorus (DOP) and nutrients should be enhanced and pollute downstream waterbodies (Meerhoff, 2022). Meanwhile, it has been observed that phosphorus tends to accumulate in highly decomposed peat in the upper layer (Zak et al., 2017). A short-term solution to reduce these mobilizations may be topsoil removal (TSR). This method consists in removing the upper layer of degraded peat by excavation (around 30cm). The aim is to set up conditions where the water table is again close to the soil surface or even above. As a pristine peatland could be. Furthermore, this topsoil is rich in all type of nutrients and removing it will facilitate nutrient-poor conditions to be re-established (Zak et al., 2017).

This study aims to investigate the effect of topsoil removal on pore water chemistry and soil phosphorus fraction. To do so, this study will compare three types of peatland sites : one where the topsoil has been removed, a ditch filled with this topsoil and one where it remains intact.

The initial hypothesis suggests that the phosphorus content in the peat may be reduced following TSR. In fact, the removal of topsoil has been demonstrated to result in a decrease in phosphorus, particularly in the form of redox-sensitive phosphorus (BD-P). Additionally, this difference may also be seen in pore water chemistry because both phenomena occur within the same environmental context.

III. Materials and methods

1. Sampling sites

This study took place in Vejrumbro, Jutland, Denmark. The site is located near the Nørreå River and is classified as a rewetted riparian fen. It receives water supply from both the Nørreå river and groundwater. The dominant vegetation is composed of mosses and *Juncus effusus*. Moreover, the soil is made of heavily degraded peat in the top 30 cm. Then, a layer of partially decomposed peat measuring approximately 1.5 to 2 meters in depth is encountered, followed by a thin layer of Gyttja , which is "a dark mud that is rich in organic nutrients and oxygen and has accumulated at the bottom of a marsh or lake." (American Heritage Dictionary, 2022). Finally, there is approximately 20 m of sand before reaching the Paleogene clay layer.
This area was drained in the 1950s using several ditches. A slow rewetting project was set up in 2020 by filling more ditches from 2020 to 2023.

Figure 3 & 4 : Sampling site location in Vejrumbro, Jutland (Personal photo and Google maps). The photo was taken the 23/07/2025, a lot of vegetation grew at that time on Sky 3, Sky 4 and Sky 5.

2. Treatments and measurements

In February 2023, five plots (3.75 × 2m) with different treatments were set up, along a 30 m long transect, to determine how rewetting in combination with other measures could affect this ecosystem. Each plot was named Sky 1, 2, 3, 4, 5 and was subject to a specific treatment :

- SKY1 : Drained mineral soil
- SKY2 : Drained mineral soil mixed with 20% Topsoil
- SKY3 : Ditch filled with topsoil
- SKY4 : Rewetted fen with TSR
- SKY5 : Rewetted fen without TSR (Control)

In this study, soil phosphorus and pore water chemistry were only analysed in Sky 3, Sky 4 and Sky 5.


Figure 5 : Treatment n°3 (Sky 3) ; the ditch partly was filled with the topsoil from Sky 4. Wooden plates were settled to fix the shape of this plot.

Sky 3 plot is a 3.75m long ditch which was created artificially. Large wooden boards were placed from bank to bank (3.75m) to stabilize the structure. Then, surface vegetation was removed and topsoil from the Sky 4 was added to the ditch surface (approximately 7m^3).


Figure 6 : Treatment n°4 (Sky 4) ; this plot is always under anoxic conditions with a soil surface at least 10 cm below the water level.

To remove the topsoil from Sky 4. A large metal board has been attached to an excavator to scrape about 30cm of the fine layers of topsoil below the surface. Finally, the Sky 5 plot was untouched in the southernmost part of the transect to act as a control treatment.

2.1 Groundwater table measurements :

To measure groundwater table, piezometers tubes were installed in Sky 3, 4 and 5 with a 1m screening depth. To estimate the water table's depth, pressure water loggers (Arduino data loggers) were installed in each piezometer. Sky 1 and 2 were under drained conditions, piezometers has not been installed in these plots.

2.2 Soil moisture, temperature and electric conductivity :

Soil moisture, temperature and electrical conductivity probes with coupled data loggers (Dragino SE-01) were installed the 10$^{th\ of}$ September 2024. Since, they captured these data each 20s.

3. Protocol for determination of phosphorus and carbon fraction

5 replicates samples of peat were extracted from each of the 3 plots and were named following their location : Sky X.1, Sky X.2 , Sky X.3, Sky X.4 and Sky X.5.

To collect soil cores, we used a PVC sampling tube (diameter = 5 cm) for each replicate and extract between 0 and 15 cm of peat.
The collection of soil cores was executed by employing a PVC sampling tube (diameter = 5cm), for each replicate. The extraction of peat was conducted at depths ranging from 0 to 15 cm. Each sample was placed into a labelled plastic bag and then put in a cooler waiting for the analysis.

3.1 Weighing of peat samples :

For each treatment, peat samples were weighed with their plastic bag to calculate later their dry bulk density (DBD) . Subsequently, a 5g sample was transferred into a 40 ml centrifuge tube for the P-fractionation process and shaken with 25 ml of chemical extraction solution (Figure 5). Concurrently, 10g was weighed in an aluminium tray to determine the dry mass (DM) and the loss of ignition (LOI). The aluminium tray and the plastic bag were also weighed.

$$DBD = \frac{Fresh\ mass\ of\ the\ whole\ sample - Mass\ of\ plastic\ bag}{Volume\ of\ the\ sample} \times DM\ (at\ 60°C)$$

3.2 Dry mass and LOI :

Our 15 samples were then dried in an oven maintained at a temperature of 60°C for a minimum period of three days. Then, the sample was weighed with the aluminium tray following the drying process to calculate the LOI and calculate the DM of fresh mass.

$$DM\ of\ fresh\ mass = \frac{Weight\ after\ drying - Mass\ of\ aluminium\ tray}{Weight\ of\ freshmass} \times 100$$

To calculate the LOI, the 15 sample were warmed at 450°C for 3 hours in an oven. Then also weighed.

$$LOI = \frac{Weight\ DM - (Weight\ sample\ after\ 450°C - Weight\ aluminium\ tray)}{Weight\ DM} \times 100$$

3.2 P-fractionation :

Following our scheme (Figure 5), our 15 samples were shaken into a rolling mechanical shaker at least for 30 minutes then centrifuged at 4500 rpm for 5 minutes. The solution then decanted and filtrate using Advantec mixed cellulose ester membrane filters with pore size of 0.45 µm. Afterwards, the residue was treated with 25 ml of BD solution, shaken for 1 hour, and centrifuged at 4500 rpm for 5 minutes. The solid and aqueous phases were then separated, the solid phase was washed, and both phases were combined. The solution was decanted and filtered in the same way. Finally, the same procedure was applied, but with 25 ml of HCl added to the residue. These samples will be analysed using the Inductively Coupled Plasma (ICP) methods. ICP is “an analytical technique used to measure and identify elements within a sample matrix based on the ionization of the elements withing the sample. Mass Spectrometer (MS) separates the ions out by their mass-to-charge ratio after going through the ICP, and the detector counts the number of selected ions per second which allows the instrument to determine the concentration of each chosen element” (OHSU website).

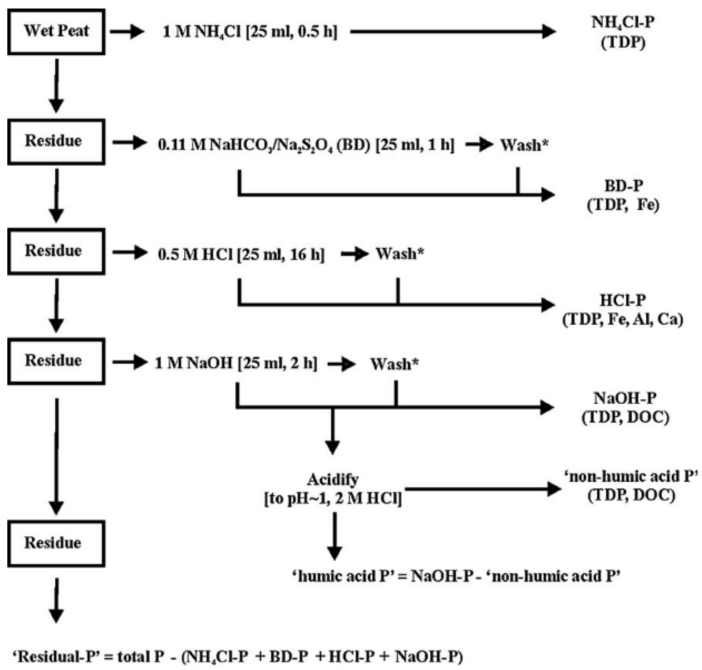

Figure 7 : The extraction steps (* wash step 25 ml deionised water and 5 minutes shaking) of the sequential chemical extraction procedure (modified after Zak et al., 2008) for the detection of different operationally defined P fractions in peat of varying degrees of decomposition. (TDP, total dissolved phosphorus; DOC, dissolved organic carbon).

The phosphorus obtained by the first extraction (SRP) is considered bioavailable for plants, it is a highly reactive fraction of phosphorus. While BD-P can only be available under anaerobic conditions and HCl-P is generally considered as unavailable. Finally, other residuals P are considered as non-reactive P (Reddy et al., 2022).

4. Protocol for pore water analysis

Pore water samples were extracted by using the dialysis sampler technique (Hesslein, 1976). The sampler is made of acrylic plastic (as Plexiglas) to avoid any problems associated with metals. The chamber is also filled with deoxygenated deionized water and covered with a membrane before insertion into the soil. Then, it requires at least 7 days to guarantee an equilibrium between the peat pore water and the water in the chamber (Zak et al., 2004)

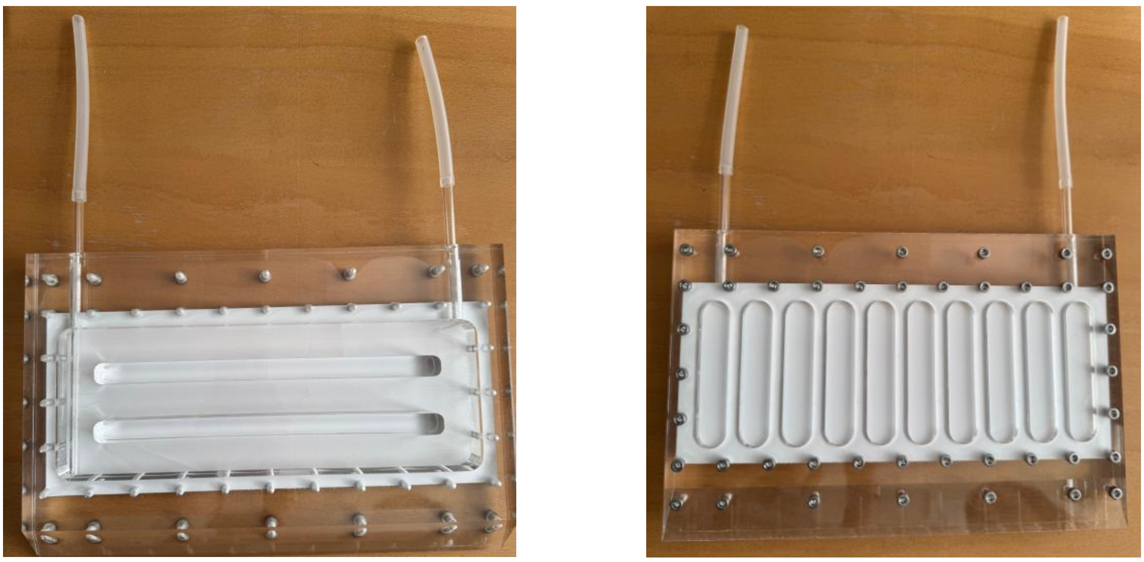

Figure 8 : Assembled rechargeable dialysis sampler (Personal photo)

Five samples were taken in the three plots each month from 24/06/2024 to 02/05/2025. Variable-volume pipettes were used, and the samples were immediately combined in an oxygen-free 1-L polyethylene bottle. This was done to avoid oxidation of the redox-sensitive parameter (Fe-P).
Later, these samples are analysed using ICP, SEAL, and Total Organic Carbon (TOC) methods. Seal analytic method is focus on nutrient analysis. The concentration of nutrient can be determined with a colorimetric detection following the intensity of the coloured reaction productions. This method meets the standards of many global organizations (SEAL analytical website). Finally, TOC method is a well-known indicator which is used to estimate the amount of organic content in a water sample (Shetty, 2022).

5. Statistical tests

The utilization of statistical tests is imperative in circumstances where raw data may be susceptible to misinterpretation. The observed differences between groups or conditions may be attributable to random variation rather than to a true underlying effect. This objective approach is characterized by the quantification of uncertainty, the utilization of statistical tools such as p-values or confidence intervals and the management of error rates.

In our study, we will use the Friedman's statistical test. The objective of its design is to facilitate the comparison of quantitative appraised values derived from more than two samples. In this study, a data set was utilized that was derived from three distinct plots. These plots were considered appraised, as five samples were collected from each plot on the same day. Consequently, Friedman's test provides information regarding the presence of a statistically significant difference among related groups, but not the specific groups involved. Finally, a post-hoc test is necessary to identify the precise location of the observed difference.

IV. Results

In the table 1, sky 4 peat showed the lowest concentrations for each parameter (TP, Fe, Ca, Al, HCl-P, BD-P, BD-Fe). In addition, it has also a lower DBD and Fe:P ratio than Sky 3 peat and Sky 5 peat. Finally, there is more organic matter (OM) in this peat. Meanwhile, the statistical test of Friedman highlighted that only BD-Fe, Fe, Al, TP concentrations and DBD were significantly lower in Sky 4 peat. OM was significantly higher. So, Fe:P ratio, HCl-P, KCl-P, and BD-P is not significantly lower in Sky 4 peat than in the other plots.

Table 1 : The range of soil parameters (n = 5) and median value in the three types of peatland sites after ICP analysis and calculation. DBD : Dry Bulk Density ; OM : Organic Matter ; TP : Total Phosphorus ; BD-P : bicarbonate-dithionite extractable phosphorus (redox-sensitive phosphorus).

Soil Parameter	**Sky 3 – peat**	**Sky 4 – peat**	**Sky 5 – peat**
DBD ($g.cm^{-3}$)	0.26 (0.20 – 0.35)	0.15 (0.12 – 0.21)	0.27 (0.17 – 0.30)
OM (% of DM)	42.0 (38.7 – 50.1)	72.4 (57.1 – 85.2)	63.9 (59.5 – 69.4)
TP ($mg.dm^{-3}$)	286 (169 – 401)	93 (39 – 257)	331 (208 – 421)
Fe ($mg.dm^{-3}$)	2690 (2586 – 4298)	1076 (416 – 1853)	1984 (1258 – 2636)
Ca ($mg.dm^{-3}$)	1952 (1184 – 2865)	1592 (1375 – 1758)	2395 (1634 – 2809)
Al ($mg.dm^{-3}$)	1826 (1460 – 2807)	650 (199 – 1537)	1519 (1187 – 2042)
HCl-P ($mg.dm^{-3}$)	64 (32 – 103)	10 (1 – 65)	65 (42 – 80)
KCl-P ($mg.dm^{-3}$)	0.3 (0.1 – 0.3)	0.4 (0.1 – 0.5)	0.5 (0.4 – 0.7)
BD-P ($mg.dm^{-3}$)	43 (18 – 65)	11 (2 – 33)	32 (20 – 34)
BD-Fe ($mg.dm^{-3}$)	583 (275 – 731)	154 (20 – 327)	383 (227 – 452)
Fe:P ratio	8.1 (5.1 – 11.6)	5.6 (4.6 – 7.9)	6.5 (6.2 – 7.4)

A secondary tendency was observed in the initial segments of the plots that exhibited the greatest proximity to the ditch. Indeed, the first two replicates Sky 4.1 and Sky 4.2 have an OM around 57% while the three other replicates are above 70%. Moreover, they have reach level of OM between Sky 3 and Sky 5, regardless of the anoxic conditions.
In the Figure 10, TP content in Sky 4.1 and Sky 4.2 is at least two times higher than in the other replicates. Compared to the two other plot, the topsoil removal treatment does not show real difference for these 2 replicates even if our statistical test showed significantly difference.

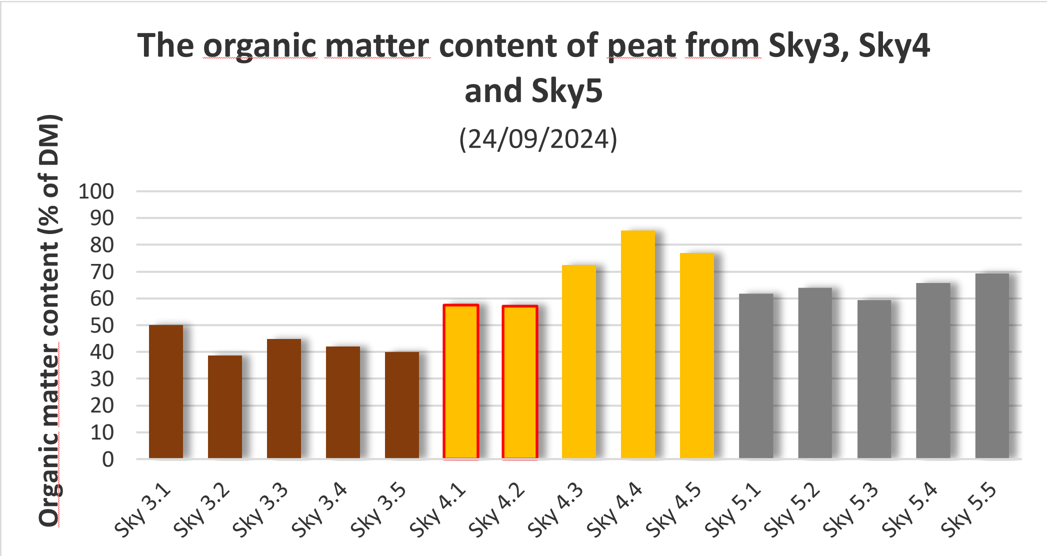

Figure 9 : Organic matter content of peat from Sky 3 (ditch filled with topsoil), Sky 4 (Rewetted fen with TSR) and Sky 5 (Rewetted fen without TSR). Values of Sky 4.1 and Sky 4.2 are indicated with a red frame.

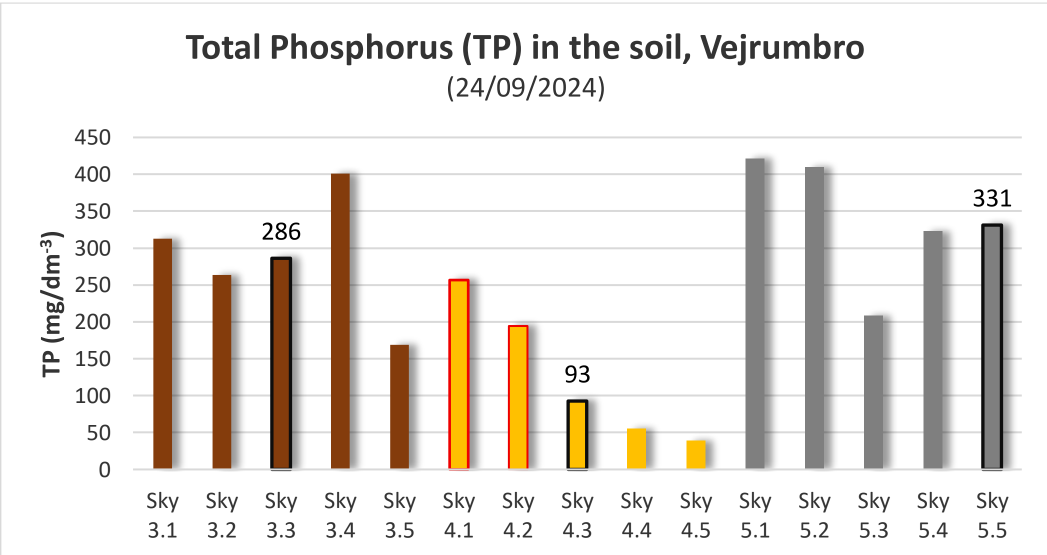

Figure 10 : Total Phosphorus in the soil in Sky 3 (ditch filled with topsoil), Sky 4 (Rewetted fen with TSR) and Sky 5 (Rewetted fen without TSR). The median values are indicated by bold font and a black frame.

Pore water analysis (Table 2) revealed significant differences between our plots (Friedman's test) for SRP, Nitrites, Ammonium TDP, Fe and Mg. Indeed, p-values show that SRP and TDP concentrations are very significantly lower in Sky 5 than in the two others (Annexe 4 & Annexe 5). Moreover, there is very significantly less Iron and Manganese in Sky 5 than in Sky 3 and Sky 4. In Sky 4, SRP and TDP median values are closed to Sky 3 values but that is not the case for the first four months, during which very high concentrations of phosphorus were recorded (Figure 11). These high SRP concentrations will be discussed later.

Table 2 : The range of dissolved substances in the pore water (n = 12 × 5 replicates) and median value of our three investigated plots after SEAL, TOC and ICP methods. SRP : Soluble Reactive Phosphorus ; NPOC : Non-Purgeable Organic Carbon ; TN : Total Nitrogen ; TDP : Total Dissolved Phosphorus.

Parameter	Sky 3 – pore water	Sky 4 – pore water	Sky 5 – pore water
SRP (mg/L)	1.89 (0.02 – 83.30)	2.22 (0.00 – 10.06)	0.20 (0.00 – 6.72)
Nitrates NO3 (mg N/L)	0.00 (0.00 – 4.28)	0.00 (0.00 – 0.07)	0.00 (0.00 – 0.11)
Nitrites (mg N/L)	0.00 (0.00 – 0.11)	0.00 (0.00 – 0.04)	0.00 (0.00 – 0.03)
Ammonium (mg N/L)	0.32 (0.01 – 20.95)	3.43 (0.02 – 8.92)	0.08 (0.02 – 5.84)
NPOC (mg/L)	63.8 (7.9 – 572.3)	211.1 (26.7 – 351.6)	163.4 (10.3 – 498.8)
TN (mg/L)	6.1 (0.3 – 53.1)	11.8 (1.4 – 27.0)	8.96 (0.43 – 55.48)
Iron (mg/L)	22.6 (1.1 – 117.0)	14.4 (1.0 – 34.6)	7.3 (0.2 – 44.6)
Calcium (mg/L)	26.2 (17.3 – 96.3)	34.9 (22.7 – 49.2)	26.2 (0.9 – 67.7)
Manganese (mg/L)	2.3 (0.3 – 5.4)	1.6 (0.3 – 2.5)	0.9 (0.1 – 2.1)
Aluminium (mg/L)	0.7 (0.1 – 4.2)	1.4 (0.2 – 2.6)	1.2 (0.0 – 3.3)
TDP (mg/L)	2.9 (0.1 – 83.3)	2.9 (0.0 – 12.7)	0.4 (0.1 – 7.7)

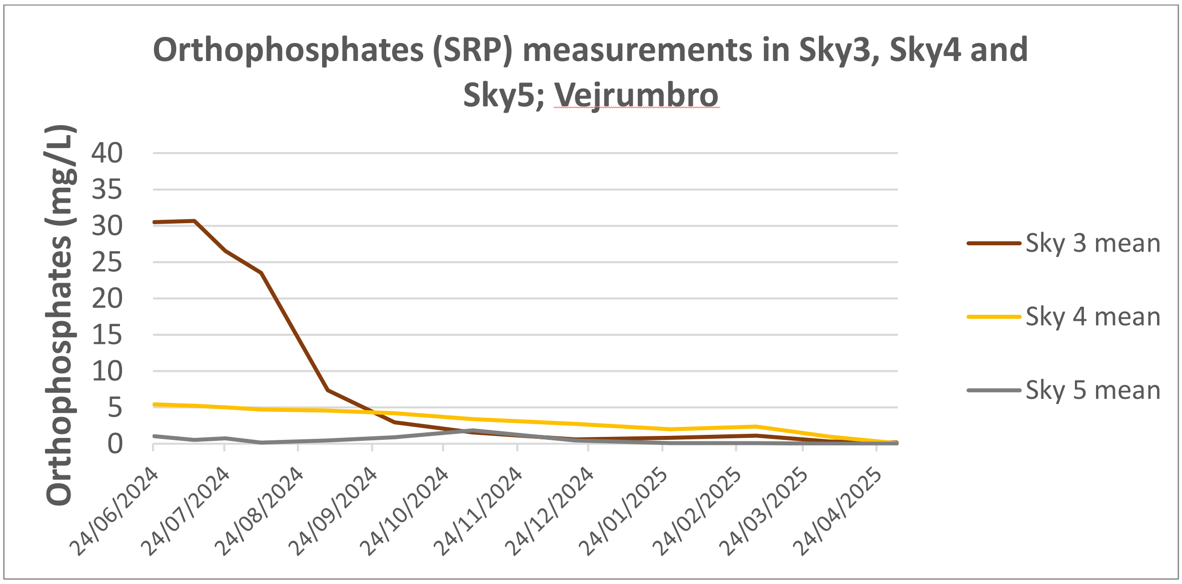

Figure 11 : Orthophosphates (SRP) measurements in Sky3, Sky4 and Sky5; Vejrumbro. The ditch filled with topsoil release a lot of phosphorus .

V. Discussion :

1. Effect of TSR on P fractions :

The elevated proportion of OM in Sky 4 (Table 1) indicates that anaerobic conditions are well set up, the peat is slowly decomposed. However, the initial hypothesis remains unconfirmed. As indicated by the results, different phosphorus and especially BD-P are lower. However, this decline does not reach a statistically significant level. Concurrently, only TP is significantly lower. A first conclusion could be that, in our plot, TSR may not restricted primarily BD-P but rather a range of phosphorus fractions. Moreover, Fe:P ratio is high (>>3) in each plot (Zak et al., 2017 ; Lu et al., 2015), but the lowest recorded median value is observed in Sky 4, at 5,6. This ratio is employed to predict the amount of iron-bound phosphorus that may be released following rewetting of peat soils, with a high ratio potentially resulting in reduced mobilization. The findings of the statistical test reveal a substantial decrease in the iron content of the peat. The observed variations in the iron concentrations could be attributed to the reduction of iron (II) under oxic conditions, which facilitates its mobilization in the water. Indeed, it is worth noting that the plot is inundated in water, a factor that may result in further mobilization.
A notable observation regarding the Sky 4 data is the presence of disparities among the replicates in Sky 4.1 and Sky 4.2, which often exhibit slight variations compared to the other replicates.

2. TSR in Sky 4.1 and Sky 4.2 :

The topsoil that was extracted has been discarded in the ditch adjacent to Sky 4 plot. It is possible that residual substances remained in proximity to our plot, thereby contaminating it. Indeed, a substantial variance in the organic composition of the peat is observed in the difference part of Sky 4 (Figure 9). The value of the peat in this area is approximately 57% of OM. These samples correspond to peat with a content of between Sky 3 and Sky 5, which is much lower than that of other Sky 4 replicates.
This tendency is also evident in the TP content of the soil (Figure 10). To avoid the occurrence of such bias, it is recommended that a greater distance be established between the various plots and that a more profound topsoil removal be implemented (extending to a depth of 50 centimeters).

3. Effect of TSR on pore water chemistry :

Firstly, it is imperative to reiterate the observation that aerobic conditions persist in Sky 5, characterized by a water table that invariably resides beneath the soil surface, which could lead to less mobilization. In Sky 4, a 10 cm layer of water consistently covers the soil surface, while in Sky 3, the water level is nearly level with the soil surface (Annexe 1). This variance may serve as a primary factor contributing to the observed gap in the concentration of Sky 5 dissolved substance as compared to those of Sky 3 and Sky 4 (Table 2). This major difference led to a lot of mobilisations in the pore water.

4. Usage of the topsoil removed :

In the context of restoration projects, local peat is typically employed for the purpose of filling ditches. The utilization of local materials in restoration projects is a more economical approach when compared with the transportation of materials from external locations. Peat possesses notable characteristics: it has a low permeability, a low weight, and it is readily available (Joosten, 2022). However, there is a lack of knowledge regarding the greenhouse gas emissions and nutrient mobilization that these ditches filled with peatlands could emit. As indicated by the data presented in Figure 11, a significant quantity of orthophosphates was observed to be leached from Sky 3 over the course of several months during the measurement of the pore water chemistry. (Figure 11).
The efficacy of ditch filling, particularly with topsoil, during rewetting restoration may be subject to review, particularly in cases where the outcomes of the restoration are not achieved.

VI.Conclusion

This study focuses on the effects of topsoil removal on phosphorus fractions and pore water chemistry. While the removal of topsoil does not lead to a substantial decrease in any phosphorus fraction, it does result in a general reduction in the total phosphorus concentration. Moreover, the removal process induced submersion of the study plot, enhancing the mobilization of dissolved substances and leading to increased nutrient concentrations in pore water. These findings suggest that topsoil removal modifies both nutrient stocks and hydrological conditions in ways that may accelerate nutrient release into surrounding environments. This highlights the necessity for precise management and potential pre-treatment of removed topsoil to prevent rapid nutrient leaching, particularly in restoration projects where water bodies and sensitive habitats are nearby.

In addition to the dynamics of phosphorus, it is imperative to recognize that the alterations induced by topsoil removal also have repercussions for other biogeochemical processes. The restoration of elevated water levels and the resulting anaerobic conditions have been demonstrated to directly influence greenhouse gas fluxes. This phenomenon has been extensively studied in recent literature. Integrating this dimension would allow a more precise assessment of the trade-off between nutrient reduction and the climate impacts of restoration.

In conclusion, while topsoil removal appears to be an effective measure to reduce soil phosphorus and restore nutrient-poor conditions, its short-term effects on pore water chemistry and its broader ecological and climatic implications call for further investigation.

VII. References

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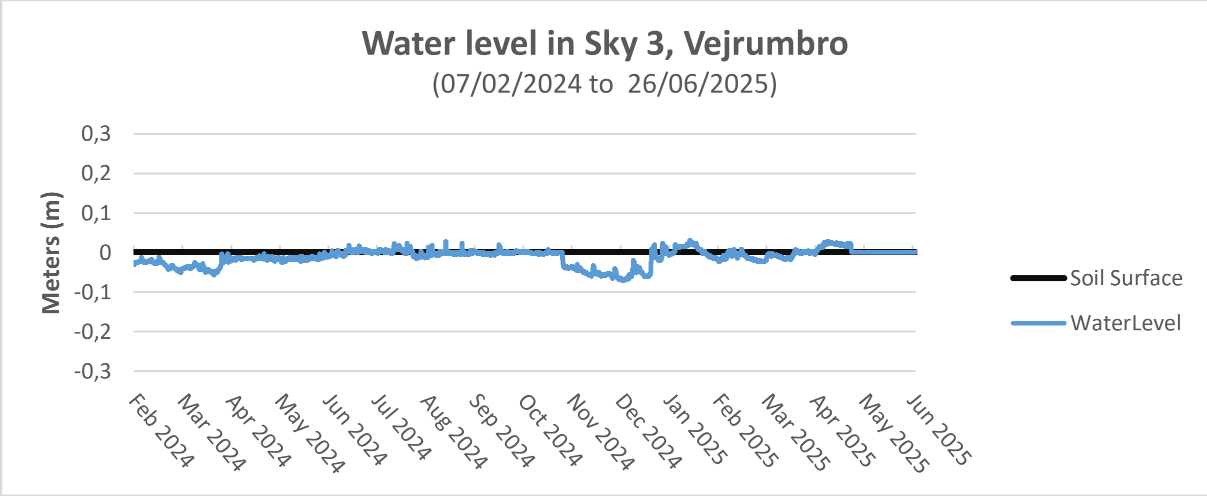
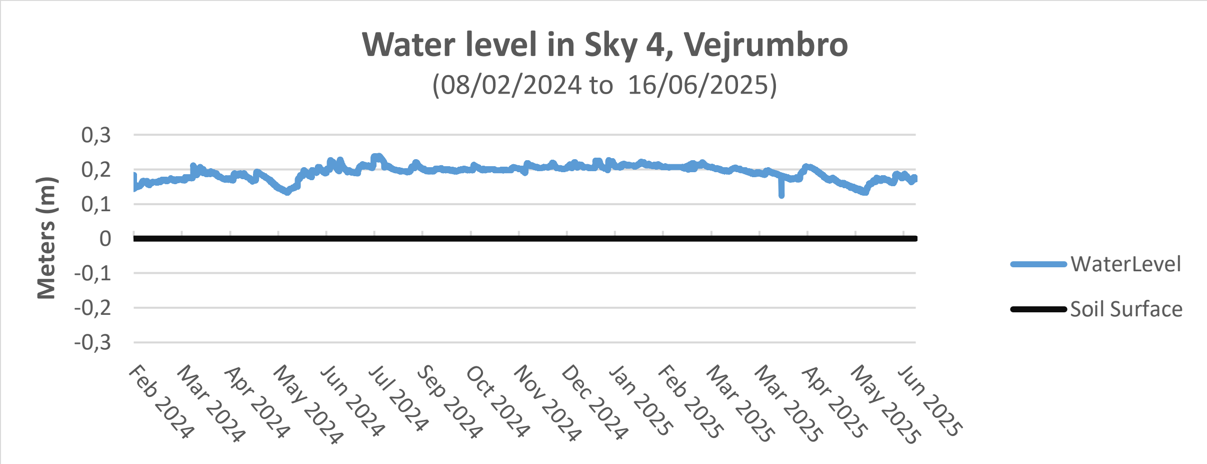
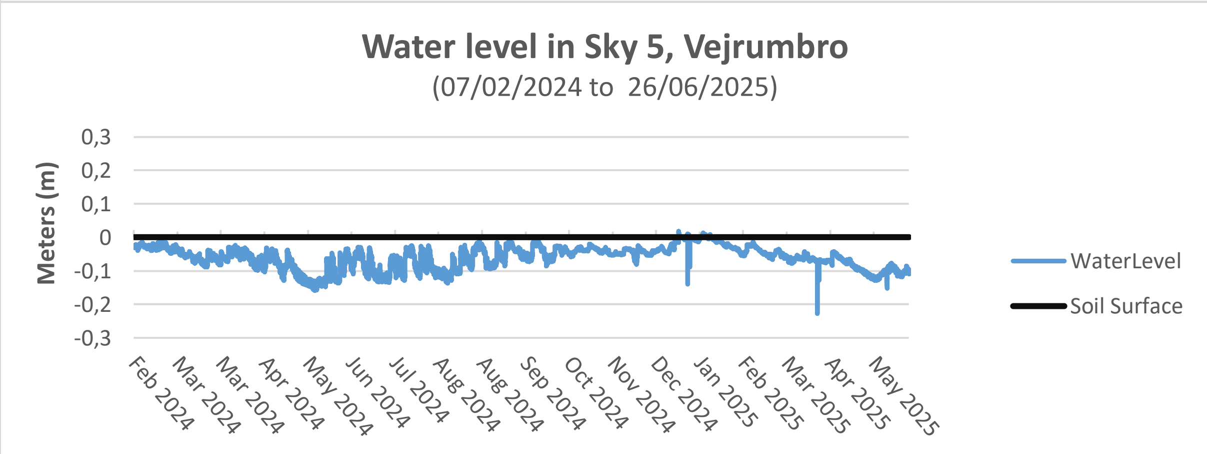
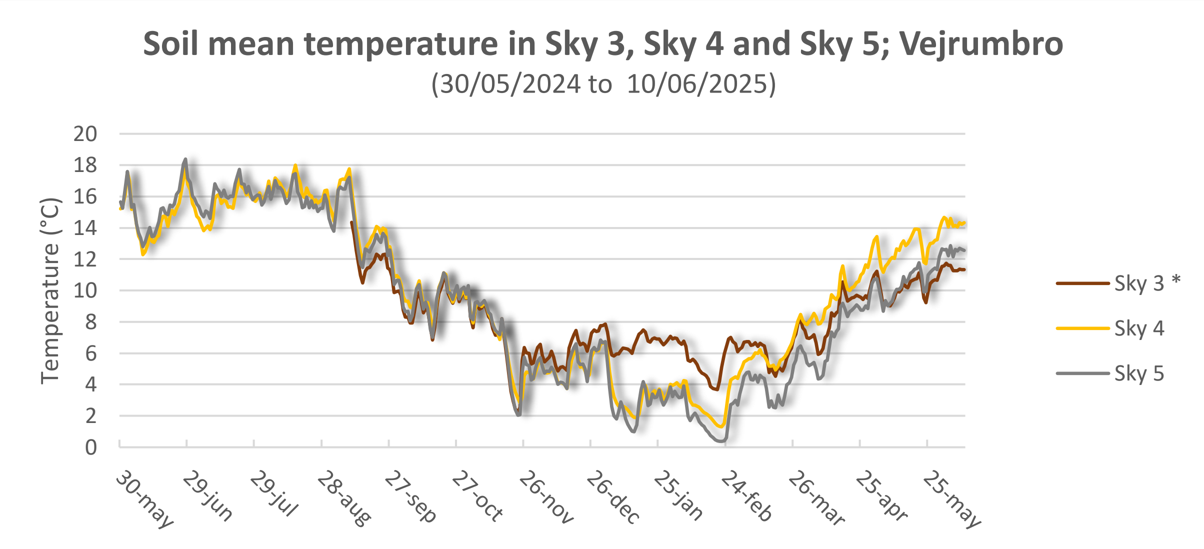
VIII. Annexes

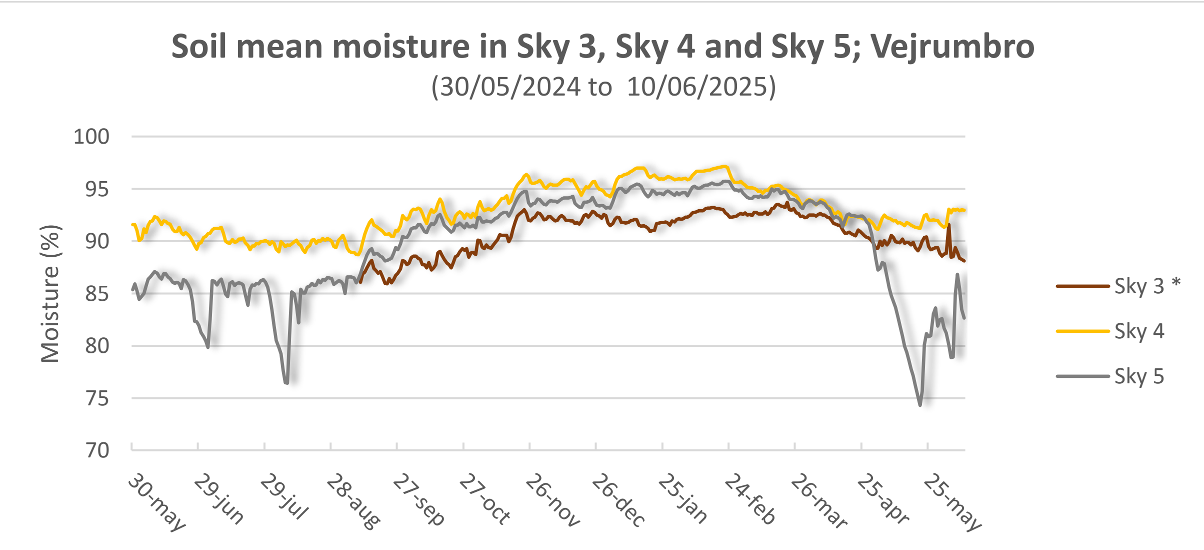


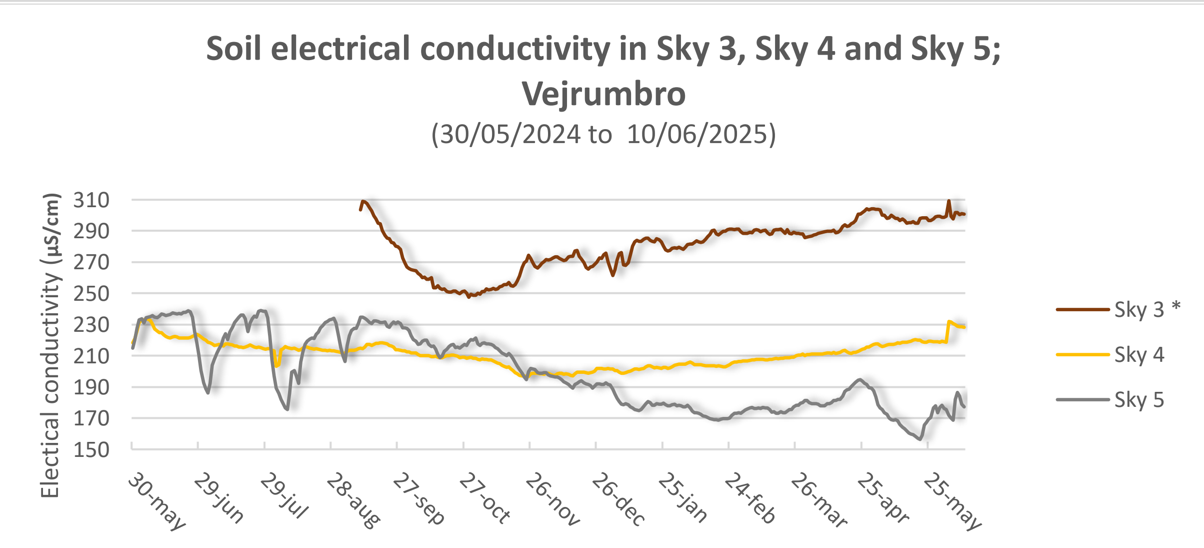




Annexe 2 : Soil parameters measurements
***Measurements started later for Sky 3**







Annexe 3 : Peat analysis data

Bloc	Traitement	Ratio Fe:P	BD-Fe	BD-P	HCl-P	KCl-P	Fe	Ca	Al	TP	OM	DBD
1	Sky 3	8,1	623	43	64,00	0,30	4181	2174	2074	313	50,1	0,29
2	Sky 3	8,6	275	18	37,00	0,20	2668	1701	1826	263	38,7	0,26
3	Sky 3	5,1	488	53	63,00	0,30	2690	1952	1728	286	44,7	0,23
4	Sky 3	6,3	731	65	103,00	0,30	4298	2865	2807	401	42,0	0,35
5	Sky 3	11,6	583	28	32,00	0,10	2586	1184	1460	169	39,9	0,20
	Mean Sky 3	**7,9**	**540,0**	**41,4**	**59,80**	**0,24**	**3284,6**	**1975,2**	**1979,0**	**286,4**	**43,1**	**0,27**
1	Sky 4	5,4	327	33	65,00	0,40	1853	1592	1537	257	57,5	0,21
2	Sky 4	5,6	235	23	42,00	0,50	1450	1702	1285	194	57,1	0,19
3	Sky 4	7,9	154	11	10,00	0,30	1076	1758	650	93	72,4	0,15
4	Sky 4	4,6	74	9	7,00	0,40	416	1375	213	55	85,2	0,14
5	Sky 4	6,7	20	2	1,00	0,10	488	1581	199	39	76,9	0,12
	Mean Sky 4	**6,0**	**162,0**	**15,6**	**25,00**	**0,34**	**1056,6**	**1601,6**	**776,8**	**127,6**	**69,8**	**0,16**
1	Sky 5	7,1	407	32	74,00	0,50	2636	2395	2042	421	61,8	0,30
2	Sky 5	6,2	383	34	80,00	0,60	2330	2809	1852	410	63,9	0,30
3	Sky 5	6,3	227	20	42,00	0,40	1258	1634	1187	208	59,5	0,17
4	Sky 5	6,5	354	30	59,00	0,50	1916	2417	1519	323	65,7	0,27
5	Sky 5	7,4	452	34	65,00	0,70	1984	2161	1381	331	69,4	0,26
	Mean Sky 5	**6,7**	**364,6**	**30,0**	**64,00**	**0,54**	**2024,8**	**2283,2**	**1596,2**	**338,6**	**64,1**	**0,26**
Test de Friedman	p-value	0.246	0.015	0.246			0.007	0.449	0.015	0.022	0.022	0.022

Tests post-Hoc to determine where there is a significant difference :

BD - Fe (Test Post-hoc)	Sky 3	Sky 4
Sky 4	0,012	
Sky 5	0,609	0,139

Al (Test Post-hoc)	Sky 3	Sky 4
Sky 4	0,012	
Sky 5	0,609	0,139

OM (Test Post-hoc)	Sky 3	Sky 4
Sky 4	0,031	
Sky 5	0,069	0,946

Fe (Test Post-hoc)	Sky 3	Sky 4
Sky 4	0,0045	
Sky 5	0,2538	0,254

TP (Test Post-hoc)	Sky 3	Sky 4
Sky 4	0,069	
Sky 5	0,946	0,031

DBD (Test Post-hoc)	Sky 3	Sky 4
Sky 4	0,069	
Sky 5	0,946	0,031

Annexe 4 : Dialysis porewater analysis data (1)

Date	Condition	SRP	Nitrates	Nitrites	Ammonium	NPOC	TN
24/06/2024	Sky 3 mean	30,49	0,00	0,08	9,22	337,98	27,26
24/06/2024	Sky 4 mean	5,42	0,01	0,02	3,51	216,96	13,01
24/06/2024	Sky 5 mean	1,03	0,01	0,02	1,79	260,83	16,76
11/07/2024	Sky 3 mean	30,66	0,00	0,01	13,47	336,26	31,39
11/07/2024	Sky 4 mean	5,24	0,00	0,00	4,52	229,76	13,83
11/07/2024	Sky 5 mean	0,54	0,00	0,00	4,58	281,70	19,25
24/07/2024	Sky 3 mean	26,53	0,00	0,01	14,01	284,62	30,59
24/07/2024	Sky 4 mean	4,99	0,03	0,00	4,75	219,24	14,44
24/07/2024	Sky 5 mean	0,71	0,00	0,00	2,46	344,80	26,82
08/08/2024	Sky 3 mean	23,55	0,00	0,01	9,16	276,36	24,43
08/08/2024	Sky 4 mean	4,70	0,00	0,00	4,91	199,22	14,37
08/08/2024	Sky 5 mean	0,14	0,03	0,00	0,14	274,22	13,76
05/09/2024	Sky 3 mean	7,38	0,00	0,00	0,08	178,62	10,94
05/09/2024	Sky 4 mean	4,54	0,00	0,00	5,11	215,57	16,91
05/09/2024	Sky 5 mean	0,43	0,00	0,00	0,70	193,92	12,36
03/10/2024	Sky 3 mean	2,94	0,07	0,01	0,08	80,28	4,97
03/10/2024	Sky 4 mean	4,16	0,06	0,02	4,70	189,02	13,75
03/10/2024	Sky 5 mean	0,87	0,06	0,01	0,40	222,84	11,54
05/11/2024	Sky 3 mean	1,53	0,01	0,00	0,38	47,74	4,06
05/11/2024	Sky 4 mean	3,37	0,00	0,02	3,24	196,65	13,75
05/11/2024	Sky 5 mean	1,84	0,00	0,01	0,22	265,16	14,34
18/12/2024	Sky 3 mean	0,57	1,47	0,01	1,00	16,22	4,12
18/12/2024	Sky 4 mean	2,71	0,00	0,01	2,87	180,92	11,41
18/12/2024	Sky 5 mean	0,47	0,00	0,01	0,13	137,25	7,09
27/01/2025	Sky 3 mean	0,84	0,42	0,00	0,97	23,15	3,71
27/01/2025	Sky 4 mean	1,99	0,04	0,01	2,13	153,79	11,53
27/01/2025	Sky 5 mean	0,10	0,05	0,00	0,04	77,21	5,08
04/03/2025	Sky 3 mean	1,12	1,25	0,00	0,39	27,39	5,11
04/03/2025	Sky 4 mean	2,36	0,01	0,00	2,59	147,33	11,43
04/03/2025	Sky 5 mean	0,12	0,01	0,00	0,05	94,64	6,98
04/04/2025	Sky 3 mean	0,34	0,00	0,00	0,15	23,68	1,10
04/04/2025	Sky 4 mean	1,00	0,00	0,01	0,88	140,07	7,15
04/04/2025	Sky 5 mean	0,04	0,00	0,00	0,04	110,97	5,40
02/05/2025	Sky 3 mean	0,17	0,00	0,00	0,09	45,67	4,65
02/05/2025	Sky 4 mean	0,08	0,00	0,01	0,64	124,29	8,02
02/05/2025	Sky 5 mean	0,01	0,00	0,00	0,03	120,26	8,17
	P-values	0,0005	0,423	0,026	0,00376	0,066	0,986

Annexe 5 : Dialysis porewater analysis data (2)

Date	Condition	Iron	Calcium	Manganese	Aluminium	TDP
24/06/2024	Sky 3 mean	66,84	59,52	0,87	2,75	35,20
24/06/2024	Sky 4 mean	21,60	41,13	0,47	1,23	6,31
24/06/2024	Sky 5 mean	13,91	39,38	0,33	2,04	1,72
11/07/2024	Sky 3 mean	68,54	56,64	0,91	2,71	37,94
11/07/2024	Sky 4 mean	19,97	40,76	0,47	1,33	6,41
11/07/2024	Sky 5 mean	19,31	45,28	0,38	2,34	0,84
24/07/2024	Sky 3 mean	54,75	43,27	3,21	2,23	33,74
24/07/2024	Sky 4 mean	17,58	35,16	1,90	1,32	6,18
24/07/2024	Sky 5 mean	9,91	29,26	1,15	1,65	0,58
08/08/2024	Sky 3 mean	43,82	37,60	2,83	1,94	25,03
08/08/2024	Sky 4 mean	15,50	31,93	1,67	1,24	5,72
08/08/2024	Sky 5 mean	6,63	21,11	0,66	1,20	0,32
05/09/2024	Sky 3 mean	28,98	34,32	2,98	1,42	9,22
05/09/2024	Sky 4 mean	16,07	33,79	1,75	1,40	5,66
05/09/2024	Sky 5 mean	10,58	32,62	1,11	1,76	0,79
03/10/2024	Sky 3 mean	15,08	27,47	2,70	0,81	3,58
03/10/2024	Sky 4 mean	15,03	32,15	1,72	1,35	5,06
03/10/2024	Sky 5 mean	16,72	35,06	1,27	2,02	1,19
05/11/2024	Sky 3 mean	20,77	26,30	2,48	0,70	2,87
05/11/2024	Sky 4 mean	14,32	33,24	1,70	1,35	4,01
05/11/2024	Sky 5 mean	20,74	41,56	1,39	2,18	2,18
18/12/2024	Sky 3 mean	19,51	22,58	2,28	0,31	0,95
18/12/2024	Sky 4 mean	12,59	31,11	1,69	1,30	3,31
18/12/2024	Sky 5 mean	8,01	23,75	1,10	0,96	0,62
27/01/2025	Sky 3 mean	10,01	20,63	2,31	0,34	1,10
27/01/2025	Sky 4 mean	12,53	32,20	1,73	1,24	3,16
27/01/2025	Sky 5 mean	4,87	16,35	0,79	0,66	0,30
04/03/2025	Sky 3 mean	17,53	25,32	2,79	0,27	1,45
04/03/2025	Sky 4 mean	12,98	35,62	1,77	1,13	2,75
04/03/2025	Sky 5 mean	4,21	21,33	0,84	0,78	0,23
04/04/2025	Sky 3 mean	10,10	27,32	2,88	0,24	0,61
04/04/2025	Sky 4 mean	10,62	34,61	1,69	1,03	1,30
04/04/2025	Sky 5 mean	4,49	23,43	0,77	0,91	0,16
02/05/2025	Sky 3 mean	14,94	25,29	2,79	0,56	2,40
02/05/2025	Sky 4 mean	8,93	33,25	1,69	0,94	1,04
02/05/2025	Sky 5 mean	4,54	25,34	0,55	0,94	0,15
	P-values	0,000477	0,16	1,9E-10	0,447	0,0001234

Tests post-Hoc to determine where there is a significant difference :

SRP (Test Post-hoc)	Sky 3	Sky 4
Sky 4	1	
Sky 5	0,01	0,001

Ammonium (Test Post-hoc)	Sky 3	Sky 4
Sky 4	1	
Sky 5	0,063	0,003

Manganese (Test Post-hoc)	Sky 3	Sky 4
Sky 4	1,18E-06	
Sky 5	2,53E-06	4,06E-05

Nitrites (Test Post-hoc)	Sky 3	Sky 4
Sky 4	1	
Sky 5	1	0,012

Iron (Test Post-hoc)	Sky 3	Sky 4
Sky 4	0,012	
Sky 5	0,004	0,007

TDP (Test Post-hoc)	Sky 3	Sky 4
Sky 4	1	
Sky 5	0,0007	0,0007

IX. Reflective feedback on the internship

During my internship, I had the opportunity to communicate in English, particularly on scientific topics. This allowed me to develop my language skills and technical knowledge. I gained a deeper understanding of research work and the daily life of a researcher by observing and participating in various stages of the scientific process. This experience exposed me to diverse environments, including the field, office, and laboratory, offering me a comprehensive, practical view of the profession. Finally, I had the chance to attend the international Land Use and Water Quality conference, where I met experts and learned about major environmental issues.

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Étudiant
2024-2025

What is the effect of topsoil removal on soil phosphorus and pore water chemistry ?

Résumé : This study examines the impact of topsoil removal (TSR) in degraded peatlands, a short-term method aimed at reducing nutrient availability, particularly phosphorus, and restoring hydrological conditions close to those of a pristine peatlands. The study site is located in Vejrumbro, where samples of peat and pore water were collected and analyzed. TSR involves removing approximately 30 cm of highly decomposed peat, which could limit the release of phosphorus linked to redox processes during rewetting. The main objective is to assess the effects of this technique on pore water chemistry and on the different forms of phosphorus present in the soil. The study compares three types of sites: an rewetted fen restored with TSR, a ditch filled with peat from TSR, and an rewetted fen restored without TSR. The results should provide a better understanding of whether TSR is an effective solution for limiting eutrophication and restoring the ecological functions of peatlands.

Mots Clés : Topsoil Removal (TSR) ; Peatland ; Phosphorus mobilization ; Restoration

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